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Equilibrium Unemployment with Capital Investments under Labour Market Imperfections*

Abstract

We study the effects of labour market imperfections and capital stock on equilibrium unemployment. With an exogenous capital-labour ratio stronger labour market imperfections promote equilibrium unemployment. The relationship between the long-run unemployment and the capital stock is not monotonic. With sufficiently strong (weak) labour market imperfections capital investment has a wage-moderating (wage-increasing) effect, thereby decreasing (increasing) equilibrium unemployment if the relative bargaining power of the labour union is sufficiently strong (weak). Empirically, we find dispersed long-run effects of capital on unemployment by focusing on 16 OECD countries over 28 years.

JEL classification: E22, E24, J51, L11.

Keywords: equilibrium unemployment, capital-labour ratio, labour market imperfections.

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I. Introduction

The employment consequences of long-term investments have been controversial in economics for a long time. This issue underlies many disputes between firm owners and labour unions. In some influential models of imperfectly competitive labour markets, for example Layard et al. (1991), investments have no effect on equilibrium unemployment. This is due to the specified Cobb-Douglas production function, which implies a constant wage elasticity of labour demand. This in turn means that investments or interest rates will have no effect on the wage determination, and therefore no effect on equilibrium unemployment.

Several recent empirical contributions have established that the capital stock and related variables significantly affect wage formation and unemployment in the long run. Malley and Moutos (2001) find that differences in capital accumulation between several OECD countries explain significant elements of the unemployment histories in these countries. Arestis et. al. (2007) and Karanassou et. al. (2008) obtain significant long-run relationships between capital and labour for EMU countries and Nordic countries, respectively, using cointegration techniques. We contribute to this empirical literature in the following ways: Firstly, we design a model which presents structural explanations for why countries might differ with respect to the relationship between capital and wage formation as well as that between capital and unemployment. In this respect, our theoretical model establishes novel systematic interaction effects between long-term investments and equilibrium unemployment in the presence of labour market imperfections. Secondly, we present empirical cointegration analyses on these relationships for a broader set of countries than what has previously been analyzed.

In light of the literature, the nature of the production function is a significant determinant of the effects of investments on equilibrium unemployment.¹ Our analysis focuses on labour market imperfections with a production function where

capital and labour inputs are substitutes. Wages are determined through bargaining within a ‘right-to-manage’ framework. We show that a higher capital-labour ratio has a wage-moderating (wage-increasing) effect with sufficiently strong (weak) labour market imperfections. Based on this mechanism we find that an increased capital stock decreases (increases) equilibrium unemployment if the relative bargaining power of the labour union is sufficiently strong (weak). Furthermore, theoretically we find that increases in the bargaining power of the union or the benefit replacement ratio promote equilibrium unemployment.

From our theoretical results we form the empirical hypothesis that the effects of the capital stock on wages and unemployment are to a large extent determined by labour market institutions and capital-labour ratios. In particular, there seems to be no reason for these relationships to be uniform across different countries, a priori. Instead our theory implies country-specific relationships between the capital stock and wages as well as capital stock and unemployment, respectively. Our empirical investigation explores the relationship between capital and unemployment by using quarterly observations for roughly 28 years in 16 OECD-countries. We find a great deal of disparity between the countries regarding the long-run effects of capital on unemployment. These dispersed long-run effects of capital on unemployment seem consistent with our theory, which emphasizes that the effect of the capital stock on wages is determined by three factors: the bargaining power, the capital-labour ratio and production function parameters.

Our study proceeds as follows. Section II presents the basic structure of the model with the time sequence of the decisions. Labour demand is studied in section III, and wage determination through Nash bargaining is analyzed in section IV. Section V analyzes equilibrium unemployment and characterizes the long-run effects of capital on equilibrium unemployment. We present empirical evidence in section VI and discuss our results in section VII. Finally, we present concluding comments in Section VIII.

¹ See section VII for a more detailed discussion of this issue.

II. Basic Framework

We introduce a model of wage formation with labour market imperfections. In the long run, at stage 1, firms commit themselves to their investment programs, which determine capital stocks and thereby ultimately capital-labour ratios. The investment decisions are made in anticipation of their effects on wage setting and labour demand. At stage 2, with firms committed to their investments, wage negotiations between firms and labour unions take place. The wage negotiations are conducted in anticipation of the consequences for labour demand. At stage 3 firms make employment decisions by taking the negotiated wages and the investment decisions as given.

We summarize the time sequence of decisions in Figure 1. In the subsequent sections we derive the decisions taking place at different stages by using backward induction.

