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2 December 2019

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Abstract

This paper examines how specific human capital affects labour turnover and real wage cyclicality in a frictional labour market. I develop an equilibrium search model with long-term contracts and imperfect monitoring of worker effort. Imperfect monitoring creates a moral hazard problem that requires firms to pay efficiency wages. The optimal contract implies that more specific capital reduces job separation, thereby alleviating the moral hazard and increasing wage stability over the business cycle. I apply this model to explain novel stylised facts about the cyclicality of the postgraduate-undergraduate wage premium. Postgraduate degree holders experience lower cyclical variation in real wages than those with undergraduate degrees. This effect is significant for workers with a long tenure, but not for new hires. Moreover, postgraduates have more specific human capital than undergraduates. Estimates reveal that specific capital can explain the educational gaps both in labour turnover and in real wage cyclicality.

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1 Introduction

The literature on human capital theory makes an important distinction between general and specific human capital (Becker, 1962). General human capital does not depreciate when a worker switches firms, whereas specific human capital is lost on job separation. Becker suggests that a higher amount of specific human capital should reduce incentives of firms and workers to separate and increase employment stability. Therefore, specific human capital is key to many equilibrium search models that have direct implications for the cyclical behaviour of employment for workers of different skill levels (Cairó and Cajner, 2016; Hudomiet, 2015). So far, however, little evidence is available on the impact of specific capital on real wage variation over the business cycle in a frictional labour market.

In this paper, I address this question by providing an empirical framework where firms optimally choose how aggregate shocks transmit to workers based on their workers' specific human capital. I solve the firm's optimal contracting problem in a directed search model with risk averse workers and firm commitment in the spirit of Tsuyuhara (2016) and Lamadon (2016).[1] I augment it by adding specific human capital and aggregate shocks to matches. The optimal contract implies that a higher amount of specific human capital reduces job separation and increases wage stability over the business cycle. Then I apply this model to explain novel stylised facts about the cyclicality of the postgraduate-undergraduate wage premium.

The model has several important features. First, I assume all new hires lack some specific human capital, which they obtain through a period of learning. This process generates some specific capital, leading to lower outside options. Second, I assume long-term contracts between risk-neutral firms and risk-averse workers. Because of the difference in risk aversion, firms would provide insurance to workers by equating marginal utilities across realizations of aggregate shocks, and thereby increase wage stability (Azariadis, 1975). With this assumption, firms have an risk-sharing motive to increase wage stability. Third, I assume job output depends on worker effort, which is unobserved by firms. The worker is laid off if the output is

[1] Mortensen and Pissarides (1994) type search models have been used extensively to model long-term relationships between workers and firms. These models typically assume continual Nash wage bargaining, which would impose transmission of productivity shocks to wages by construction. As workers are usually risk-neutral in these models, they do not care about wage variation. Allowing risk-aversion will make these models as complicated as mine.

too low. As workers might shirk their effort, firms have to pay efficiency wages to incentivize their workers to exert optimal effort. With this assumption, firms have an incentivizing motive to reduce wage stability.

There are three key results in this study. First, a higher amount of specific human capital increases an experienced worker's optimal effort and reduces the probability of job separation. After gaining specific capital, experienced workers have strong incentives to keep their jobs longer. As these incentives increase with the level of specific capital, experienced workers with more specific capital exert a higher effort for their projects, and their jobs are less likely to break down.

The second result is that, under the optimal contract, wage changes track aggregate productivity shocks. When aggregate productivity increases, firms promise a higher wage next period to incentivize their workers to make a greater effort, and vice versa if aggregate productivity decreases.

Finally, the third result is that, under some mild regularity conditions, a higher amount of specific human capital increases wage stability of an experienced worker. Firms face the trade-off between the risk-sharing motive and the incentivizing motive. On the one hand, as experienced workers with more specific capital have a lower probability of job separation, they will value more about firms' future promises, and thus, firms' promises become more effective in motivating workers. On the other hand, if providing incentives for worker effort becomes increasingly costly, a higher amount of specific capital increases an experienced worker's effort, thereby increasing firm's marginal cost of providing incentives. As more specific capital increases both the effectiveness and the marginal cost of providing incentives, it becomes optimal for firms to provide more insurance to workers with more specific capital.

My model helps to analyze the cyclicality of the education wage gap. In the literature, Keane and Prasad (1993) find college graduates and noncollege workers experience the same degree of cyclical variation in real hourly wages.[2] Hoynes (2000) compare workers at a lower education margin (High School vs. Some College) and find similar results between males in these two groups.[3] Since 1980, the employment share held by postgraduates has doubled. By 2012 nearly 15% of the US adult

[2]College graduates include both undergraduates and postgraduates.

[3]Some College are workers with more than a high school education, and High School are workers with a high school education and less. However, Hoynes (2000) find that males in the Some College group are subject to less cyclical variation in annual earnings, employment and hours than males in the High School group.

workforce, or 40% of all college graduates, have a postgraduate degree (Lindley and Machin, 2016). Therefore, in addition to the college-noncollege margin, I also compare postgraduates to those with only undergraduate degrees and document a new result: In the US, the postgraduate-undergraduate wage premium is counter-cyclical.

To illustrate, Figure 1 plots the detrended real GDP and the postgraduate wage premium.[4] The postgraduate wage premium increases substantially during all recent recessions, and its correlation with real GDP is -0.47. As I discuss further in the empirical evidence, when real GDP goes up by 1%, the median postgraduate wage increases by 0.34%, and the median undergraduate wage increases by 0.58%, indicating that postgraduate wages respond less to business cycle shocks than undergraduate wages.

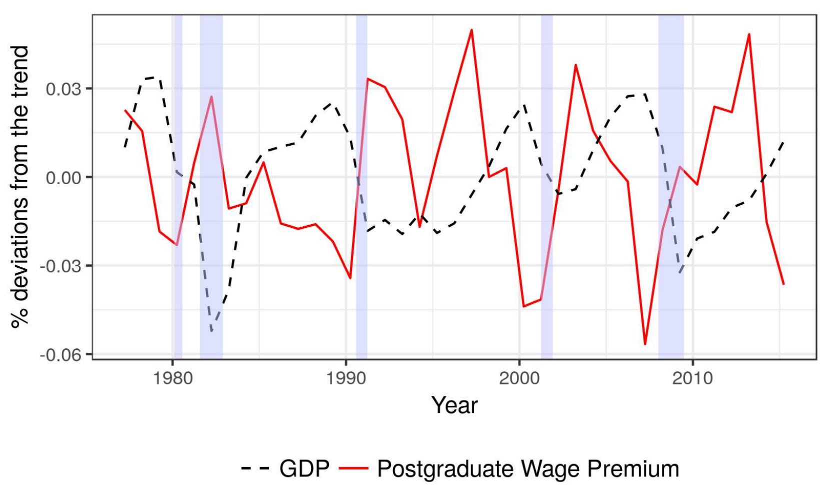

Figure 1: Detrended Real GDP and Postgraduate Wage Premium

Source. Current Population Survey March Supplement (March CPS) 1976–2016, males, aged 26–64. NBER dated recessions are shaded. Series are logged and detrended using a Hodrick–Prescott (HP) filter with parameter 100.

I show that the counter-cyclical postgraduate wage premium is due neither to cyclical changes in the composition of the workforce, nor to postgraduates and undergraduates sorting into different industries and occupations. Furthermore, I find

[4]See Appendix A for a description of the data. Postgraduate degrees include 5 years of college completed and more prior to 1992 and master's, professional school and doctoral degrees after 1992.

that the difference in wage cyclicality between postgraduates and undergraduates is significant for workers with a long tenure in a given job, but not for new hires. As workers' job tenure is the generally used proxy for specific human capital (Altonji and Shakotko, 1987), I argue that this phenomenon occurs because experienced postgraduates have accumulated more specific human capital in their jobs than their undergraduate degree-holding counterparts, and thus, they are offered contracts with more stable wages. Since new hires have not yet built any specific capital, the difference in wage cyclicality between postgraduates and undergraduates is small. I provide two empirical evidence showing postgraduates have more specific capital. First, the time needed by postgraduates to become fully competent in a new job is twice as long as the time needed by undergraduates. Second, as more specific capital leads to larger wage losses from exogenous job displacement, I show that percent losses in wages for postgraduates are twice as much as those for undergraduates. There is thus a strong complementarity between education and specific capital, which confirms the findings in Cairó and Cajner (2016).

I use my model to quantify the effect of specific human capital on the educational gap in labour turnover and real wage cyclicality. In the model, specific capital is determined by 2 parameters: the upgrading probability from a new hire to an experienced worker and the productivity gap between them. The upgrading probability is calculated using the Multi-City Study of Urban Inequality (MCSUI), which measures how long it takes new hires to be fully competent in their jobs. The productivity gap is estimated by targeting the percent losses in wages after job displacement from the Displaced Workers Survey (DWS). Although the model is parsimonious, it can endogenously generate the differences in both labour turnover and real wage cyclicality across education groups, given the observed empirical differences in specific human capital. The model also shows that, as postgraduates have more specific capital, the gap between their starting wage and average wage is larger than that of undergraduates, but the subsequent wage growth of postgraduates is faster. This result extends the specific human capital hypothesis in Chapman and Tan (1980) – that the starting wage and rate of wage growth are negatively related – to the context of education wage gaps.

I also use my model to quantitatively evaluate two alternative explanations for the counter-cyclical postgraduate wage premium. The two alternative explanations are based on differences in job profitability and hiring costs. I simulate the model under each of these alternative hypotheses and then use empirical evidence to discriminate between them. Finally, I briefly discuss two alternatives not nested by my model: cyclical change in relative supply and difference in risk aversion. I compare them to the available empirical evidence and suggest that they can not provide a reasonable explanation.

Related Literature

This paper contributes to three strands of literature. First, a large literature has studied the consumption self-insurance in the face of uncertain labour income (see e.g. Blundell, Pistaferri and Preston 2008, Heathcote, Storesletten and Violante 2014, and Guner, Kaygusuz and Ventura 2012). This paper explores where income shocks arise from in the first place and contributes to the literature on insurance within the firm. In a competitive framework, Azariadis (1975) and Beaudry and DiNardo (1991) argue that firms can provide employment contracts to insure workers from aggregate shocks. Lagakos and Ordonez (2011) study how the role of displacement costs for workers in determining risk sharing between workers and firms. Lustig, Syverson and Van Nieuwerburgh (2011) study how the portability of organizational capital by managers affects their compensation dynamics. To my knowledge, the current paper is the first to quantify the impact of specific capital on insurance against aggregate shocks within the firm in a noncompetitive framework.

Second, this paper contributes to the theoretical literature on long-term contracts in frictional labour markets. Burdett and Coles (2003) and Shi (2009) derive the optimal wage-tenure contracts with risk averse workers. Menzio and Shi (2011) prove the existence of a block recursive equilibrium in directed search models. Rudanko (2009) derive the optimal contract with two-sided lack of commitment and aggregate shocks but without unobserved worker behaviour. Tsuyuhara (2016), Lentz (2015), and Lamadon (2016) introduce unobserved worker behaviour and dynamic incentive contract, but without shocks to aggregate productivity. The main contributions here are to incorporate specific human capital and aggregate shocks, and to formally derive the optimal wage contracts over the business cycle.

Finally, this paper contributes to the empirical literature that studies the cyclicality of real wages across education groups.[5] In the US, Bils (1985) and Solon, Barsky

[5] A large literature has studied earnings risk across other observables – see, e.g., Guvenen, Ozkan

and Parker (1994) find that estimated real wage cyclicality varies insignificantly with worker's years of education. Keane and Prasad (1993), Lindquist (2004), and Balleer and Rens (2013) find no significant difference in the cyclicality of real hourly wage between college graduates and noncollege workers. Hoynes (2000) find similar result between workers with more than a high school education and workers with a high school education and less. However, using 1967-1991 PSID, Swanson (2007) find that wages of high school dropouts aged 20-29 exhibit greater pro-cyclicality than all other groups. In the UK, Blundell, Crawford and Jin (2014) show that real hourly wages fell by about 10% for all education groups during the Great Recession, and Delaney and Devereux (2019) find that more education lowers the pro-cyclicality of wages. Ammermueller, Kuckulenz and Zwick (2009) find the opposite in Germany that workers with more years of education suffer higher cyclical wage variation. In a related but different literature, Doniger (2019) document that the user cost of labour (allocative wage) is more pro-cyclical for college graduates than noncollege workers. In this paper, I compare workers at a higher education margin and provide novel empirical evidence that postgraduates experience lower cyclical variation in real wages than undergraduates. I then use a combination of microdata and a theoretical model to quantitatively discriminate among several possible explanations for the observed empirical patterns.

Outline

Section 2 provides empirical evidence. Section 3 presents the equilibrium search model. Section 4 characterizes the optimal contract. In Section 5, I outline the estimation strategy, discuss the identification, and report the estimation results. In Section 6, I analyze the estimated model and report the counterfactual simulations. Section 7 evaluates other potential explanations. Section 8 concludes.

and Song (2014) and Bloom et al. (2017) for some recent empirical evidence.