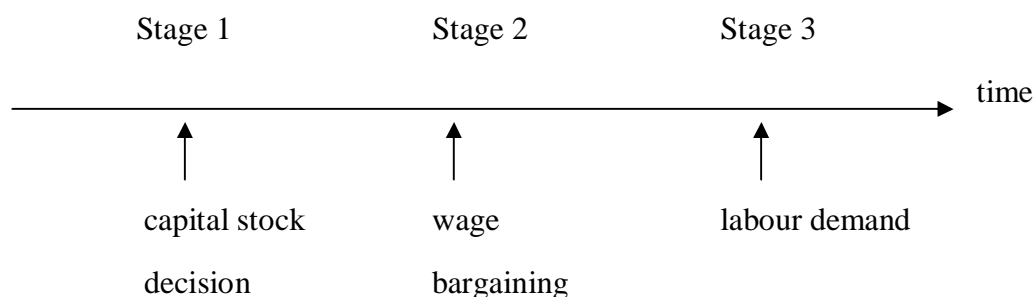


Figure 1: *Time sequence of decisions*

This timing structure captures the idea of long-term investment decisions, which are inflexible at the stage when the wage negotiations are undertaken. Such a timing structure seems plausible if the investments represent, for example, irreversible long-term technology choices. Of course, the relative timing between the negotiated wage setting and the investment decisions could also be reversed so as to capture that the negotiated outcome is a long-term contract relative to the investment decision (see e.g. Anderson and Devereux (1991) or Cahuc and Zylberberg (2004),

chapter 9). Hellwig (2004) has compared a number of key properties associated with these two alternative timing structures within the framework of an intertemporal general equilibrium model. He argues that although the long-term labour demand – with endogenous investment – is more elastic than the short-term demand, it does not necessarily lead to a less aggressive wage policy. This holds true because the effect of the more elastic long-term demand may be more than outweighed by the reactions of real interest rates, to anticipated wage policies.

We proceed by analyzing the decisions in reverse order according to the principles of dynamic optimization. First, we characterize labour demand and subsequently we analyze wage formation based on Nash bargaining. Once we have delineated wage formation we explore the long-term effects of the capital stock on equilibrium unemployment.

III. Labour Demand

We assume that the production function satisfies

$$R(L, K) = \frac{\delta}{\delta - 1} (L + \gamma K)^{\frac{\delta - 1}{\delta}}, \quad \delta > 1 \quad (1)$$

where L is the amount of labour employed and K is the capital stock. The parameter assumption $\delta > 1$ implies that the production function is increasing and concave in the inputs. Furthermore, the parameter $\gamma > 0$ captures the productivity of capital relative to labour. Overall the production function (1) implies that labour and capital are substitutes. Formally, $R_{LK} = R_{KL} = -\frac{\gamma}{\delta} (L + \gamma K)^{\frac{-(1+\delta)}{\delta}} < 0$, which means that there is a negative marginal effect of capital on the marginal product of labour and vice versa.

At stage 3 the representative firm decides on employment so as to maximize the profit function

$$\underbrace{\text{Max}}_L \pi = \frac{\delta}{\delta-1} (L + \gamma K)^{\frac{\delta-1}{\delta}} - wL \quad (2)$$

by taking both the negotiated wage, w , and the established capital stock, K , as given. Thus, from the point of view of the employment decision, the cost for creating the capital stock, $(1+r)K$, where r is the opportunity cost of capital, is considered a sunk investment. The necessary first-order condition associated with (2) is

$$\pi_L = (L + \gamma K)^{\frac{1}{\delta}} - w = 0, \quad (3)$$

and the second-order condition is $\pi_{LL} = -\frac{1}{\delta} (L + \gamma K)^{\frac{-(1+\delta)}{\delta}} < 0$. The first-order condition (3) can be expressed as

$$L = w^{-\delta} - \gamma K, \quad (4)$$

from which we can conclude that labour demand $L = L(w, K)$ is a negative function of the capital stock, the wage and the productivity of capital stock relative to labour.

The wage elasticity of labour demand turns out to be important later on and it can be expressed as

$$\eta\left(\frac{K}{L}, w\right) \equiv -\frac{L_w w}{L} = \frac{\delta w^{-\delta}}{L} = \delta\left(1 + \gamma \frac{K}{L}\right). \quad (5)$$

As (5) shows, the wage elasticity of labour demand, $\eta\left(\frac{K}{L}, w\right) > 1$, depends on the parameters δ and γ of the production function. Importantly, it also depends on the capital stock both directly and indirectly via L and w .

IV. Wage Negotiations

We now proceed to investigate wage formation. Consistent with the introduced time sequence of decisions, we continue to consider the capital stock K as irreversibly given. We apply the Nash bargaining solution following the ‘right-to-manage’ approach. This means that wage negotiations take place in anticipation of an optimal employment decision by the firm (see e.g. Cahuc and Zylberberg (2004), Chapter 7). The labour union’s objective function is assumed to be

$\hat{U} = wL + b(N - L)$, where b denotes the (exogenous) outside option available to union members and N is the number of union members ($N > L$). The labour union conducts the wage negotiations with $U^0 = Nb$ as the threat point. Thus, the relevant target function of the labour union for the negotiations is $U = \hat{U} - Nb = L(w - b)$. The firm conducts the wage negotiations with $\pi^0 = -(1 + r)K$ as the treat point. This threat point captures the idea that the capital stock is irreversibly given at the stage when the wage negotiations take place.