2 Empirical Evidence

2.1 Aggregate Cyclicality

I start by showing the aggregate cyclicality of wage premium across different education levels. Table 1 reports that the undergraduate wage is more pro-cyclical than the postgraduate wage: when real GDP goes up by 1%, the median (mean) postgraduate wage increases by 0.34% (0.25%), and the median (mean) undergraduate wage increases by 0.58% (0.85%). Because of this, the postgraduate-undergraduate wage premium is counter-cyclical. Table 1 also shows that both the college-noncollege wage premium and the undergraduate-noncollege wage premium are largely acyclical.[6]

Table 1: Elasticity with respect to GDP

	Wage			Wage Premium		
	Postgrad	Undergrad	Noncollege	$\frac{\text{Postgrad}}{\text{Undergrad}}$	$\frac{\text{Undergrad}}{\text{Noncollege}}$	$\frac{\text{College}}{\text{Noncollege}}$
Median	.34**	.58***	.57***	-.24*	.01	.03
	(.14)	(.16)	(.12)	(.14)	(.14)	(.13)
Top25%	.04	.71***	.53***	-.67***	.18	-.03
	(.19)	(.15)	(.11)	(.16)	(.12)	(.12)
Mean	.25	.85***	.50***	-.60***	.35**	.12
	(.18)	(.17)	(.12)	(.18)	(.15)	(.13)

Notes. March CPS 1976–2016, males, aged 26–64. Wages are deflated to constant 2000 dollars. College graduates = undergraduates + postgraduates. Standard errors are in parentheses. ***p<0.01, **p<0.05, *p<0.1.

2.2 Regression of Wage on Degree Interaction

I go on to use individual-level data to compare the wage cyclicality between postgraduates and undergraduates, controlling for observed characteristics. To estimate the effects of postgraduate degree on the wage cyclicality, I follow Keane and Prasad (1993) and run the regression of log real hourly wage

[6] The undergraduate-noncollege wage premium is weakly pro-cyclical in the mean, while it is acyclical in the median and the top 25%. As is argued by Lindquist (2004), the median wage premium is a more suitable measure of the correlation between output and the wage premium than the mean wage premium, because composition bias and top-coding have a smaller impact on the median wage premium.

$$\ln W_{it} = \theta PG_{it} + \alpha U_t + \gamma PG_{it} \times U_t + X_{it}\beta + \varepsilon_{it} \quad (1)$$

where PG_{it} is a postgraduate degree dummy, which equals 1 if the worker has a postgraduate degree and 0 if he only has an undergraduate degree. I use unemployment rate U_t as an indicator of the business cycle.[7] α measures the cyclicality of the undergraduate wage. For instance, a negative estimate of α would imply that the average real wage of undergraduates declines when the unemployment rate rises, i.e. the undergraduate wage is pro-cyclical. The coefficient γ on the interaction term $PG_{it} \times U_t$ captures the difference between the cyclicality of the postgraduate wage and the undergraduate wage, and $\alpha + \gamma$ measures the cyclicality of the postgraduate wage. A positive estimate of γ would indicate a counter-cyclical postgraduate wage premium — the premium increases when the unemployment rate rises. X_{it} is a vector of observables including state dummies, a race dummy, a marriage dummy, a cubic age trend and a quartic time trend.

Empirical Results

Table 2 presents the estimates from regression (1). I use the 1976-2016 March CPS and restrict the sample to males aged 26-64 not self-employed. I further restrict the above sample to postgraduates and undergraduates only. The sample size is 364,864 individuals. Following Robin (2011), the unemployment rate is successively log-transformed, HP-filtered and exponentiated. I HP-filter the annual series with a conventional smoothing parameter 100. The results are robust to the detrending method.[8]

The first column of Table 2 shows the regression result on log real hourly wages. Hourly wages are computed as annual labour earnings divided by annual hours, and are deflated to constant 2000 dollars. The estimated coefficient α on the unemployment rate is -0.0124 (s.e. 0.0012), indicating that a 1 percentage point rise in the unemployment rate causes a 1.24% decline in the real wage for undergraduates. Thus, the undergraduate wage is strongly pro-cyclical. The estimated coefficient γ on the interaction term $PG_{it} \times U_t$ is 0.0086 (s.e. 0.0021), indicating that when the

[7]The results are not affected by the choice of the indicator of the business cycle. See the discussion in the next section.

[8]I also detrend the unemployment rate using a cubic trend and obtain very similar results. See column (2) of Table 13 in Appendix B.1.

Table 2: Regression on Degree Interaction

Data	March CPS 76-16			PSID 85-15
Method	OLS			FE
Dependent	lnWage	lnHour	lnEarnings	lnWage
$URATE\,(\alpha)$	-.0124***	-.0064***	-.0188***	-.0125***
	(.0012)	(.0007)	(.0015)	(.0032)
$PG \times URATE\,(\gamma)$	.0086***	.0035***	.0121***	.0120*
	(.0021)	(.0011)	(.0024)	(.0062)
$\alpha + \gamma$	-.0038**	-.0029***	-.0067***	-.0005
	(.0017)	(.0009)	(.0019)	(.0053)
Observations		364,864		12,692

Notes. Sample is males aged 26–64 not self-employed. Robust standard errors are reported in parentheses. ***p<0.01, **p<0.05, *p<0.1.

unemployment rate goes up by 1 percentage point in a downturn, postgraduates face a 0.86% increase in their real wage relative to that of undergraduates. Therefore, the postgraduate wage premium is counter-cyclical. The sum of the coefficients α and γ is -0.0038 (s.e. 0.0017), indicating that a 1 percentage point rise in the unemployment rate causes a 0.38% decline in the postgraduate wage, which is less pro-cyclical than the undergraduate wage.

I also experiment with other indicators of the business cycle, such as log real GDP. I find that when real GDP increases by 1%, the average real hourly wage for postgraduates increases by 0.403% and that for undergraduates increases by 0.988%. See column (1) of Table 13 in Appendix B.1 for the estimates. Column (3)-(5) of the same table presents robustness checks, including median regression and regression by age groups, all confirming my finding that the postgraduate wage is in fact less pro-cyclical than the undergraduate wage.[9]

Hours and Earnings

The second column of Table 2 provides estimates of the cyclicality of annual hours worked. The estimation framework is identical to that used for real hourly wages

[9] Figure 6 in Appendix B.3 plots wage growth rates in booms and recessions. The wage growth rates for postgraduates are relatively more stable over the business cycle than those for undergraduates.

(Equation 1). The coefficient on U_t is -0.0064 (s.e. 0.0007) and the coefficient on $PG_{it} \times U_t$ is 0.0035 (s.e. 0.0011). Thus, for postgraduates, annual hours worked are less pro-cyclical than those for undergraduates. The difference in the cyclicality of hours between undergraduates and postgraduates is smaller than that of wages. The third column of Table 2 shows estimates of cyclicality of annual labour earnings. When the unemployment rate goes up by 1 percentage point, the real earnings of undergraduates fall by 1.88%, and those of postgraduates fall by 0.67%. Postgraduate earnings are less pro-cyclical than undergraduate earnings. In conjunction, these results suggest that postgraduates have more stable wages, hours, and earnings than undergraduates.

Selection Bias

The typical selection bias problem in this type of analysis is: undergraduates are more likely to be unemployed than postgraduates during recessions, so the relative wage of undergraduates increases mechanically. Therefore, my finding that the postgraduate wage premium is counter-cyclical is not generated by selection bias, because selection bias reduces the counter-cyclicality. Furthermore, the unemployment rates for both undergraduates and postgraduates are less than 3% (Table 6), which illustrates the limited effect of the selection bias problem.

To eliminate such systematic selection regardless, I focus on job stayers – workers who stayed in the same job last year, did not look for work during that period, and worked for 52 weeks. This essentially compares average postgraduates with good undergraduates, so the estimated coefficient should be smaller. Column (6) of Table 13 shows that the estimated coefficient γ shrinks slightly to 0.0069. To further support my findings, I run Heckman (1979) selection model with a first-stage probit employment equation.[10] The estimates are in Column (7) of same table, which is similar to the baseline.

[10] The variables included in the first-stage employment equation but excluded from wage equation are: number of own children in the household, number of own children under age 5 in the household, and age of youngest own child in the household.

Industries and Occupations

Table 14 in Appendix B.2 presents the estimates from the wage regression by major industries and occupations. This can be used to check whether this phenomenon occurs because postgraduates and undergraduates sort into different industries and occupations, which are subject to different cyclical shocks in productivity. I find that the postgraduate wage premium is counter-cyclical in all major industries and in Managerial, Professional Specialty, Technical, and Sales occupations (added up to 82% of all college graduates).

In addition, I also check how the coefficient γ on $PG_{it} \times U_t$ shrinks after controlling for interactions between U_t and industries and occupations in Table 15 in the same appendix. The more this coefficient shrinks, the more industries and occupations can explain the counter-cyclicality of the postgraduate wage premium. After controlling for 43 industry dummies $\times$ 60 occupation dummies, I find that γ shrinks from 0.0086 to 0.0059. Therefore, γ does not shrink substantially.

Individual Fixed-Effects

I also run regression 1 with individual fixed-effects controlling for a cubic age trend and a quartic time trend. I use the 1985–2015 Panel Study of Income Dynamics (PSID) and restrict the sample to male heads aged 26-64 not self-employed. The last column of Table 2 presents the estimates. The estimated coefficient α on the unemployment rate U_t is -0.0125 (s.e. 0.0032) indicating that a 1 percentage point rise in the unemployment rate causes a 1.25% decline in the real hourly wage for undergraduates.[11] The estimated coefficient γ on the interaction term $PG_{it} \times U_t$ is 0.0120 (s.e. 0.0062) indicating that when the unemployment rate goes up by 1 percentage point, postgraduates face a 1.2% increase in their real wage relative to that of undergraduates, which confirms that the postgraduate wage premium is counter-cyclical.

[11] Using 1968-1992 PSID, Swanson (2007) regress log real hourly wage on the unemployment rate without distinguishing education levels. He finds that a 1 percentage point rise in the unemployment rate causes a 1.22% decline in the real wage, which is of the similar magnitude as my estimates.

2.3 Job Tenure and Specific Capital

Is there a link between counter-cyclical postgraduate wage premium and job tenure? I test for it using PSID, which is particularly advantageous here because of the information it provides on the length of uninterrupted tenure on the current job. I run the following fixed-effects regression of log wage on interactions between U_t, PG_{it} and length of tenure

$$\begin{aligned} \ln W_{it} = {} & ShortTenure_{it} \times (\alpha_1 U_t + \gamma_1 PG_{it} \times U_t) \\ & + (1 - ShortTenure_{it}) \times (\alpha_2 U_t + \gamma_2 PG_{it} \times U_t) + X_{it}\beta + \mu_i + \varepsilon_{it} \end{aligned} \tag{2}$$

where $ShortTenure_{it}$ is a dummy on the length of tenure, which equals 1 if the worker has at most κ years of uninterrupted tenure on the current job and equals 0 if he has a longer tenure. μ_i stands for unobserved individual-specific characteristics that are fixed over time. X_{it} includes a cubic age trend and a quartic time trend. For new hires, the coefficient α_1 measures the cyclicality of the undergraduate wage, and γ_1 measures the difference in wage cyclicality between postgraduates and undergraduates. α_2 and γ_2 are the corresponding coefficients for workers with a long tenure.

I restrict the sample to male heads aged 26-64 not self-employed. First, following Altonji and Williams (2005), I set $ShortTenure$ as, at most, 1.5 years of tenure. The estimates are presented in the Column "$\kappa = 1.5$" of Table 3. For new hires, the estimated coefficient γ_1 on the interaction term $PG_{it} \times U_t$ has the positive sign but is not significant. For workers with a long tenure, the estimated coefficient γ_2 is significantly positive, indicating that postgraduates have smaller wage cyclicality than undergraduates. γ_2 is significantly larger than γ_1 indicates that the difference in wage cyclicality between postgraduates and undergraduates is higher for workers with a long tenure than new hires. Then, in the Column "$\kappa = 2$" and $\kappa = 2.5$", I set $ShortTenure$ as at most 2 years and 2.5 years of tenure respectively. The results are not changed.

A worker's job tenure is the generally used proxy for specific human capital (Altonji and Shakotko, 1987; Topel, 1991). Thus, this phenomenon is consistent with a story of specific capital: Postgraduates accumulate more specific capital in their jobs than undergraduates. As new hires have not yet built any specific capital, the difference in wage cyclicality between postgraduates and undergraduates is small. As workers with a long tenure have accumulated specific human capital, the difference in wage cyclicality is large.

Table 3: Fixed-effect Regressions by Job Tenure

lnWage	$\kappa = 1.5$	$\kappa = 2$	$\kappa = 2.5$
$ShortTenure$			
$URATE\,(\alpha_1)$	-.0172**	-.0151**	-.0160***
	(.0075)	(.0065)	(.0062)
$PG \times URATE\,(\gamma_1)$	.0052	.0059	.0052
	(.0068)	(.0066)	(.0066)
$1 - ShortTenure$			
$URATE\,(\alpha_2)$	-.0118***	-.0123***	-.0122***
	(.0035)	(.0035)	(.0036)
$PG \times URATE\,(\gamma_2)$	.0111*	.0114*	.0118*
	(.0062)	(.0062)	(.0062)
$\gamma_2 - \gamma_1$	.0059**	.0054**	.0066**
	(.0030)	(.0027)	(.0027)
Observations		12,692	
Workers		1,804	

Source. PSID 1985-2015, males heads, aged 26–64, not self-employed. "$\kappa = 1.5$": $ShortTenure$ is set as, at most, 1.5 years of tenure. "$\kappa = 2$": $ShortTenure$ is set as, at most, 2 years of tenure. "$\kappa = 2.5$": $ShortTenure$ is set as, at most, 2.5 years of tenure. Controls: a cubic age trend and a quartic time trend. Robust standard errors are reported in parentheses. ***p<0.01, **p<0.05, *p<0.1.

2.4 Empirical Evidence on Specific Capital

In previous sections, I showed that postgraduates have more stable wages than undergraduates over the business cycle, and that this effect is significant for workers with a long tenure, but not for new hires. My theory for this phenomenon is that postgraduates have more specific capital which reduces their wage cyclicality. Specific capital has two dimensions: the size of the specific capital that new hires have to build and the time needed for this process. In what follows, I show that postgraduates have more specific capital in these two dimensions.

Time Dimension

First, I study the time it takes to accumulate specific capital. I construct a new measurement in a US employer survey – the Multi-City Study of Urban Inequality (MCSUI), which measures how long it takes new hires to be fully competent in their jobs. The MCSUI was conducted between 1992 and 1994, in the middle of the time period with which this paper is concerned. The survey asked employers a series of specific questions about the last new employee the company hired. One of these questions reads "How many weeks does it take the typical employee in this position to become fully competent in it?" Table 4 provides descriptive statistics on this measure of the time dimension of specific capital. The results show a considerable difference between postgraduates and undergraduates: a newly hired postgraduate needs 58.5 weeks on average to become fully competent, which is twice as long as the time needed for a newly hired undergraduate (29.2 weeks). The difference is significant at the one percent level. A newly hired noncollege worker needs 22.5 weeks to become fully competent, which is about 80% of the time needed for a newly hired undergraduate. There is thus a strong complementarity between education and specific capital, which confirms the findings in Cairó and Cajner (2016).[12] However, the difference between postgraduates and undergraduates is larger than that between undergraduates and noncollege workers.

Table 4: Time Dimension of Specific Capital by Education

Education	Noncollege	Undergrad.	Postgrad.
Weeks until competent	22.5	29.2	58.5
	(.88)	(2.32)	(8.98)
Observations	2566	515	159

Source. MCSUI 1992-1994. Robust standard errors are reported in parentheses.

[12]Cairó and Cajner (2016) use a measure of specific human capital from the Employment Opportunity Pilot Project (EOPP) in 1980 that is similar to my measure from the MCSUI. They also find that education and specific human capital are complementary. In the EOPP, employers were first asked about the current productivity of the last hired worker on a scale of 0 to 100 with 50 being the perceived average of an experienced worker in the position. Second, they asked about the productivity of the last hired worker at the time of hiring on the same scale. Third, if the initial productivity of the workers was below 50, they asked the employers about the time it took for the last hire to reach average productivity. However, no question was asked if the initial productivity of the last hire was at least 50 (only 14% of employers reported a value below 50). The MCSUI data is not affected by this inconsistency, and its sample size is 5 times that of the EOPP.

Size Dimension

With regard to the size dimension, more specific capital leads to larger wage losses from exogenous job displacement. I examine this implication using the 1994-2008 Displaced Workers Survey (DWS), which is a supplement to the CPS. The DWS identifies displaced workers who have been separated from their employers for reasons of slack work, plant closings, and abolished jobs — reasons which have been taken by the literature to instrument for "exogenous" layoffs. The DWS records information on earnings on both the displaced and current job. I construct a sample of male workers who were involuntarily displaced from a full-time job last year and who were reemployed in a full-time job at the time of their interview.

In Table 5, I show the change in log wages across the current job and the displaced job. The resulting statistics represent the fraction of a typical worker's wage that would be lost if he was exogenously removed from his current match and left to find a new job. Percent losses in wages are significant from zero for all education levels, showing a sizable productivity gap between new hires and experienced workers. The percent losses in wages are significantly larger for postgraduates than undergraduates at the ten percent level, and the difference is substantial: -0.178 for displaced postgraduates, twice as large as that for displaced undergraduates (-0.086). The difference between undergraduates and noncollege workers is not significant. In Section 5, by targeting the percent losses in wages for displaced workers by education, I estimate the initial productivity gap of new hires in my model, which is indeed higher for postgraduates than that for undergraduates.

Table 5: Wage Loss from Job Displacement by Education

Education	Noncollege	Undergrad.	Postgrad.
$\mathbb{E}\left(\log w_t - \log w_{t-1}\right)$	-.086	-.086	-.178
	(.013)	(.030)	(.060)
Observations	2576	543	210

Source. DWS 1994-2008, males who were involuntarily displaced from a full-time job last year and are reemployed in a full-time job now. Robust standard errors are reported in parentheses.

2.5 Worker Flows

Table 6 shows unemployment rates and worker flows for males aged 26-64. Postgraduates have lower unemployment rate than undergraduates. Their job separation rate is 0.46%, which is 50% lower than that of undergraduates. The job finding rate of postgraduates is 24.5%, which is 7.3% lower than that of undergraduates, and the job-to-job transition rate of postgraduates is 1.78%, which is 8.4% lower than that of undergraduates. Thus, postgraduates have lower probabilities of job separation than undergraduates, indicating that workers with more specific capital have lower outside options.

Table 6: Unemployment Rates and Monthly Worker Flows

Education	Postgrad.	Undergrad.
Unemployment rate	2.05%	2.90%
Job separation rate	0.46%	0.69%
Job finding rate	24.5%	26.3%
Job-to-job transition rate	1.78%	1.93%

Source. Job-to-job transition rate uses Monthly CPS 1994-2014. Other variables use Monthly CPS 1979–2014. Males aged 26-64.

3 Contracting Model of Asymmetric Information

In this section, I develop an equilibrium search model with dynamic incentive contracts, accumulation of specific human capital, and aggregate shocks. I use it to evaluate the impact of specific capital on labour turnover and wage cyclicality by education. In the model, the amount of specific capital is equal to the productivity gap between new hires and experienced workers. New hires obtain specific capital through a period of learning. I assume risk-averse workers and risk-neutral firms, which make long-term contracts optimal.[13] Imperfect monitoring of worker effort creates a moral hazard problem that requires firms to pay efficiency wages.

[13] This assumption is based on the arguments that entrepreneurs are less risk-averse than workers, and their risk can be insured through better access to asset markets.

Job search is directed, and the equilibrium is block-recursive, such that individuals' optimal decisions and optimal contracts are independent of the distribution of workers.

3.1 Preferences and Technology

Time is discrete and indexed by t. Aggregate productivity z_t evolves as a first-order Markov chain with transition probabilities $\pi(z_{t+1}|z_t)$, such that the transition matrix Π is monotone.

Workers are characterized in terms of their education: either noncollege (NC), undergraduate (BA), or postgraduate (PG). Workers in each education group possess a certain amount of general human capital, denoted by $h \in \{h_{NC}, h_{BA}, h_{PG}\}$. Let $s \in \{0, 1\}$ denotes a worker's level of specific human capital in the match, where $s = 1$ represents an experienced worker possessing specific capital, and $s = 0$ represents a new hire without specific capital.

I follow the standard approach in the search literature by assuming that a firm is a single-worker production unit. A match with an experienced worker ($s = 1$) could produce $y^h(s, z) = y^h(1, z) = hz$, which is strictly increasing in education h and aggregate shock z. New hires are initially unskilled in matches. They obtain specific capital through a period of learning. In each period, a new hire may upgrade to an experienced worker with probability ϕ^h.[14] τ^h is the productivity gap between new hires and experienced workers, i.e. $y^h(1, z) - y^h(0, z) = \tau^h$. Note that ϕ^h and τ^h depend on the education level h.

Workers are risk-averse. They are endowed with one unit of labour each period, which they supply to firms for a wage w_t. Workers cannot save or borrow against their future income.[15] Worker's consumption each period equals his wage if employed, or equals the unemployment benefit b^h if unemployed.

Following Tsuyuhara (2016), I assume a job consists of a series of projects, one of which is executed in each period. Employed workers exert effort e_t for a project of the firm during each period. With probability $r(e_t)$, the project succeeds, and the output is $y^h(s, z)$, where the aggregate state is z and the worker is of education

[14]Then $1/\phi^h$ yields the average duration of learning.

[15]A search model combing saving and long-term contracts is very complicated in a business cycle setting, because it requires firms to post jobs depending on workers' wealth. But this is an interesting extension, and I will explore it in future research.

h and skill type s. With probability $1 - r(e_t)$, the project fails, and the output is 0. If the project succeeds, the job continues in the following period, whereas the worker is laid off and becomes unemployed if the project fails. The probability of success $r(.)$ is a twice continuously differentiable, strictly increasing, and concave function. The preference of the worker is

$$\mathbb{E}\sum_{t=0}^{\infty}\beta^t\left[\frac{w_t^{1-\gamma}-1}{1-\gamma}-c(e_t)\right]$$

where he has constant relative risk aversion preference over consumption, and the effort cost function $c(.)$ is a twice continuously differentiable, strictly increasing, strictly convex, and satisfies standard Inada conditions so that effort is interior.

3.2 Employment Contracts

In the beginning of each match, a risk-neutral firm offers a long-term contract to a risk-averse worker. The contract specifies wages and recommended effort for all continuation histories. Let $x_t = (s_t, z_t)$ be the state of the match at period t. History up to period t is denoted by $x^t = (x_1, \ldots, x_t)$. Then the contract is a function

$$\sigma = \left\{w_t\left(x^t\right), e_t\left(x^t\right)\right\} \text{ for all } x^t$$

where w_t is the wage and e_t is the recommended effort. I assume firms commit to contract σ and that, once the employment relationship begins, the firm cannot adjust the prespecified sequences of wages and effort.

The optimal contract depends crucially on the observability of the effort level. If effort were observable, because of the difference in risk aversion between firms and workers, the problem would be purely one of efficient risk sharing in which firms would bear all the risk, offer constant wages, and prescribe constant effort (Azariadis, 1975). I assume the level of effort e_t is unobserved by firms. As cost of effort enters negatively in his utility function, the worker might shirk his effort. Then, firms have to adjust wages to provide incentives. Thus, the moral hazard problem requires firms to pay efficiency wages.

3.3 Worker Effort Choice Problem

Following the recursive contracting approach in Spear and Srivastava (1987), history dependence can be summarized by introducing an additional state variable, the promised value V, which is the expected discounted future value that the firm promised to deliver to the worker from this period onwards. At each state (h, s, z, V), the firm chooses $\left\{w, \left\{V^h_{s'z'}\right\}, e\right\}$. Here w is the current wage, $\left\{V^h_{s'z'}\right\}$ is the value promised to the worker for each realization of aggregate state z' and skill type s' next period, and e is the recommended effort level.

An employed worker optimally chooses effort e prescribed by the contract. Let U^h_z be the value of unemployment for a worker of education level h at aggregate state z. The incentive-compatibility constraint for a worker of education h and skill type s at aggregate state z is

$$e \in \underset{\hat{e}}{\operatorname{argmax}} \frac{w^{1-\gamma}-1}{1-\gamma} - c\left(\hat{e}\right) + \beta\left\{r\left(\hat{e}\right)\mathbb{E}_{sz}V^h_{s'z'} + \left[1-r\left(\hat{e}\right)\right]\mathbb{E}_z U^h_{z'}\right\} \tag{3}$$

where the expected promised value next period

$$\mathbb{E}_{sz}V^h_{s'z'} = \begin{cases} \mathbb{E}_z V^h_{1z'} & \text{if } s=1 \\ \mathbb{E}_z\left[\phi^h V^h_{1z'} + \left(1-\phi^h\right)V^h_{0z'}\right] & \text{if } s=0 \end{cases}$$

Here ϕ^h is the upgrading probability from a new hire to an experienced worker. Then the necessary and sufficient condition for e to be the optimal effort is

$$\frac{c'\left(e\right)}{r'\left(e\right)} = \beta\left(\mathbb{E}_{sz}V^h_{s'z'} - \mathbb{E}_z U^h_{z'}\right) \tag{4}$$

Intuitively, effort is chosen to equate the marginal cost of effort with its marginal benefit. According to this equation, there is little hope to separately identify the convexity of $c\left(.\right)$ and the concavity of $r\left(.\right)$. Therefore, I normalize the probability of success $r\left(e\right) = e$. Then Equation (4) becomes $c'\left(e\right) = \beta\left(\mathbb{E}_{sz}V^h_{s'z'} - \mathbb{E}_z U^h_{z'}\right)$. Hopenhayn and Nicolini (1997) have a similar setup with convex cost function of job search effort and concave job finding probability. They normalize the cost function of job search effort to be linear and estimate the concavity of the job finding probability.

As effort cost function $c\left(.\right)$ is strictly increasing and strictly convex, e increases with the expected promised value next period $\mathbb{E}_{sz}V^h_{s'z'}$ and decreases with the expected value of unemployment next period $\mathbb{E}_z U^h_{z'}$. By promising a higher value next period, the firm can extract a higher effort in the current period.