Following the Nash bargaining approach, the firm and the labour union negotiate with respect to wage to solve the following optimization problem

$$\underbrace{\text{Max}}_w \Omega = [L(w - b)]^\beta [R(L, K) - wL]^{1-\beta} \text{ s.t. } \pi_L = 0 \quad (6)$$

where the relative bargaining power of the labour union is β and that of the firm is $(1 - \beta)$.

Following the standard approach for finding the Nash bargaining solution, the necessary first-order condition can be written as

$$\beta \frac{U_w}{U} + (1 - \beta) \frac{\pi_w}{\pi} = 0, \quad (7)$$

where

$$\frac{U_w}{U} = \frac{1}{w} \frac{\left[w(1 - \eta(\frac{K}{L}, w)) + b\eta(\frac{K}{L}, w) \right]}{w - b} > 0, \quad (8)$$

and

$$\frac{\pi_w}{\pi} = -\frac{1}{w} \left(\frac{\delta - 1}{1 + \delta \gamma \frac{K}{L}} \right) = -\frac{1}{w} \left(\frac{\delta - 1}{1 - \delta + \eta(\frac{K}{L}, w)} \right) < 0. \quad (9)$$

Substituting (8) and (9) into (7) the necessary condition for the Nash bargaining solution can be written according to

$$[\beta w(1-\eta) + \beta b\eta](1 + \delta\gamma \frac{K}{L}) = (w-b)(1-\beta)(\delta-1).$$

From this equation we find the following Nash bargaining solution

$$w^N = \frac{\beta\eta(1 + \delta\gamma \frac{K}{L}) + (1-\beta)(\delta-1)}{\beta(\eta-1)(1 + \delta\gamma \frac{K}{L}) + (1-\beta)(\delta-1)} \quad b = A(K, w, \beta)b. \quad (10)$$

where we refer to Appendix A for the crucial steps in the derivation of (9). According to (10) the negotiated wage is proportional to the outside option with the

$$\text{mark-up factor } A(K, w, \beta) = \frac{\beta\eta(1 + \delta\gamma \frac{K}{L}) + (1-\beta)(\delta-1)}{\beta(\eta-1)(1 + \delta\gamma \frac{K}{L}) + (1-\beta)(\delta-1)}. \quad \text{This mark-up}$$

factor strictly exceeds one if $0 < \beta \leq 1$ and it is strictly increasing as a function of the bargaining power of the labour union. It should be emphasized that the negotiated wage in (10) is reported in implicit form as both the numerator and the denominator in the mark-up factor depend on wage w in a non-linear way via labour demand and the wage elasticity of labour demand (see (4) and (5)). From a structural perspective the mark-up factor in (10) incorporates an important strategic link between the capital stock and wage formation. Formally, by (10) the negotiated wage depends on the capital-labour ratio K/L .

Before initiating a detailed analysis of the relationship between the capital stock and wage formation we report the negotiated wage for the two special cases with all the bargaining power concentrated into the hands of the labour union or the firm, respectively. In the case of a monopoly labour union ($\beta=1$) the wage is determined in implicit form according to

$$w^N \Big|_{\beta=1} = \frac{\eta(1-\delta+\eta)}{(\eta-1)(1-\delta+\eta)} b = \frac{\eta(\frac{K}{L}, w)}{\eta(\frac{K}{L}, w) - 1} b. \quad (11)$$

If the firm has all the bargaining power the mark-up factor is reduced to one according to

$$w^N|_{\beta=0} = b. \quad (12)$$

We now turn to a detailed analysis of the relationship between the capital stock and wage formation. By implicit differentiation of (10) with respect to the capital stock K we find that $\frac{dw}{dK} = \frac{A_K b}{1 - A_w b}$ and by further substituting $b = w/A$ we can characterize the effect of the capital stock on the negotiated wage according to (see Appendix B for details)

$$\frac{dw^N}{dK} = \frac{\frac{A_K w}{A}}{1 - \frac{A_w w}{A}}, \quad (13)$$

where

$$1 - \frac{A_w w}{A} > 0 \quad (14)$$

and

$$\frac{A_K w}{A} \begin{cases} < \\ = \\ > \end{cases} 0 \text{ if } \beta \begin{cases} > \\ = \\ < \end{cases} \frac{\delta - 1}{(1 + \delta\gamma \frac{K}{L})^2 + (\delta - 1)} \quad (15)$$

so that

$$\frac{dw^N}{dK} = \frac{\frac{A_K w}{A}}{1 - \frac{A_w w}{A}} \begin{cases} < \\ = \\ > \end{cases} 0 \text{ if and only if } \beta \begin{cases} > \\ = \\ < \end{cases} \frac{\delta - 1}{(1 + \delta\gamma \frac{K}{L})^2 + (\delta - 1)}. \quad (16)$$

From (16) we can draw the following general conclusion.