3.4 Firm Contracting Problem

I now describe the firm problem in terms of promised value. Consider the situation faced by a firm that is matched with a worker of skill type s and education h. Let $\Pi^h(s,z,V)$ be the expected discounted profit for the firm when the aggregate state is z and the worker is offered with a continuation value V. If the match separates, the firm is left with zero profit. Then $\Pi^h(s,z,V)$ must satisfy the following Bellman equation:

$$\Pi^h(s,z,V) = \max_{w,\left\{V^h_{s'z'}\right\},e} e\cdot y^h(s,z) - w + e\cdot\beta\mathbb{E}_{sz}\Pi^h\left(s',z',V^h_{s'z'}\right) \tag{5}$$

where the expected profit next period

$$\mathbb{E}_{sz}\Pi^h\left(s',z',V^h_{s'z'}\right) = \begin{cases}\mathbb{E}_z\Pi^h\left(1,z',V^h_{1z'}\right) & \text{if } s=1\\ \mathbb{E}_z\left[\phi^h\Pi^h\left(1,z',V^h_{1z'}\right)+\left(1-\phi^h\right)\Pi^h\left(0,z',V^h_{0z'}\right)\right] & \text{if } s=0\end{cases}$$

subject to the promise-keeping constraint and the incentive-compatibility constraint

$$V = \frac{w^{1-\gamma}-1}{1-\gamma} - c(e) + \beta\left[e\mathbb{E}_{sz}V^h_{s'z'} + (1-e)\,\mathbb{E}_z U^h_{z'}\right] \tag{6}$$

$$c'(e) = \beta\left(\mathbb{E}_{sz}V^h_{s'z'} - \mathbb{E}_z U^h_{z'}\right) \tag{7}$$

The promise-keeping constraint (6) requires that the firm delivers the promised value V to the worker. By increasing future promises, the firm can increase the effort level of its worker, and thus, increase the probability that the match continues.[16]

[16] Note that promise-keeping and incentive-compatibility restrictions may define a set that is not convex. Then the profit function may not be concave. In this case, the solution to the dynamic programming problem above can be improved by using lotteries (Phelan and Townsend, 1991). However, as is argued by Hopenhayn and Nicolini (1997), the optimal contract may not involve the use of lotteries, because convexity of the choice set is a sufficient but not necessary condition for concavity of the profit function. Indeed, in all my numerical computations, the profit function turns out to be concave, making lotteries redundant. Since the objective of this section is to derive some general properties of the optimal contracts, I will focus on the optimal program defined above, disregarding the use of lotteries.

The first-order conditions for firm problem are

$$y^h(s,z) + \beta \mathbb{E}_{sz} \mathit{\Pi}^h\left(s', z', V^h_{s'z'}\right) = \kappa c''(e) \tag{8}$$

$$\frac{e \cdot \partial \mathit{\Pi}^h\left(s', z', V^h_{s'z'}\right)}{\partial V^h_{s'z'}} + e \cdot w^\gamma_{sz} + \kappa = 0 \tag{9}$$

where κ is the multiplier on the incentive-compatibility constraint. The envelope condition is

$$\frac{\partial \mathit{\Pi}^h(s,z,V)}{\partial V} = -w^\gamma_{sz} \tag{10}$$

3.5 Search Markets and Equilibrium

The meeting process between unemployed workers and vacancies is constrained by search frictions. The labour market is organized in a set of queues indexed by (h, v), which are the required education level and the value promised to workers in that given queue.

Each firm chooses in which queue they want to open a vacancy with a flow cost $\eta^h > 0$, and each unemployed worker chooses where to queue. Each sub-market is characterized by its tightness represented by θ, which is the ratio of the number of vacancies to the number of unemployed workers in this sub-market. The tightness captures the fact that a high ratio of vacancies to workers will make it harder for firms to hire. In a directed search model like the one presented here, the tightness is queue specific. I use a standard matching function that in the sub-market with tightness θ, a vacancy is filled with probability $q(\theta) = \theta^{\alpha-1}$, and a worker matches with probability $\mu(\theta) = \theta^\alpha$.[17] Then

$$\mu(\theta) = q(\theta)^{\frac{\alpha}{\alpha-1}} \tag{11}$$

In principle, different sub-markets could co-exist at the same time, but this does not happen in equilibrium. Anticipating such an outcome, the equilibrium definition specifies the labour market as a single tightness and promised value pair $\left(\theta^h_z, v^h_z\right)$ for each aggregate productivity z and education level h. Appendix C.1 shows this

[17] According to Equation (24), vacancy posting cost and α is not separately identified. Therefore, I draw from the evidence reported in Shimer (2005) and accordingly set $\alpha = 0.28$.

result.

A competitive search equilibrium is defined along the lines of Moen (1997).

Definition 1. A competitive search equilibrium consists of: for each (z,h), a value for unemployment U_z^h and a sub-market with tightness θ_z^h and promised value $v_z^h = \mathbb{E}_z V_{0z'}^h$, such that

1. Search offers zero profit for a firm, i.e. the free entry condition equalizes the costs of posting a vacancy with the expected discounted profit

$$q\left(\theta_z^h\right) \cdot \beta \mathbb{E}_z \mathit{\Pi}^h \left(0, z', V_{0z'}^h\right) - \eta^h = 0 \tag{12}$$

where η^h is the vacancy posting cost, and $q\left(\theta_z^h\right)$ is the probability of filling a vacancy. As the worker is initially unskilled, $\mathbb{E}_z \mathit{\Pi}^h \left(0, z', V_{0z'}^h\right)$ is the firm's expected profit when matched with a new hire in the beginning of the match.

2. No Pareto improving sub-market is possible, i.e. there does not exist a sub-market with tightness $\hat{\theta}_z^h$ and promised value $\hat{v}_z^h = \mathbb{E}_z \hat{V}_{0z'}^h$, s.t.

$$\mu\left(\hat{\theta}_z^h\right) \mathbb{E}_z \left(\hat{V}_{0z'}^h - U_{z'}^h\right) > \mu\left(\theta_z^h\right) \mathbb{E}_z \left(V_{0z'}^h - U_{z'}^h\right) \tag{13}$$

$$q\left(\hat{\theta}_z^h\right) \cdot \beta \mathbb{E}_z \mathit{\Pi}^h \left(0, z', \hat{V}_{0z'}^h\right) > \eta^h \tag{14}$$

3. The value for unemployment U_z^h is consistent:

$$U_z^h = \frac{\left(b^h\right)^{1-\gamma} - 1}{1-\gamma} + \beta \mathbb{E}_z \left\{\mu\left(\theta_z^h\right) V_{0z'}^h + \left[1 - \mu\left(\theta_z^h\right)\right] U_{z'}^h\right\} \tag{15}$$

4 Characterization of the Optimal Contract

4.1 Specific Capital, Effort, and Job Separation

Lemma 1. *The pareto frontier $\mathit{\Pi}^h(s,z,V)$ increases with the level of aggregate productivity z and skill type s.*

Proof. See Appendix C.2. □

Lemma 2. *Under the optimal contract, a higher amount of specific human capital reduces the value of a new job.*

Proof. See Appendix C.3. □

From Lemma 2, a higher amount of specific capital reduces a firm's incentive to post vacancies, leading to a decrease in the job finding rate in every sub-market, thereby reducing the value of a worker's outside options. This is consistent with Becker (1962) that costs of acquiring specific capital are shared between workers and firms.

Proposition 1. *Under the optimal contract, a higher amount of specific human capital increases an experienced worker's optimal effort and reduces the probability of job separation.*

Proof. See Appendix C.4. □

The intuition behind Proposition 1 is that, in leaving their current jobs, experienced workers have to build up specific human capital again, so they have strong incentives to keep their jobs longer. These incentives increase with the level of specific capital, as more specific capital reduces the value of a worker's outside options in all aggregate states. Thus, experienced workers with more specific capital exert a higher effort for their projects, and their jobs are less likely to break down.

4.2 Wage Changes and Aggregate Shocks

Proposition 2. *Under the optimal contract, wage changes track aggregate productivity shocks.*

Proof. From (8) and (9) I obtain

$$-\frac{e \cdot \partial \mathit{\Pi}^h \left(s', z', V^h_{s'z'}\right)}{\partial V^h_{s'z'}} - e \cdot w^{\gamma}_{sz} = \frac{y^h\left(s, z\right) + \beta \mathbb{E}_{sz} \mathit{\Pi}^h \left(s', z', V^h_{s'z'}\right)}{c''\left(e\right)}$$

From envelope condition (10), I substitute the first term on the left with the wage next period and get

$$w^{\gamma}_{s'z'} - w^{\gamma}_{sz} = \frac{y^h\left(s, z\right) + \beta \mathbb{E}_{sz} \mathit{\Pi}^h \left(s', z', V^h_{s'z'}\right)}{e \cdot c''\left(e\right)} \tag{16}$$

When $y^h\left(s, z\right) + \beta \mathbb{E}_{sz} \mathit{\Pi}^h \left(s', z', V^h_{s'z'}\right) = 0$, the wage will not change, i.e. $w_{s'z'} = w_{sz}$. Define $\tilde{w}_{sz}$ as the wage such that $y^h\left(s, z\right) + \beta \mathbb{E}_{sz} \mathit{\Pi}^h \left(s', z', V^h_{s'z'}\right) = 0$. From

Lemma 1, $\mathbb{E}_{sz}\Pi^h\left(s', z', V^h_{s'z'}\right)$ increases with the level of aggregate productivity. At the same time, as the flow output $y^h(s,z)$ is also strictly increasing in aggregate productivity, when aggregate productivity increases, $y^h(s,z) + \beta\mathbb{E}_{sz}\Pi^h\left(s', z', V^h_{s'z'}\right)$ becomes positive. As the effort cost function is strictly convex $c''(e) > 0$, we have $w^\gamma_{s'z'} > \tilde{w}^\gamma_{sz}$, and then $w_{s'z'} > \tilde{w}_{sz}$ by concavity. Therefore, the wage increases with the level of aggregate productivity, and vice versa. □

4.3 Specific Capital and Wage Stability

Next, I show that wage stability is affected by specific capital, given that firms face the trade-off between increasing wage stability to provide insurance to workers (risk-sharing motive) and increasing wage cyclicality to incentivize their workers to exert the optimal effort (incentivizing motive). Assumption 1 is an additional convexity requirement on the effort cost function, which is the sufficient condition for Proposition 3.

Assumption 1. *The marginal cost of effort is convex. In other words, the second derivative of the effort cost function $c''(e)$ increases with the level of effort.*

Proposition 3. *Given Assumption 1, a higher amount of specific human capital increases wage stability of an experienced worker.*

Proof. The response of an experienced worker's optimal effort to increased incentives is

$$\frac{de}{d\beta\mathbb{E}_z\left(V^h_{1z'} - U^h_{z'}\right)} = \frac{d\left(c'\right)^{-1}\left[\beta\mathbb{E}_z\left(V_{z'} - U_{z'}\right)\right]}{d\beta\mathbb{E}_z\left(V^h_{1z'} - U^h_{z'}\right)} = \frac{de}{dc'(e)} = \frac{1}{c''(e)}$$

For an experienced worker, Equation (16) can be rewritten as

$$e \times \left(w^\gamma_{1z'} - w^\gamma_{1z}\right) = \frac{de}{d\beta\mathbb{E}_z\left(V^h_{1z'} - U^h_{z'}\right)} \times \left[hz + \beta\mathbb{E}_z\Pi^h\left(1, z', V^h_{1z'}\right)\right] \tag{17}$$

The first term on the left-hand side of Equation (17) is worker's optimal effort. When aggregate productivity increases (decreases), firms promise a higher (lower) wage next period to extract a higher (lower) effort in the current period. From Proposition 1, experienced workers with more specific capital exert a higher effort, so their projects are more likely to succeed and their jobs are less likely to break down. Therefore, they will value more about firms' future promises. As firms' promises become more effective in motivating workers, firms do not need to give workers a lot of incentives.

The first term on the right-hand side of Equation (17) is the response of e to increased incentives. According to Assumption 1, as the level of effort increases, this response becomes smaller, and thus, it becomes increasingly costly for firms to provide incentives for worker effort. A higher amount of specific capital increases an experienced worker's effort, thereby increasing firm's marginal cost of providing incentives.

Firms face the trade-off between the risk-sharing motive and the incentivizing motive. As a higher amount of specific capital increases both the effectiveness and the marginal cost of providing incentives, it becomes optimal for firms to provide more insurance rather than more incentives, i.e. smaller wage changes caused by changes in aggregate productivity. Therefore, a higher amount of specific human capital increases wage stability of an experienced worker. □

5 Estimation

To be able to use the model for quantifying the effect of specific capital on wage cyclicality, some of the model parameters are calibrated or fixed at externally estimated values, while others are directly estimated. I begin by describing fixed and externally estimated parameters and then turn to parameters estimated by the simulated method of moments.

5.1 Fixed and Externally Estimated Parameters

The parameter values that are fixed or externally estimated are listed in Table 7. The probability of being upgraded from a new hire to an experienced worker ϕ captures the time dimension of specific human capital in the model. It is calculated using MCSUI as the inverse of the time it takes new hires to be fully competent (Table 4).[18] A period in the model is 1 month. The discount factor is consistent

[18] Weeks are transformed to months by multiplying 4.33, so that

$$\phi_{PG} = 4.33/58.52 = 0.07, \quad \phi_{BA} = 4.33/29.17 = 0.15, \quad \phi_{NC} = 4.33/22.46 = 0.19$$

with an annual real interest rate of 5%, which is the long term average of the 3-month Treasury Bill in 1976-2016. I normalize the amount of general skills for undergraduates $h_{BA} = 1$.