Result 1 *With sufficiently strong (weak) labour market imperfections, capital investment has a wage-moderating (wage-increasing) effect.*

The relationship (16) characterizes how the capital stock can serve as a strategic commitment device with the effect of inducing wage moderation as long as the relative bargaining power of the labour union exceeds the threshold determined in (16). This threshold is inversely related to the capital stock.

In particular, from (16) we can directly infer that $\left. \frac{dw^N}{dK} \right|_{\beta=1} < 0$, which means that

capital investments will always moderate wages in a labour market with a monopoly

union. Furthermore, it holds true that $\left. \frac{dw^N}{dK} \right|_{\beta=0} = 0$ so that in the absence of any

labour market imperfections there is no relationship between the capital stock and wage formation. This seems to make sense, because the capital investments cannot have any wage-moderating effect if there is no wage mark-up.

In terms of the underlying economic intuition we can identify two different mechanisms explaining the effects of the capital stock on wage formation. Firstly, a higher capital stock increases the wage elasticity of labour demand (5), inducing discipline and thereby a negative effect on the wage mark-up. Secondly, as capital and labour are substitutes a higher capital stock will moderate the profit-reducing effect π_w / π of a wage increase. From (9), an increase in the capital stock would promote the wage mark-up through this mechanism. The overall effect on the negotiated wage of an increased capital stock reflects a trade-off between these two forces. From (16) we can conclude that the first effect tends to dominate when the labour market imperfection is sufficiently strong.

V. The Effect of Capital Investment on Equilibrium Unemployment

We now move on to explore the determinants of equilibrium unemployment in a general equilibrium framework. In this framework we are not interested in the adjustment process, which capture the effects of how a change in the capital stock impacts on the unemployment in the short run. Instead we analyze the structural effects of an increased capital stock on equilibrium unemployment in the long run for an economy consisting of a large number of identical industries. We are in this section only interested in the relationships between the exogenous capital stock and equilibrium unemployment.

In a general equilibrium, the term b should be re-interpreted as the endogenous outside option, which we specify in a conventional way as

$$b = (1-u)w^N + uB, \quad (17)$$

where u is the unemployment rate, B captures the unemployment benefit and w^N denotes the negotiated wage rate in all identical industries in the economy (see e.g. Nickell and Layard (1999) p. 3048-3049 for a further discussion). Assuming a constant benefit-replacement ratio $q = B/w^N$ and substituting (17) for b into the Nash bargaining solution (10) yields the equilibrium unemployment

$$u^N = \frac{1}{1-q} \left[1 - \frac{1}{A(K, w, \beta)} \right], \quad (18)$$

where the wage mark-up, as derived in the previous section, is

$$A(K, w, \beta) = \frac{\beta\eta(1 + \delta\gamma \frac{K}{L}) + (1-\beta)(\delta-1)}{\beta(\eta-1)(1 + \delta\gamma \frac{K}{L}) + (1-\beta)(\delta-1)} \geq 1.$$

As for the impact of the capital stock on equilibrium unemployment we initially observe from (18) that $\frac{du^N}{dK} = \frac{1}{1-q} \frac{A_K}{A^2}$. Combining this observation with (15) we can draw the conclusion that

$$\frac{du^N}{dK} \begin{cases} < \\ = \\ > \end{cases} 0 \quad \text{if and only if} \quad \beta \begin{cases} > \\ = \\ < \end{cases} \frac{\delta-1}{(1 + \delta\gamma \frac{K}{L})^2 + (\delta-1)}. \quad (19)$$

Consequently, capital investments will reduce (increase) equilibrium unemployment if and only if the relative bargaining power of the labour union is sufficiently high (low). Analogously, we can directly infer that a higher bargaining power of the

labour union or an increased benefit replacement ratio always promote equilibrium unemployment, i.e. $\frac{du^N}{d\beta} = \frac{1}{1-q} \frac{A_\beta}{A^2} > 0$ and $\frac{du^N}{dq} = \frac{1}{(1-q)^2} \left[1 - \frac{1}{A} \right] > 0$.

We now summarize our analysis of equilibrium unemployment in

Result 2 *An increased capital stock decreases (increases) equilibrium unemployment if the relative bargaining power of the labour union is sufficiently strong (weak). Furthermore, an increased bargaining power of the union or an increased benefit replacement ratio promotes equilibrium unemployment.*

Importantly, the effects of the capital stock on equilibrium unemployment are primarily determined by the imperfections prevailing in the labour market, i.e. by β . Capital investments reduce equilibrium unemployment if these imperfections are sufficiently strong so as to exceed the threshold determined in (15). This threshold is inversely related to the capital – labour ratio K/L .

VI. Capital Stock and Equilibrium Unemployment: Empirical Evidence

In this section we will investigate the relationship between capital and unemployment from an empirical perspective. From (16), we can see that the effect of the capital stock on wages is determined by three factors: the bargaining power of the union, the capital-labour ratio and the parameters of the production function. In particular, capital is more likely to impact negatively on wages if the bargaining power and the capital-labour ratio are high. Similarly, from Result 2

$$\frac{du^N}{dK} \begin{cases} < \\ = \\ > \end{cases} 0 \quad \text{if and only if} \quad \beta \begin{cases} > \\ = \\ < \end{cases} \frac{\delta - 1}{(1 + \delta \gamma \frac{K}{L})^2 + (\delta - 1)} .$$

From (16) and (19) we can form the empirical hypothesis that the effects of the capital stock on wages and unemployment are to a large extent determined by labour market institutions and by capital-labour ratios. In particular, we see no reason for these relationships to be uniform across different countries. Instead our theory seems to imply country-specific relationships between the capital stock and wages as well as between the capital stock and unemployment.

Our estimation strategy is to approximate the Nash bargaining solution and the unemployment rate with empirical steady states derived from dynamic wage and unemployment equations. The comparative statics properties with respect to the capital stock can then be obtained from the steady state coefficients for capital in respective equations. In principle, the estimation of these equations requires a full system specification for all endogenous variables, since it is difficult to reconcile trending capital with unemployment otherwise (see Karanassou et al. (2008)). However, when the data are approximately difference stationary, as turns out to be the case in our study, the steady states take the form of cointegration relationships, which may yield ambiguous estimates of the coefficients. The reason is that it may be difficult to interpret individual cointegration vectors as describing the steady states of either unemployment or wages, especially if these variables appear in several of the cointegration vectors. Therefore, it is more convenient to focus on either (16) or (19), and to estimate the steady state from a single equation, since this procedure generates unambiguous estimates, which are uniformly derived for different countries. This can be achieved by both adding variables which balance the trend in the capital stock, as suggested by Karanassou et al. (2008) in their multiple equation framework, and linearly detrending the series prior to estimation. We follow this approach and restrict our attention to (19), which seems justified in light of our assumed time sequence, according to which unemployment is endogenous relative to all other variables. This implies that the unemployment equation can be consistently estimated in isolation by treating all the other variables as exogenous.

We make the simplifying assumptions that the bargaining power of the labour union (β), the parameters of the production function (δ, γ) and the capital-labour

ratio (K/L^*) are constant over time.² We further assume that the parameters δ and γ , related to the production function, are identical for each country in the sample. With these assumptions a log-linearized empirical steady state representation of the equilibrium unemployment for country j in period t takes the form

$$u_{j,t}^N = \zeta_K(k_j, \beta_j, \delta, \gamma) c_{j,t} + \zeta_{jx} x_{j,t} + \zeta_{jd} d_{j,t}, \quad (20)$$

where $c_{j,t} = \log(K_{j,t})$, $x_{j,t}$ is a vector of variables (discussed in detail below) that are relevant for equilibrium unemployment, $d_{j,t}$ collects deterministic terms, and the parameters $\zeta_K(k_j, \beta_j, \delta, \gamma)$, ζ_{jx} and ζ_{jd} describe the steady state relationships. Taking the derivative of (20) with respect to $c_{j,t}$ yields

$$\frac{\partial u_{j,t}^N}{\partial c_{j,t}} = \zeta_K(k_j, \beta_j, \delta, \gamma) = \zeta_{jK} \quad (21)$$

as an econometric representation of (19).

A dynamic equation for unemployment corresponding to (20) is given by

$$u_{j,t} = \sum_{i=1}^h \zeta_{j0i} u_{j,t-i} + \sum_{i=0}^h \zeta_{j1i} k_{j,t-i} + \sum_{i=0}^h \zeta_{j2i} x_{j,t-i} + \zeta_{j3} d_{j,t} + \varepsilon_{j,t} \quad (22)$$

where the relationships between steady state parameters in (20) and the parameters in (22) are given by

$$\zeta_{jK} = \left(\sum_{i=0}^h \zeta_{j1i} \right) / \left(1 - \sum_{i=1}^h \zeta_{j0i} \right), \quad \zeta_{jx} = \left(\sum_{i=0}^h \zeta_{j2i} \right) / \left(1 - \sum_{i=1}^h \zeta_{j0i} \right) \quad \text{and}$$

$$\zeta_{jd} = \left(\zeta_{j3} \right) / \left(1 - \sum_{i=1}^h \zeta_{j0i} \right).$$