Table 7: Exogenous Parameter Values

Description	Param.	Value	Source
discount factor	β	.996	3-month Treasury Bill
general skill for BA	h_{BA}	1	Normalization
upgrading probability for a new hire			
Postgraduates	ϕ_{PG}	.07	MCSUI
Undergraduates	ϕ_{BA}	.15	MCSUI
Noncollege workers	ϕ_{NC}	.19	MCSUI

5.2 Model Specification

Given the parameters above, I estimate the model using the simulated method of moments and a parametrized model. I present the specification I use in this section. The aggregate productivity follows an AR(1) in logs, such that

$$\ln z_t = \rho_z \ln z_{t-1} + v_{zt} \quad \text{where } v_{zt} \sim \mathcal{N}\left(0, \sigma_z^2\right) \tag{18}$$

The worker's effort cost function is

$$c(e) = c_0 \left[(1-e)^{-c_1} - 1\right] \tag{19}$$

such that $c(0) = 0$, $\lim_{e \to 1} c(e) = \infty$, $c'(.) > 0$, $c''(.) > 0$, $c'''(.) > 0$.[19] I assume the vacancy posting cost and the unemployment benefit are proportional to the amount of general skills to rule out different profitability (Pissarides, 2000)

$$\eta^h = \eta * h \tag{20}$$

$$b^h = b * h \tag{21}$$

[19] $c'(e) = c_0 c_1 (1-e)^{-c_1 - 1}$, $c'(0) = c_0 c_1$, $\lim_{e \to 1} c'(e) = \infty$. To deal with the corner solutions, I set effort to 0 if $c'(0) < c_0 c_1$, and effort can never be 1 as the cost is infinite.

where b can be interpreted as the unemployment insurance replacement rate. I relax these proportionality assumptions in Section 7.1 and 7.2.

These specifications leave me with the following 12 parameters to estimate:

$$\{\rho_z, \sigma_z, \eta, b, c_0, c_1, \gamma, \tau_{PG}, \tau_{BA}, \tau_{NC}, h_{PG}, h_{NC}\}$$

I perform my estimations using the simulated method of moments. The objective function is minimized over all parameters. The initial productivity gap between new hires and experienced workers τ determines the size dimension of specific human capital in the model. To pin down $\{\tau_{PG}, \tau_{BA}, \tau_{NC}\}$, I target the empirical data from DWS on percent losses in wages after job displacement (Table 5).

The parameters of the aggregate productivity shock $\{\rho_z, \sigma_z\}$ are identified by the standard deviation and auto-correlation of log GDP. The amount of general skills $\{h_{PG}, h_{NC}\}$ are pinned down by the median postgraduate wage premium and the median undergraduate-noncollege wage premium. The vacancy cost η affects the meeting rate through firm's free entry condition (12). The unemployment insurance replacement rate b affects the value of unemployment, and thus, affects the probabilities of starting a job, since individuals without jobs will choose where to apply based on present value. Thus, job finding probabilities by education pin down η and b. The parameters of the effort cost function c_0 and c_1 affect the average rate at which workers lose their jobs. They are pinned down by job separation rates by education. As GDP is only provided on a quarterly frequency, I take the quarterly average for all monthly series. Then, I log and HP filter the data with smoothing parameter 10^5 to produce business cycle statistics.[20]

The parameter of risk aversion γ controls how quickly changes in aggregate productivity are transmitted into wage changes. I target it at the elasticity of median wages with respect to GDP for undergraduates. Please note that the elasticity of median wages for postgraduates and noncollege workers are not targeted. I leave them as model outcomes and show that the model is successfully able to match the non-targeted moments.

[20]The smoothing parameter is suggested by Shimer (2005).

5.3 Estimation Results

Estimation is performed using the simulated method of moments. Since the model is strongly parametrized, I choose the weighting matrix to reflect how informative each moment should be about the parameters of interest. The default weight is chosen to be the inverse of the level to minimize a distance in relative deviation. The computation of standard errors is based on the pseudo-likelihood estimator presented in Chernozhukov and Hong (2003). Using Markov Chain Monte Carlo (MCMC) rejection sampling, I can perform the estimation without having to compute derivatives and still obtain standard errors on the parameters.

The parameter estimates are displayed in Table 8. The monthly aggregate productivity shock has a persistence of 0.985. The standard deviation of the shock to the aggregate productivity is 0.0052. The vacancy posting cost is 7.324. The unemployment insurance replacement rate is 0.557. The level and the curvature of effort cost are 0.157 and 0.096 respectively. The risk aversion parameter is 1.116. The initial productivity gap for undergraduates is 0.173, which is 35% of that for postgraduates. The initial productivity gap for noncollege workers is 0.137. The amount of general human capital for noncollege workers is 0.682 and for postgraduates is 1.222.

The fitted moments in the data and their model simulations are shown in the columns "Data" and "Baseline" of Table 9. The model fits the moments quite well. One success of the model is that it can capture the turnover rates between postgraduates and undergraduates: undergraduates have higher probabilities both in job finding and job separation compared to postgraduates, and the relative differences are generally accurate. The job separation rate for noncollege workers is lower than its counterpart in the US. This is because, in this model, the probability of job separation is affected by worker effort. This suggests that the estimation might benefit from making the parameters for the effort cost function heterogeneous across education levels. On the other hand, there are many other factors that might lead to higher job separation for noncollege workers, and thus, imposing an exogenous job separation rate would move the fit in the right direction.

Table 8: Parameter Estimates

Parameters		Value	s.e.
Persistence of aggregate productivity	ρ_z	.985	.0056
Std. of shock to aggregate productivity	σ_z	.0052	.0019
Vacancy posting cost	η	7.324	2.022
Unemployment insurance replacement rate	b	.557	.077
Level of effort cost	c_0	.157	.048
Curvature of effort cost	c_1	.096	.024
Risk aversion	γ	1.116	.028
Initial productivity gap			
Postgraduate	τ_{PG}	.498	.065
Undergraduate	τ_{BA}	.173	.051
Noncollege	τ_{NC}	.137	.053
Formal human capital			
Postgraduate	h_{PG}	1.222	.041
Noncollege	h_{NC}	.682	.061

Note. The computation of standard errors is based on the pseudo-likelihood estimator presented in Chernozhukov and Hong (2003).

6 Analysis

6.1 Cyclical Properties of Wages and Wage Premium

Table 10 shows the cyclicality of wages and wage premium in the data and their model simulations. Please note only the wage cyclicality for undergraduates is targeted in the estimation; the wage cyclicalities for postgraduates and noncollege workers are not targeted.

Overall, the model correctly captures the cyclicality of wages and wage premium: The undergraduate wage is more pro-cyclical than the postgraduate wage, and is about the same as the noncollege wage. The postgraduate wage premium is countercyclical; the undergraduate wage premium is acyclical. The elasticity of median postgraduate wage premium to GDP is -0.258, and the elasticity of undergraduate wage premium is 0.006, which are about the same size as the data.

Figure 2 plots the GDP and wages simulated from the model. The dotted line is the GDP, the solid line is the postgraduate wage, and the dashed line is the un-

Table 9: Model Fit (Targeted Moments)

Moments	Data	Baseline
Postgraduates		
Job separation rate	.005	.005
Job finding rate	.245	.248
Percent wage losses after displacement	-.178	-.176
Undergraduates		
Job separation rate	.007	.009
Job finding rate	.263	.263
Percent wage losses after displacement	-.086	-.089
Elasticity of median wage to GDP	.58	.58
Noncollege workers		
Job separation rate	.016	.009
Job finding rate	.272	.265
Percent wage losses after displacement	-.086	-.086
Common moments		
Median postgraduate wage premium	1.23	1.219
Median undergraduate wage premium	1.47	1.466
std $[GDP]$	.024	.024
autocorr $[GDP]$	.954	.955

dergraduate wage. As each series is logged and demeaned, it shows the percentage deviation from the mean. It shows that both the postgraduate wage and the undergraduate wage are pro-cyclical, but the postgraduate wage fluctuates less than the undergraduate wage. Therefore, the model picks up the fact that the postgraduate wage is more stable than the undergraduate wage over the business cycle.

6.2 Impact of Specific Capital on Labour Turnover and Wage Cyclicality

To examine the importance of specific capital on labour turnover and wage cyclicality, I run a counterfactual simulation where postgraduates have the same low level of specific capital as undergraduates: the upgrading probability ϕ is increased from 0.07 to 0.15, and the initial productivity gap τ is reduced from 0.498 to 0.173. I report the simulation results in the column "Low Capital" of Table 11.

Table 10: Cyclicality of Wages and Wage Premium

Moments	Type	Data	Baseline
Elasticity of median wage to GDP			
Postgraduates	Non-targeted	.34	.322
Undergraduates	Targeted	.58	.58
Noncollege workers	Non-targeted	.57	.574
Elasticity of median wage premium to GDP			
Postgraduate wage premium (w_{PG}/w_{BA})	Non-targeted	-.24	-.258
Undergrad. wage premium (w_{BA}/w_{NC})	Non-targeted	.01	.006

Note. Non-targeted moments are not targeted in the estimation.

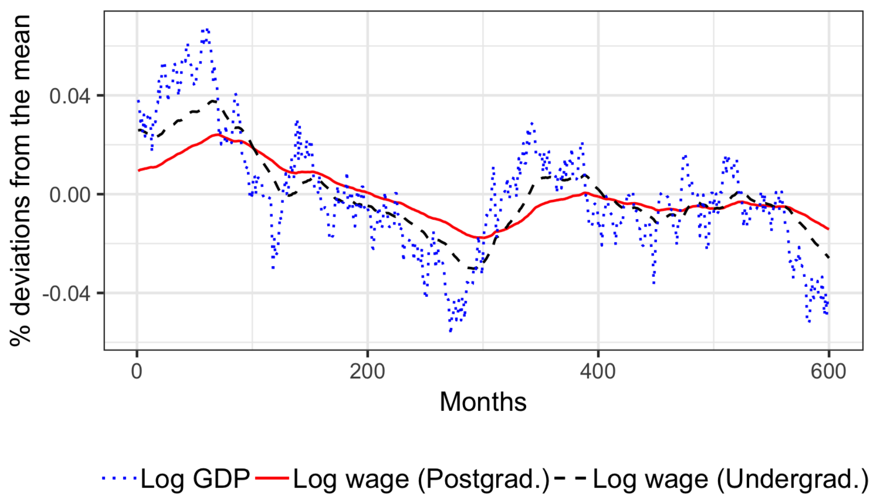

Figure 2: Demeaned Log GDP and Log Wages by Education

The first row of column "Low Capital" shows that, when postgraduates have lower specific capital, the job separation rate increases from 0.005 to 0.01. As there is less to lose if they move to a new job, they exert a lower effort for their projects, and their jobs are more likely to break down. An increase in the upgrading probability and a decrease in the initial productivity gap increase the value of a new job. Consequently, firms have a greater incentive to post vacancies. In the second row of "Low Capital", the job finding rate of the postgraduates increases from 0.248 to 0.265. Hence, when holding the same level of specific capital, postgraduates and undergraduates have the same level of labour market turnover rates.

Table 11: Low Level of Specific Capital for Postgraduates

Moments	Baseline	Low Capital
Postgraduates		
Job separation rate	.005	.010
Job finding rate	.248	.265
Percent wage losses after displacement	-.176	-.083
Elasticity of median wage to GDP	.322	.599
Undergraduates		
Job separation rate	.009	.009
Job finding rate	.263	.263
Percent wage losses after displacement	-.089	-.089
Elasticity of median wage to GDP	.58	.58
Postgraduate wage premium (w_{PG}/w_{BA})		
Median	1.219	1.222
Elasticity to GDP	-.258	.018

Note. Baseline: baseline calibration; Low Capital: Postgraduates have the same low level of specific capital as undergraduates.

The 4th row of "Low Capital" shows that when postgraduates have lower specific capital, the wage elasticity to GDP increases from 0.322 to 0.599, indicating that, relative to the baseline simulation, the postgraduate wage fluctuates more over the business cycle and is as cyclical as the undergraduate wage. In the last row of "Low Capital", the elasticity of postgraduate wage premium to GDP changes from -0.258 to 0.018, i.e. the postgraduate wage premium changes from counter-cyclical to acyclical. So once holding the level of specific capital equal, the model generates same wage cyclicality across education groups. This result shows that specific capital explains the difference in the wage cyclicality between postgraduates and undergraduates.

Figure 3 compares log median wages with different levels of specific capital. The solid line is the log median wage of postgraduates in the baseline simulation, the dashed line is the log median wage of postgraduates in the "Low Capital" simulation, and the dotted line is the log median wage of undergraduates in the baseline. First, in comparing educations levels, postgraduate wages are higher than undergraduate wages. When I compare within postgraduate wages, the postgraduate wage in the baseline is more stable than that in the "Low Capital" simulation, which is also the result of Proposition 3. The postgraduate wage in the "Low Capital" simulation fluctuates as much as the undergraduate wage in the baseline. Interestingly, in Figure 3, the postgraduate wage in the "Low Capital" simulation is higher than that in the baseline simulation. Thus, a low level of specific capital shifts the postgraduate wage up. In the penultimate row of column "Low Capital" of Table 11, the postgraduate wage premium increases from 1.219 to 1.222. Therefore, when I hold the level of specific capital equal, the postgraduate wage premium increases. As postgraduates have more specific capital than undergraduates, they accept relatively lower wages, leading to a smaller wage premium in the baseline.