Furthermore, the error terms are identically and independently distributed following a normal distribution $N(0, \sigma^2)$ with mean zero and variance σ^2 . Hence an estimate

² In fact, it is sufficient that β_t , δ_t and K_t/L_t are stationary variables, since in this case, they do not distort the long-run cointegration coefficients which are of main concern here.

of ζ_{jK} can be recovered directly from (22). A formula for calculating the standard error of this parameter can be found in Bårdsen (1989). The parameter ζ_{jK} may be significantly different from zero when $(u_{j,t-1} - \zeta_{jK}k_{j,t-1} - \zeta_{jK}x_{j,t-1}) \equiv \varepsilon_{j,t}^N$ is $I(0)$, whereas it is zero in a statistical sense otherwise.

The sample data consist of roughly 28 years with quarterly time series observations for 16 OECD-countries on unemployment, $u_{j,t}$, (the log of) real consumer wages, $w_{j,t}$, and (the log of) the real capital stock, $c_{j,t}$. In addition, we include a set of other variables which are potentially important for the determination of unemployment. This set is chosen to be large enough to ensure cointegration (for most countries), but does not exhaust the list of all possible variables suggested in the literature. In order to get a valid estimate of ζ_{jK} when the data are difference stationary, it is sufficient that the vector of variables, $x_{j,t}$, accounts for those stochastic trends in $u_{j,t}$, which are not explained exclusively by $c_{j,t}$, since the cointegration relationship is invariant to extensions of the information set. However, other representations of $x_{j,t}$ with the same property would do as well. In line with, for example, Marcellino and Mizon (2001) and Nymoen and Rodseth (2003) we include (the log of) average productivity, $\alpha_{j,t}$, and consumer price inflation, $\Delta p_{j,t}$. We also include the wedge between consumer and producer prices, $\tau_{j,t}$, to proxy foreign competition and indirect taxes (see Bårdsen et al. (2003)) and a measure of the output gap, $\tilde{y}_{j,t}$, based on a production function. Detailed definitions and descriptions of the data are provided in Appendix C.

Table 1 reports the estimates of ζ_{jK} with corresponding t-values and summarizes the main empirical findings from the regressions (22), where $x_{j,t} = (w_{j,t}, \alpha_{j,t}, \Delta p_{j,t}, \tau_{j,t}, \tilde{y}_{j,t})$ for each country. The lag length, h , is chosen based on standard information criteria. Moreover, variables in $x_{j,t}$ that have insignificant both long-run and short-run coefficients are excluded from the regression (the

column “Excl.” in Table 1). As can be seen from Table 1, both inflation and the wedge between consumer and producer prices were insignificant for most countries. Table 1 also shows that a unit-root in $\varepsilon_{j,t}^N$ is rejected for most countries. For the few countries where cointegration is not found, i.e. Belgium, Japan and Spain, unemployment rates contained near $I(2)$ components, possibly reflecting major structural breaks during the sample period.

Overall, the estimates of ζ_{jK} in Table 1 indicate a great deal of disparity between the countries and are suggestive of a more complex relationship between capital and labour than previously hypothesized. For roughly half of the countries, capital is insignificant as a determinant of unemployment in the long run. In three countries (Australia, Sweden, and the UK) capital has a negative long-run effect on unemployment, whereas this effect is positive in four countries (Canada, Finland, Ireland, and Japan). These dispersed long-run effects of capital on unemployment seem consistent with our theory, which emphasized that the effect of the capital stock on wages is determined by three factors: the bargaining power, the capital-labour ratio and production function parameters. It is of great interest to relate these results to ongoing debate between the proponents of the Layard et al. (1991) framework, denying a lasting role for capital in unemployment determination, and the “aspirations gap” approach proposed by Rowthorn (1995, 1999), who argue in favour of such a relationship. Key to this debate has been the issue of whether the Cobb-Douglas specification is a reasonable representation of the production technology or not. Our evidence suggests that the relationship between the capital investments and equilibrium unemployment is more significant in some countries than in others. Indeed, this conclusion is consistent with a view emphasizing the importance of the production function. Namely, if the production function is captured by the Cobb-Douglas specification no such relationship is visible.

We next investigate whether we can explain the different country-specific estimates of ζ_{jK} by capital-labour ratios and by proxies of the bargaining power of labour unions, as suggested by our theoretical model. To this end we linearize equation (21) according to

$$\zeta_{jK} = \psi_0 + \psi_1 k_j^e + \psi_2 \beta_j + v_j, \quad (23)$$

where the error v_j depends on the following three factors: (i) the degree of nonlinearities in $\zeta_K(\cdot)$, (ii) estimation errors in ζ_{jK} , and (iii) other stochastic noise. Since the error v_j is likely to be large and the number of observations is relatively small, the estimates tend to have a low precision. Nevertheless, we tentatively view the evidence as indicative for the empirical support of the predictions generated by our theoretical model. Table 2 reports the estimates.