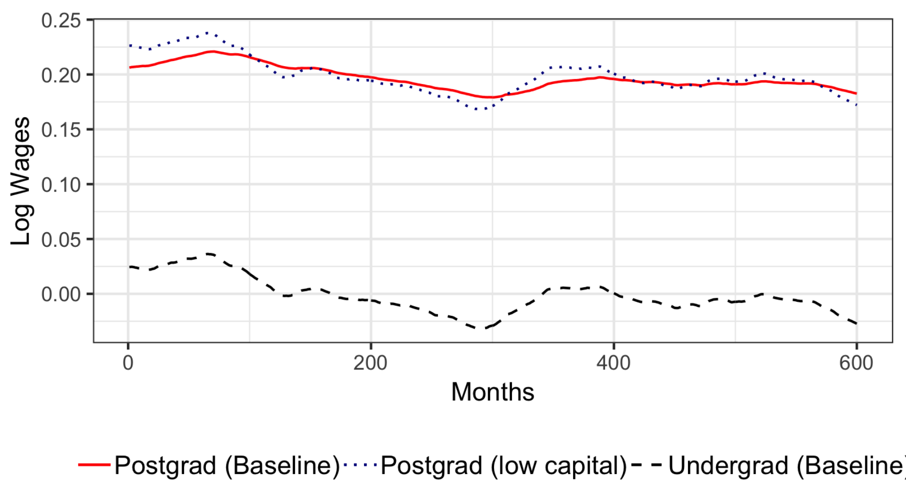

Figure 3: Effect of Specific Capital on Wage Cyclicality

6.3 Wage-tenure Profiles

Different levels of specific capital also have different implications for wage-tenure profiles. These implications can be summarized by plotting the wage-tenure profiles by education, which are displayed in Figure 4. The solid line depicts the postgraduate wage against current job tenure, and the dashed line depicts the undergraduate wage. As each series is logged and demeaned, the results show the percentage deviation from the mean. For both education groups, the wage-tenure profiles are upward sloping. The gap between the starting wage of postgraduates and their average wage is greater than that of undergraduates.[21] This can also be seen in the column "Baseline" of Table 11, where the percent wage loss after displacement for postgraduates is -0.176, and that for undergraduates is about -0.089. The third row of column "Low Capital" of Table 11 shows that when postgraduates have the same low level of specific capital as undergraduates, the immediate wage loss after displacement changes from -0.176 to -0.083, which is almost the same to undergraduates.

Figure 4 also shows that wage growth is rapid during the early stage of employment, and is faster for postgraduates than that for undergraduates. In fact, the first year of job tenure raises the postgraduate wage by 7 percent and the undergraduate wage by 5 percent, and the first 10 years (120 months) of job tenure raise the postgraduate wage by 21 percent and the undergraduate wage by 11 percent.[22] Hence, as postgraduates have more specific capital, their starting wage on a new job is relatively low, but their subsequent wage growth is faster.

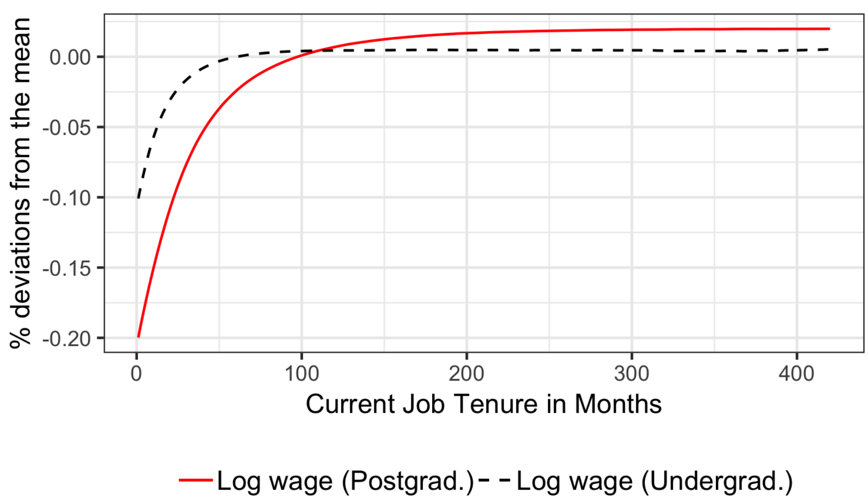

Figure 4: Compare Wage-tenure Profiles by Education

[21]The starting wage is the wage of the first month of the new job.

[22]Topel (1991) estimates that 10 years of job tenure raise the wage by 25%. Altonji and Williams (2005) place the tenure effect on wages at 11% per decade.

7 Evaluating Other Potential Explanations

This section evaluates the plausibility of other potential explanations for the countercyclical postgraduate wage premium. In particular, I use my model to evaluate two alternative explanations that are based on differences in job profitability and hiring costs. I simulate the model under each of these alternative hypotheses and then confront the obtained simulation results with empirical evidence.

7.1 Differences in the Profitability of Jobs

A possible explanation for why postgraduates have smaller cyclical wage shocks than their undergraduate counterparts might be related to the higher profitability of their jobs. In the terminology of search models, postgraduates might have a lower unemployment insurance replacement rate. In my baseline simulation, I ruled out this possibility by assuming the proportionality between the unemployment benefit and the amount of general skills across education groups in Equation (21).

Here I relax the proportionality assumption between postgraduates and undergraduates. To test this hypothesis, I first assign postgraduates and undergraduates the same level of specific capital. Then, instead of assuming the unemployment benefit for postgraduates as $b^{PG} = b * h_{PG} = 0.557 * 1.222 = 0.681$, I search for the value of b^{PG} that generates the empirical elasticity of postgraduate wage to GDP. I find $b^{PG} = 0.172$, which is smaller than that in the baseline. The simulation results, reported in the column "Profit" of Table 12, indicate that postgraduates have less wage cyclicality than undergraduates. However, the model now counterfactually predicts higher job finding rates for postgraduates than undergraduates. Intuitively, since postgraduate jobs yield higher profit, firms are willing to post more vacancies in this segment of the labour market, leading in turn to higher labour market tightness and job finding rates.

7.2 Differences in Hiring Costs

Another possible explanation might be that postgraduates have higher hiring costs. In my baseline simulation, I already assumed that the vacancy posting cost grew

Table 12: Other Potential Explanations

Moments	Data	Baseline	Profit	Hiring
Postgraduates				
Job separation rate	.005	.005	.005	.004
Job finding rate	.245	.248	.351	.099
Elasticity of median wage to GDP	.34	.322	.34	.34
Undergraduates				
Job separation rate	.009	.009	.009	.009
Job finding rate	.263	.263	.263	.263
Elasticity of median wage to GDP	.58	.58	.58	.58

proportionally with the amount of general skills in Equation (20). However, it might understate the true differences in hiring costs between postgraduates and undergraduates.

I assign postgraduates and undergraduates the same level of specific capital. I search for the value of η^{PG} that generates the empirical postgraduate wage elasticity instead of assuming proportionality, i.e. $\eta^{PG} = \eta * h_{PG} = 7.324 * 1.222 = 8.95$. I find $\eta^{PG} = 516$, which is much larger than that in the baseline. The simulation results, reported in the column "Hiring" of Table 12, indicate that postgraduates have less wage cyclicality than undergraduates. However, the model now counterfactually predicts much lower job finding rates for postgraduates than the data predict. Intuitively, since it is more costly to hire postgraduates, firms will post fewer vacancies in this labour market segments. As a result, their job finding rates drop.

7.3 Other Alternative Explanations

The model presented in this paper cannot be used to quantitatively examine all alternative explanations for counter-cyclical postgraduate wage premium. Here I briefly discuss some alternatives not nested by my model and compare them to the available empirical evidence.

Relative Supply One possibility for why the postgraduate wage premium is counter-cyclical is that the relative supply of postgraduates to undergraduates declines in recessions, and thus, the postgraduate wage increases relative to the undergraduate wage. Therefore, I test whether the relative supply of postgraduates to undergraduates is pro-cyclical. Figure 5 plot the detrended real GDP and the relative supply of postgraduates to undergraduates. The relative supply of postgraduates to undergraduates increases in all of the recessions except the recent Great Recession, and its correlation with real GDP is -0.32, indicating that the relative supply of postgraduates to undergraduates is largely counter-cyclical.

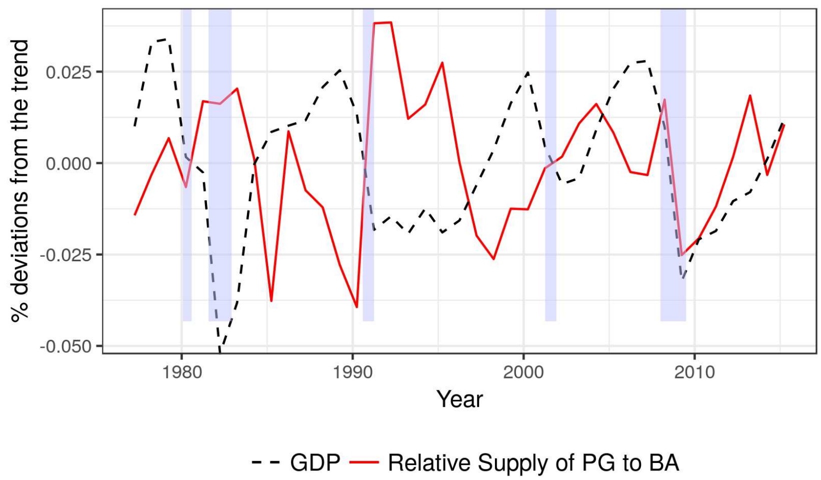

Figure 5: Detrended Real GDP and the Relative Supply of PG to BA

Notes. March CPS 1976–2016, males, aged 26–64. NBER recessions are shaded. Series are logged and detrended using a Hodrick–Prescott (HP) filter with parameter 100.

Risk Aversion Is it because postgraduates are more risk averse than undergraduates, so they self-select into jobs with more stable wages? I test for this argument using the 1992-2014 US Health and Retirement Study (HRS) and restricting the sample to males aged 50-64. On entering the study, each HRS respondent is asked the following question: "Suppose that you are the only income earner in the family, and you have a good job guaranteed to give you your current (family) income every year for life. You are given the opportunity to take a new and equally good job, with a 50-50 chance it will double your (family) income and a 50-50 chance that it will cut your (family) income by a third. Would you take the new job?" Depending on how they answer, respondents are then asked about jobs that give a 50-50 chance of doubling income or of cutting it by 20 percent or 50 percent. Following

Schulhofer-wohl (2011), I classify those who reject any risky job as having high risk aversion (risk aversion = 1), and those who accept any risky job as having low risk aversion (risk aversion = 0). The mean of this binary variable is 0.52 for both the postgraduates and undergraduates, i.e. 48% reject even the job that might cut income by 20 percent. It shows undergraduates and postgraduates share the same level of risk aversion.

8 Conclusion

I document a new result: in the US, the postgraduate wage premium is countercyclical — postgraduates have smaller cyclical wage variation than undergraduates. I further document that the difference in wage cyclicality between postgraduates and undergraduates is significant for workers with a long job tenure, but not for new hires. As workers' job tenure is the generally used proxy for specific human capital, I argue that this phenomenon occurs because postgraduates accumulate more specific capital than undergraduates. I provide robust empirical evidence that is consistent with the theory: 1) Postgraduates need a longer time to become fully competent in a new job than undergraduates; 2) Postgraduates suffer larger wage losses from job displacement.

To understand how specific capital affects labour turnover and wage cyclicality, I develop an equilibrium search model with risk averse workers and imperfect monitoring of worker effort. Imperfect monitoring creates a moral hazard problem that requires firms to pay efficiency wages. Firms face the trade-off between increasing wage stability to provide insurance to workers and increasing wage cyclicality to incentivize their workers to exert the optimal effort. The theoretical implication of the model is that more specific capital leads to lower probability of job separation, thereby increasing both the effectiveness and the marginal cost of providing incentives for worker effort. Then it is optimal for firms to provide more insurance rather than more incentives. Therefore, more specific capital leads to more stable wages.

I quantify the level of specific human capital by education in the data and use it to parameterize my model. The model can capture differences in wage cyclicality and labour turnover between education groups, indicating that specific capital can be an important driving force.

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A Additional Details on Data

A.1 Current Population Survey (CPS)

March CPS. The CPS is designed to be representative of the civilian non-institutional population. The survey interviews about 60,000 households at a monthly frequency. In march every year the CPS fields the Annual Social and Economic supplement (March CPS), which collects detailed demographic data for each household member and labor force and income information for each household member age 15 or older. I use the March CPS data prepared by IPUMS (https://cps.ipums.org/cps/), which are available at the state level starting in 1976. Labor force and income information correspond to the previous year. I use the March supplement weights to produce my estimates on wage cyclicality.

Here I describe the details of my sample selection, which broadly follows suggestions by Heathcote, Perri and Violante (2010): I start by dropping individuals with negative or zero weights. Next I drop individuals with positive earnings but zero weeks worked. Next I drop individuals whose hourly wage is less than half the legal minimum in that year. Then I select individuals who work at least 260 hours during the year. To show the aggregate cyclicality of postgraduate wage premium, I restrict the sample to males aged 26-64 in Table 1. To estimate the effects of postgraduate degree on the wage cyclicality controlling for observed characteristics, I further restrict the sample to workers not self-employed in Table 2.

Next I describe the selection of variables. For education groups, I use the IPUMS variable EDUC which is a combination of two other variables, HIGRADE and EDUC99. HIGRADE is available for years prior to 1992 and gives the respondent's highest grade of school or year of college completed. EDUC99 is available beginning in 1992 and classifies high school graduates according to their highest degree or diploma attained. My education groups consist of: i) noncollege workers (3 years of college completed and less according to HIGRADE; some college / associate's degree and less according to EDUC99); ii) college graduates (4 years of college completed according to HIGRADE; bachelor's degree according to EDUC99); iii) postgraduates (5 years of college completed and more according to HIGRADE; master's, professional school and doctoral degrees according to EDUC99).

Over the years, there are changes in the occupation/industry classifications in the CPS. I use IPUMS variable OCC90LY and IND90LY for occupation/industry classifications, which recodes information into the 1990 Census Bureau classification system and provides consistent codes for the jobs respondents reported working last year.

Recall that I compute an individual's wage as annual earnings divided by annual hours worked. To compute hours worked last year, I multiply the IPUMS variable WKSWORK1 (weeks worked last year) by UHRSWORKLY (usual hours worked per week last year). In Table 2, earnings is labour income. For years prior to 1988, labour income = INCWAGE. Beginning in 1988, labour income = INCLONGJ (if SRCEARN = 1) + OINCWAGE. Here INCWAGE = income from wage and salary; INCLONGJ = earnings from longest job before deductions; OINCWAGE = income from other wage and salary; SRCEARN = 1 indicates source of earnings from longest job is wage and salary. As the sample in Table 1 includes self-employed workers, I follow Heathcote, Perri and Violante (2010) and use labor income plus 2/3 self-employment income. For years prior to 1988, self-employment income = INCBUS + INCFARM. Beginning in 1988, self-employment income = INCLONGJ (if SRCEARN = 2 or 3) + OINCBUS + OINCFARM. Here INCBUS = income from non-farm self-employment; INCFARM = income from farm or non-incorporated self-employment; OINCBUS = income from other work included business self-employment income; OINCFARM = income from other work included farm self-employment income; SRCEARN = 2 or 3 indicates source of earnings from farm or non-farm self-employment.

In the CPS, top-code thresholds vary widely across income categories, and across time. Following Heathcote, Perri and Violante (2010), I deal with top-coded observations by assuming the underlying distribution for each component of income is Pareto, and forecast the mean value for top-coded observations by extrapolating a Pareto density fitted to the non-top-coded upper end of the observed distribution.

Monthly CPS. In addition to the March CPS, I merge monthly CPS data to create a short panel. Specifically, I use the code by Robert Shimer[23], combined with monthly CPS files downloaded from NBER[24]. See Shimer (2012) for a further discussion of the issues involved in linking individuals across months in the monthly

[23] https://sites.google.com/site/robertshimer/research/flows

[24] http://www.nber.org/data/cps_basic.html

CPS files. The short panel allows me to estimate job separation rate and job finding rate from 1979-2014. Since the introduction of dependent interviewing techniques with the 1994 redesign of the CPS, the survey asks whether an employed worker works for the same employer as last month. I use this fact to estimate the job-to-job transition rate from 1994–2014. I use the provided monthly CPS weight.

Displaced Workers Survey (DWS) The DWS is a supplement to the CPS administered in the January or February of every even year. The DWS identifies displaced workers who have been separated from their employers due to (i) insufficient demand for the worker's services, (ii) the worker's position being abolished, or (iii) the worker's plant closing — reasons which have been taken by the literature to instrument for "exogenous" layoffs. The DWS inherits the large sample size and representative structure of the CPS and also records information on earnings on both the displaced and current job.

A.2 Panel Study of Income Dynamics (PSID)

The PSID is a longitudinal study of US households and individuals. The original 1968 sample was drawn from two independent sub-samples: an over-sample of roughly 2000 poor families selected from the Survey of Economic Opportunities (SEO), and a nationally representative sample of roughly 3000 families designed by the Survey Research Center (SRC) at the University of Michigan. In 1997, the SEO sample was reduced by one-half. In 1990, PSID added 2000 Latino households, including families originally from Mexico, Puerto Rico, and Cuba. While this sample (the so-called "Latino sample") did represent three major groups of immigrants, it missed out on the full range of post-1968 immigrants, Asians in particular. Because of this crucial shortcoming, and a lack of sufficient funding, the Latino sample was dropped after 1995. A sample of 441 immigrant families, including Asians, was added in 1997 (the so-called "Immigrant sample").

Since 1968, the PSID has interviewed individuals from families in the initial samples. Adults have been followed as they have grown older, and children have been observed as they have advanced into adulthood, forming family units of their own (the "split-offs"). Survey waves are annual from 1968 to 1997, and biennial since then. Although the PSID provides a wide variety of information about all individuals in the family unit, the greatest level of detail is ascertained for the primary adult in the family unit, i.e., the head[25]. In the PSID all the questions are retrospective, i.e., variables in survey-year t refer to calendar year t − 1. The interview is usually conducted around March.

I base my empirical analysis on the SRC sample. I use all the yearly surveys from 1985–1996 and the biennial surveys from 1997-2015. I start in 1985 because the variable on highest degree received is available only since 1985[26]. I restrict the sample to male heads aged 26 to 64 who were not self-employed, and I only use the first spell I observe someone as a head. Wages are annual hourly wages (annual labour earnings divided by annual hours). Nominal wages are deflated by the Consumer Price Index. The base year is 2000. I also restrict the sample to hourly wage less than or equal to $100. Workers whose hourly wage rate was below $1 (in 2000 dollars) or less than half of the corresponding federal minimum wage in that year are viewed as non-employed. I create consistent measure of age: I determine the age in the first year the respondent was a head, and then increment age by 1 for each subsequent year the respondent was a head.

A.3 Multi-City Study of Urban Inequalities (MCSUI)

The MCSUI was collected in four large US cities (Los Angeles, Boston, Detroit and Atlanta) between 1992 and 1994. It aims to understand why high rates of joblessness have persisted among minorities living in America's central cities. One important aspect of the study was the contacting of more than 3000 employers to ask detailed questions about their hiring practices. Even though the intent of the study was to understand racial discrimination in hiring, the exhaustive information about the recruitment process makes this study valuable for broader purposes. The sampling

[25]The head of the family unit (FU) must be at least 16 years old, and the person with the most financial responsibility in the FU. If this person is female and she has a husband in the FU, then he is designated as head. If she has a boyfriend with whom she has been living for at least one year, then he is head. However, if she has 1) a husband or a boyfriend who is incapacitated and unable to fulfill the functions of head, 2) a boyfriend who has been living in the FU for less than a year, 3) no husband/boyfriend, then the FU will have a female head. A new head is selected if last year's head moved out of the household unit, died or became incapacitated, or if a single female head has gotten married. Also, if the family is a split-off family (hence a new family unit in the sample), then a new head is chosen.

[26]Although individual's years of education is available before 1985, almost no one has more than 16 years of education before 1983 in my sample, which is not useful for the analysis of postgraduates.

procedure and the provided weights intend to represent employees who worked in the 4 cities in 1992. A subsection of the survey asked employers about their most recently hired worker. One of the questions is "How many weeks does it take the typical employee in this position to become fully competent in it?" I use it to analyze the duration of learning by education in this paper.

A.4 Health and Retirement Study (HRS)

The HRS is a national longitudinal study of Americans aged 50 or older. It begun in 1992 and designed to investigate health and economic consequences of older individuals as they advance from work to retirement. It also includes experimental questions that give evidence on respondents' preferences. The original HRS cohort consisted of individuals born between 1931 and 1941 and their spouses. A sample of individuals born before 1923 was added soon thereafter. An additional sample of individuals born between 1923 and 1930 was added in 1998. Baseline surveys were conducted face-to-face. Follow-up interviews were completed by telephone or mail. The HRS has been repeated every 2 years since 1992, and data between 1992 and 2014 are used in this study.

B Additional Details on Empirical Facts

B.1 Robustness Check of Regression (1)

GDP as an Indicator of the Business Cycle

Instead of the unemployment rate, I use log real GDP as an indicator of the business cycle and run the following regression

$$\ln W_{it} = \theta PG_{it} + \alpha \ln \mathrm{GDP}_t + \gamma PG_{it} \times \ln \mathrm{GDP}_t + X_{it}\beta + \varepsilon_{it}$$

α indicates the relation between the undergraduate wage and GDP. For instance, a positive estimate of α would imply that the average real wage of undergraduates increases when GDP rises, i.e. the undergraduate wage is pro-cyclical. The coefficients γ captures the difference between the cyclicality of the postgraduate wage and the undergraduate wage, and $\alpha + \gamma$ indicates the cyclicality of the postgraduate wage.

A negative estimate of γ would indicate a counter-cyclical postgraduate wage premium — the premium decreases when GDP rises. The estimates are in column (1) of Table 13. It shows that when real GDP increases by 1%, the postgraduate wage increases by 0.403% and the undergraduate wage increases by 0.988%, confirming the finding that the postgraduate wage is less pro-cyclical than the undergraduate wage.

Table 13: Robustness – Regression of Real Hourly Wage on Degree Interaction

lnWage	(1) ln GDP		
$lnGDP\,(\alpha)$	.988***		
	(.074)		
$PG \times lnGDP\,(\gamma)$	-.584***		
	(.119)		
$\alpha + \gamma$	.403***		
	(.094)		
lnWage	(2) Cubic Detrend	(3) Median	(4) 26˜40
$URATE\,(\alpha)$	-.0105***	-.0099***	-.0157***
	(.0011)	(.0013)	(.0016)
$PG \times URATE\,(\gamma)$	.0064***	.0074***	.0086***
	(.0017)	(.0021)	(.0029)
$\alpha + \gamma$	-.0041***	-.0026	-.0071***
	(.0014)	(.0017)	(.0024)
lnWage	(5) 41˜64	(6) Job Stayers	(7) Heckman
$URATE\,(\alpha)$	-.0094***	-.0106***	-.0121***
	(0019)	(.0013)	(.0012)
$PG \times URATE\,(\gamma)$	.0070**	.0069***	.0084***
	(.0029)	(.0022)	(.0021)
$\alpha + \gamma$	-.0023	-.0037**	-.0037**
	(.0023)	(.0018)	(.0017)

Notes. (1) Use Log real GDP as an indicator of the business cycle; (2) Unemployment rate is detrended by a cubic trend; (3) Median regression; (4) Aged 26˜40; (5) Aged 41˜64; (6) Workers had only 1 employer, no stretch of looking for work, and worked for 52 weeks; (7) Heckman selection model with first-stage employment choice. Controls: postgraduate degree, state, race, and marriage dummies, a cubic age trend and a quartic time trend. Robust standard errors are reported in parentheses. ***p<0.01, **p<0.05, *p<0.1.

Cubic Detrending, Median Regression, and Age Groups

In column (2) of Table 13, I detrend the aggregate unemployment rate using a cubic time trend and find that when the unemployment rate goes up by 1 percentage point, postgraduates face a 0.64% increase in their real wage relative to that of undergraduates. In column (3), I run a median regression and find that when the unemployment rate goes up by 1 percentage point, the median wage of postgraduates increases by 0.74% relative to that of undergraduates. In column (4) and (5), I cut the baseline sample into 2 age groups. I find that when the unemployment rate goes up by 1 percentage point, postgraduates aged 26-40 face a 0.86% wage increase relative to undergraduates in the same age group, and postgraduates aged 41-64 face a 0.70% relative wage increase. So having a postgraduate degree significantly reduces wage cyclicality for both age groups.

Job Stayers and Heckman Selection Model

A typical selection bias problem is that undergraduates are more likely to be unemployed than postgraduates in recessions, so the average undergraduate wage increases mechanically relative to the average postgraduate wage. To eliminate such systematic selection, I run the regression (1) with only job stayers − workers who stayed in the same job last year, had no stretch of looking for work, and worked for 52 weeks. Column (6) of Table 13 shows that the coefficient γ on $PG_{it} \times U_t$ shrinks slightly to 0.0069 (s.e. 0.0022). Therefore, job separation can only explain a small amount of the counter-cyclical postgraduate premium.