We use the average capital-labour ratio in US dollars as a measure of k_j in each country. As proxies for the bargaining power of labour unions we make use of five indices of labour market and workplace conditions, obtained from Chor and Freeman (2005).³ These are presented in Appendix C and we denote them by β_{js} ($s = 1, \dots, 5$). The indices can range in value from 1 to 7, where higher number indicate more favourable conditions towards workers. We also try the mean of these indices, $\bar{\beta}_j = \sum_{s=1}^5 \beta_{js}$, as a proxy for β_j . Table 2 reports the results from the cross-country regressions. As is evident from Table 2, none of the coefficient estimates are significant. This is not surprising in light of the many sources of errors and the size of the sample. Nevertheless, we observe that ψ_1 is negative in all regressions consistent with the prediction in (21). Moreover, ψ_2 is negative for most of our proxies of the bargaining power of the union (except for β_{j2} and β_{j3} , which are indicators of the legal and economic position of unions, as well as, the nature and frequency of industrial disputes, institutions for resolving labour conflicts, respectively). Finally, it should be noted that (23) explains only a minor proportion, between 5 and 10 percentage points, of the variation of ζ_{jK} .

³ Du Caju et al. (2008) have studied institutional features of wage bargaining in 23 European countries, the US and Japan. They have demonstrated considerable heterogeneity across countries in the levels at which wage bargaining is conducted.

VII. Discussion

As already emphasized in the introduction, some influential models of imperfectly competitive labour markets, for example Layard et al. (1991), have argued that investments have no effect on equilibrium unemployment. This is correct if the wage elasticity of labour demand is independent of the capital-labour ratio as holds true for the Cobb-Douglas production function $R(K,L) = K^{1-a}L^a$, $0 < a < 1$.

Many reservations can be raised against the Cobb-Douglas specification, according to which the elasticity of substitution between labour and capital is equal to one. Empirical studies using U.S. data have produced estimates of this elasticity which are well below one (see e.g. Lucas (1969), Chirinko (2002), Chirinko et.al (2004), Antras (2004)). Also empirical evidence from international data seems to consistently yield estimates, which do not lie in conformity with the Cobb-Douglas specification (see e.g. Rowthorn (1995), (1999), Berthold et. al (2002), Duffy and Papageorgiou (2000), Chirinko (2008), Juselius (2008) and Driver and Munoz-Bugarin (2009)).

A production function with a more general pattern of substitution between labour and capital than the Cobb-Douglas type is the CES production function

according to $R(K,L) = \left[(1-a)K^{\frac{\sigma-1}{\sigma}} + aL^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma\rho}{\sigma-1}}$, where a , σ and ρ are parameters

satisfying $0 < a < 1$, $\sigma > 0$, and $0 < \rho < 1$, respectively. The parameter a is the distribution parameter (see e.g. Arrow et al. (1961)), while σ captures the elasticity of substitution between capital and labour and $0 < \rho < 1$ captures decreasing returns to scale in production. As demonstrated in an earlier version of this study (Koskela and Stenbacka (2007)), the qualitative nature of the relationship between capital and

equilibrium unemployment is more complicated with the CES production function and it is determined by the size of the elasticity of substitution between capital and labour in addition to the determinants emphasized in the present paper.

Overall, the CES production function can be applied to describe how technological features may introduce a relationship between capital and equilibrium unemployment. However, for the general CES production function the relationship between capital and equilibrium unemployment is very complex. In the present paper we have focused on a somewhat simpler production function, which makes it possible to explicitly characterize the effect of the capital stock on equilibrium unemployment as determined by three factors: the bargaining power, the capital-labour ratio and parameters of the production function.

VII. Conclusions

We have explored the long-term effects of capital on equilibrium unemployment in a model of labour market imperfections. The model is based on a production function where capital and labour inputs are substitutes. Furthermore, wages are determined through bargaining within a ‘right-to-manage’ framework. We established a strategic effect of capital investments by showing that a higher capital-labour ratio has a wage-moderating (wage-increasing) effect with sufficiently strong (weak) labour market imperfections. Based on this mechanism we found that an increased capital stock decreases (increases) equilibrium unemployment if the relative bargaining power of the labour union is sufficiently strong (weak).