Besides, I use a maximum likelihood version of Heckman (1979) selection model. This model estimates a wage equation jointly with probit choice equation that determines whether a worker is employed. The model is written as follows:

$$\begin{aligned} \ln W_{it} =& \theta PG_{it} + \alpha U_t + \gamma PG_{it} \times U_t + X_{it}\beta + \varepsilon_{it}, \\ & \text{observed iff } P_{it} = 1, \\ \text{where} \quad P_{it}^* =& \delta PG_{it} + \delta U_t + \eta PG_{it} \times U_t + Z_{it}\beta_0 + \omega_{it}, \\ P_{it} =& \begin{cases} 1 & \text{if } P_{it}^* \geq 0 \\ 0 & \text{if } P_{it}^* < 0 \end{cases} \end{aligned}$$

Here P^*_{it} is the latent index of a probit employment equation that determines whether worker i is employed at time t. Z_{it} is a vector of individual-specific regressors that affect the probability of employment. Typically, it contains elements that enter into X_{it} as well as some additional variables that may affect labour supply propensity but not worker productivity. The additional variables are: number of own children in the household, number of own children under age 5 in the household, and age of youngest own child in the household. The error terms ε_{it} and ω_{it} are assumed to have a bivariate normal distribution with correlation ρ and respective standard deviations σ_ϵ and 1. The latter variance is normalized to one for identification of the probit choice equation. Column (7) of Table 13 presents the estimates that when the unemployment rate goes up by 1 percentage point, postgraduates face a 0.84% wage increase relative to undergraduates, which is similar to the baseline.

B.2 Regressions by Industries and Occupations

Does this phenomenon occur because postgraduates and undergraduates sort into different industries and occupations that are subject to different cyclical variation in productivity? To test whether this argument holds, I run the wage equation at the industry and occupation level. Table 14 presents the estimates. I find that the postgraduate wage premium is counter-cyclical in all major industries and in Managerial, Professional Specialty, Technical, and Sales occupations (added up to 82% of all college graduates).

Importance of Occupations and Industries

Next, I check whether the different wage cyclicality of occupations and industries are important determinants of the counter-cyclical postgraduate wage premium. In order for this argument hold, occupations and industries must be strong predictors of counter-cyclical postgraduate wage premium. To test this condition, I run the following regression

$$\ln W_{it} = \sum_{j=1}^{J} (\kappa_j I_{ijt} + \alpha_j I_{ijt} \times U_t) + \gamma PG_{it} \times U_t + \theta PG_{it} + X_i\beta + \varepsilon_{it} \qquad (22)$$

Table 14: Wage Regression at the Industry/Occupation Level

lnWage	*URATE*	*PG*URATE*	$\frac{BA_I+PG_I}{\sum_I BA_I+PG_I}$	$\frac{PG_I}{\sum_I PG_I}$	$\frac{PG_I}{BA_I+PG_I}$
		by Industry			
Nondurable Mfg.	-.0121***	.0163***	5.95%	4.63%	29.76%
	(.0039)	(.0026)			
Durable Mfg.	-.0152***	.0126***	11.51%	9.69%	32.25%
	(.0026)	(.0023)			
T.C.U	-.0080**	.0103***	7.25%	4.40%	23.23%
	(.0036)	(.0025)			
F.I.R	-.0186***	.0101***	9.54%	7.17%	28.79%
	(.0034)	(.0025)			
Services	-.0139***	.0082***	40.79%	56.72%	53.26%
	(.0019)	(.0021)			
Trade	-.0151***	.0047**	11.79%	5.97%	19.40%
	(.0032)	(.0026)			
Public Admin.	-.0018	.0066***	8.48%	8.59%	38.78%
	(.0026)	(.0022)			
A.M.C	.0005	.0122***	4.69%	2.84%	23.15%
	(.0047)	(.0029)			
		by Occupation			
Managerial	-.0125***	.0110***	29.07%	27.94%	36.81%
	(.0019)	(.0021)			
Professional	-.0131***	.0087***	36.35%	53.56%	56.44%
	(.0019)	(.0021)			
Technical	-.0087**	.0056**	5.48%	4.47%	31.29%
	(.0037)	(.0025)			
Sales	-.0121***	.0065**	11.06%	5.32%	18.44%
	(.0034)	(.0026)			
Service & Admin.	-.0105***	.0006	9.98%	5.29%	20.30%
	(.0029)	(.0025)			
P.C.R	-.0126***	.0007	4.13%	1.71%	15.88%
	(.0044)	(.0031)			
O.F.L	-.0067	-.0071**	3.94%	1.70%	16.53%
	(.0049)	(.0033)			

Notes. $\frac{BA_I+PG_I}{\sum_I BA_I+PG_I}$: the proportion of Industry/Occupation I among all college graduates (PG+BA). $\frac{PG_I}{\sum_I PG_I}$: the proportion of Industry/Occupation I among all postgraduates. $\frac{PG_I}{BA_I+PG_I}$: the ratio of postgraduates to college graduates in Industry/Occupation I. T.C.U: Transportation, Communications and Utilities. F.I.R: Finance, Insurance and Real Estate. A.M.C: Agriculture, Mining and Construction. P.C.R: Precision production, Craft and Repair. O.F.L: Operators, Fabricators and Labourers.

where $I_{ijt} = 1$ if worker i locates in industry or occupation j at time t. I_{ijt} is interacted with the unemployment rate. The interesting question is by how much coefficient γ shrinks after I control for the interaction between the unemployment rate and I_{ijt}. The more it shrinks, the more industries and occupations can explain, in a regression sense, the counter-cyclicality postgraduate wage premium. Table 15 shows the regression results. Column (1) shows the baseline without controlling for industries or occupations. When I control for 43 industry dummies in Column (2), the coefficient γ on $PG_{it} \times U_t$ shrinks slightly from 0.0086 to 0.0078. When I control for 60 occupation dummies in Column (3), the coefficient γ shrinks to 0.0063. In Column (4), I include industry dummies × occupation dummies, and the coefficient γ shrinks from 0.0086 to 0.0059.

Table 15: Controlling for interaction between the unemployment rate and I_{ijt}

lnWage	(1)	(2)	(3)	(4)
$URATE$	-.0124***			
	(.0012)			
$PG \times URATE$	.0086***	.0078***	.0063***	.0059***
	(.0021)	(.0021)	(.0021)	(.0020)
43 Industry dummies		✓		
60 Occupation dummies			✓	
Industry × Occupation dummies				✓

B.3 Change in Log Wages

Figure 6 plots the average annual changes in log wages between booms and recessions. I use March CPS 1976–2016 and recessions years are 1980-1983, 1990-1992, 2001-2002 and 2008-2010. The figure shows a considerable difference in wage growth rates between undergraduates and postgraduates. Undergraduates have a larger wage growth rate than postgraduates in booms and a smaller (even negative) wage growth rate than postgraduates in recessions. The wage growth rates for postgraduates are relatively more stable over the business cycle than those for undergraduates.

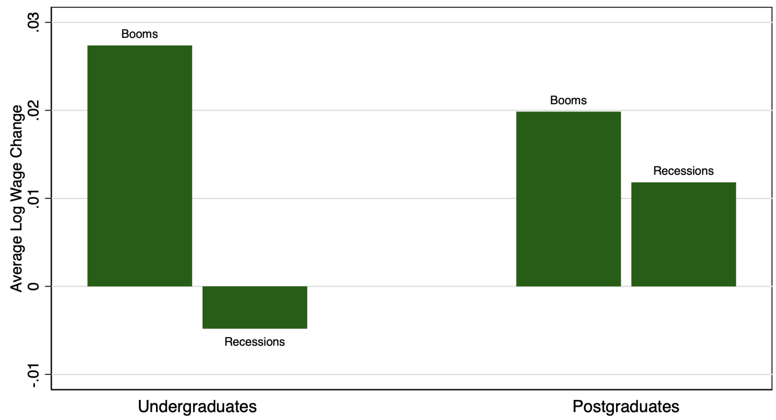

Figure 6: Change in log wages: Booms versus Recessions

C Model Appendix

C.1 Unique Search Market

The definition of equilibrium can be collapsed to the problem:

$$\max_{\hat{\theta}_z^h, \mathbb{E}_z \hat{V}_{0z'}^h} \mu\left(\hat{\theta}_z^h\right) \mathbb{E}_z\left(\hat{V}_{0z'}^h - U_{z'}^h\right) \tag{23}$$

s.t.

$$q\left(\hat{\theta}_z^h\right) \cdot \beta \mathbb{E}_z \mathit{\Pi}^h\left(0, z', \hat{V}_{0z'}^h\right) - \eta^h = 0$$

From the relationship between the probabilities of finding a job and filling a vacancy (Equation 11), we have the job finding rate in a sub-market with tightness $\hat{\theta}_z^h$ and promised value $\hat{v}_z^h = \mathbb{E}_z \hat{V}_{0z'}^h$ as follows:

$$\mu\left(\hat{\theta}_z^h\right) = \left(\frac{\beta \mathbb{E}_z \mathit{\Pi}^h\left(0, z', \hat{V}_{0z'}^h\right)}{\eta^h}\right)^{\frac{\alpha}{1-\alpha}} \tag{24}$$

Substitute it into (23), we have

$$\max_{\hat{\theta}_z^h, \mathbb{E}_z \hat{V}_{0z'}^h} \left(\frac{\beta \mathbb{E}_z \mathit{\Pi}^h\left(0, z', \hat{V}_{0z'}^h\right)}{\eta^h}\right)^{\frac{\alpha}{1-\alpha}} \mathbb{E}_z\left(\hat{V}_{0z'}^h - U_{z'}^h\right) \tag{25}$$

For any contract delivering a higher value to the worker, the market tightness must be lower for firms to break even in offering such a contract. The lower market tightness makes the contract less attractive to workers because their job-finding probability is lower. As the promised value for the worker rises, the declining job-finding probability eventually begins to dominate the rising promised value, and a unique optimal level of promised value balances these effects. Therefore, there is a unique equilibrium search market for each (z, h).

C.2 Proof of Lemma 1

Let's consider two distinct values of aggregate productivity $z_1 < z_2$. At z_2, the firm can adopt the optimal contract at z_1, which is feasible and delivers the same value V to the worker. As the transition matrix of z is assumed to be monotone,[27] this strategy generates a higher expected profit than $\Pi^h(s, z_1, V)$ – the pareto frontier at z_1. As this strategy has to be at most equal to $\Pi^h(s, z_2, V)$ – the pareto frontier at z_2, we have that $\Pi^h(s, z_1, V) < \Pi^h(s, z_2, V)$.

Similarly, when matched with an experienced worker $(s = 1)$, the firm can adopt the optimal contract when it is matched with a new hire $(s = 0)$. This strategy generates a higher expected profit than $\Pi^h(0, z, V)$ – the pareto frontier when the firm is matched with a new hire. As this strategy has to be at most equal to $\Pi^h(1, z, V)$ – the pareto frontier when the firm is matched with an experienced worker, we have that $\Pi^h(0, z, V) < \Pi^h(1, z, V)$.

C.3 Proof of Lemma 2

In the model, a higher level of specific capital is equivalent to a higher initial productivity gap τ and a lower upgrading probability ϕ. Let's consider two distinct levels of specific capital $\xi_1 = (\tau_1, \phi_1)$ and $\xi_2 = (\tau_2, \phi_2)$. ξ_2 represents a higher level of specific capital comparing to ξ_1, i.e. the initial productivity gap $\tau_2 > \tau_1$, and the upgrading probability $\phi_2 < \phi_1$. From Equation (5), the firm's value when match with a new hire is

$$\Pi^h(0, z, V; \xi_i) = e(hz - \tau_i) - w + e \cdot \beta \mathbb{E}_z \left[\phi_i \Pi^h\left(1, z', V^h_{1z'}\right) + (1 - \phi_i) \Pi^h\left(0, z', V^h_{0z'}\right) \right]$$

[27] A transition matrix is called monotone if each row stochastically dominates the row above.

At ξ_1 (the lower level of specific capital), the firm can adopt the optimal contract at ξ_2, which is feasible and delivers the same value V to the new hire. As $\Pi^h\left(1, z', V^h_{1z'}\right) > \Pi^h\left(0, z', V^h_{1z'}\right)$ (Lemma 1), the firm's expected profit next period increases with ϕ. At the same time, because the flow output $(hz - \tau)$ decreases with τ, this strategy generates a higher expected profit than $\Pi^h(0, z, V; \xi_2)$ – the pareto frontier at ξ_2. As this strategy has to be at most equal to $\Pi^h(0, z, V; \xi_1)$ – the pareto frontier at ξ_1, we have that $\Pi^h(0, z, V; \xi_2) < \Pi^h(0, z, V; \xi_1)$. As this is true for all aggregate state, a higher amount of specific human capital reduces the value of a new job.

C.4 Proof of Proposition 1

From Lemma 2, the value of a new job $\mathbb{E}_z \Pi^h\left(0, z', \hat{V}^h_{0z'}\right)$ at ξ_2 (the higher level of specific capital) is smaller than that at ξ_1 in every queue in the search market. From Equation (24), the job finding rate in a sub-market with tightness $\hat{\theta}^h_z$ and promised value $\hat{v}^h_z = \mathbb{E}_z \hat{V}^h_{0z'}$ is an increasing function of $\mathbb{E}_z \Pi^h\left(0, z', \hat{V}^h_{0z'}\right)$. Then, a higher amount specific capital reduces a firm's incentive to post vacancies, leading to a decrease in the job finding rate in every sub-market. Thus, the unique equilibrium search market for each (z, h) at ξ_2 offers a lower worker's value than that at ξ_1. Therefore, by Equation (15), the value of a worker's outside options at ξ_2 is lower than that at at ξ_1. By Equation (4), as the effort cost function is strictly increasing and strictly convex, the optimal effort level of an experienced worker at ξ_2 is lower than that at ξ_1. Finally, as the probability of a project's success increases with the level of effort, a higher amount of specific capital reduces job separation.