Our theoretical results supported the empirical hypothesis that the effects of the capital stock on wages and unemployment are to a large extent determined by labour market institutions and capital-labour ratios. We concluded that our theory would imply country-specific relationships between the capital stock and wages as well as between the capital stock and unemployment. Our empirical investigation explored the relationship between capital and unemployment by using quarterly

observations for roughly 28 years in 16 OECD-countries. We detected a great deal of disparity between the countries regarding the long-run effects of capital on unemployment. These dispersed long-run effects of capital on unemployment seem consistent with our theory, which emphasized that the effect of the capital stock on wages is not monotonic and determined by three factors: the bargaining power, the capital-labour ratio and production function parameters.

Throughout the analysis we have assumed a homogeneous labour force. However, it would be very interesting to separate the labour force into a skilled and unskilled segment with different elasticities with respect to labour demand.⁴ Within such a richer context it might be possible to characterize qualitatively different interaction patterns between and capital investments and employment across the different labour market segments.

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⁴ Goldin and Katz (1998) have analyzed the origins of technology-skill complementarity both theoretically and empirically. Krusell et al (2000) have provided a theoretical framework to explain the skill premium in terms of the relative wages of skilled and unskilled labor. Riley and Young (2007) have studied empirically the relationship between skill heterogeneity and equilibrium unemployment by using data from the UK.

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Appendix A: The Nash bargaining solution for wage

Taking labour demand (4) into account we find that

$$\frac{R_L L}{R - R_L L} = \frac{(L + \gamma K)^{\frac{1}{\delta}} L}{\frac{\delta}{\delta - 1} (L + \gamma K)^{\frac{\delta - 1}{\delta}} - (L + \gamma K)^{\frac{1}{\delta}} L} = \frac{L}{\frac{\delta}{\delta - 1} (L + \gamma K) - L} = \frac{\delta - 1}{1 + \delta \gamma \frac{K}{L}} \quad (\text{A1})$$

which gives (9). Substituting (8) and (9) into the first-order condition (7) yields

$$[\beta w(1 - \eta) + \beta b \eta] \left(1 + \delta \gamma \frac{K}{L}\right) = (w - b)(1 - \beta)(\delta - 1), \quad (\text{A2})$$

which can be solved to generate the negotiated Nash bargaining solution (10). **QED**

Appendix B: Derivation of the relationship between the negotiated wage and the capital stock

Implicit differentiation of (10) with respect to wage and capital stock $\frac{dw}{dK} = \frac{A_K b}{1 - A_w b}$

and substituting $b = \frac{w}{A}$ gives

$$\frac{dw^N}{dK} = \frac{\frac{A_K w}{A}}{1 - \frac{A_w w}{A}} \quad . \quad (\text{B1})$$

By introducing the notation $X = 1 + \delta \gamma \frac{K}{L}$ we can rewrite the mark-up as follows

$$A = \frac{\beta(X + \delta - 1)X + (1 - \beta)(\delta - 1)}{\beta(X + \delta - 2)X + (1 - \beta)(\delta - 1)}. \quad (\text{B2})$$

Based on straightforward calculations we find that the effect of capital stock on the mark-up can be expressed according to

$$\begin{aligned}
A_k &= [\beta(X + \delta - 2)X + (1 - \beta)(\delta - 1)]^{-2} \\
&\left(\frac{[\beta(X + \delta - 2)X + (1 - \beta)(\delta - 1)][\beta(X + \delta - 1)X_k + \beta XX_k] - [\beta(X + \delta - 1)X + (1 - \beta)(\delta - 1)][\beta(X + \delta - 2)X_k + \beta XX_k]}{[\beta(X + \delta - 2)X + (1 - \beta)(\delta - 1)]^2} \right) \\
&= \frac{-\beta X_k \left[\beta \left(1 + \delta \gamma \frac{K}{L} \right)^2 - (1 - \beta)(\delta - 1) \right]}{[\beta(X + \delta - 2)X + (1 - \beta)(\delta - 1)]^2} \begin{cases} < \\ = \\ > \end{cases} 0 \text{ as } \beta \begin{cases} > \\ = \\ < \end{cases} \frac{\delta - 1}{\left[1 + \delta \gamma \frac{K}{L} \right]^2 + (\delta - 1)},
\end{aligned} \tag{B3}$$

where $X_k = \frac{\delta \gamma}{L} \left(1 + \gamma \frac{K}{L} \right) = \eta \frac{\gamma}{L} > 0$, so that the effect of the capital stock on the mark-up depends on the relative bargaining power of the labour union. Therefore

$$\frac{A_{k^w}}{A} \begin{cases} < \\ = \\ > \end{cases} 0 \text{ as } \beta \begin{cases} > \\ = \\ < \end{cases} \frac{\delta - 1}{\left[1 + \delta \gamma \frac{K}{L} \right]^2 + (\delta - 1)}. \tag{B4}$$

Differentiating the mark-up with respect to the wage we find that

$$\begin{aligned}
A_w &= [\beta(X + \delta - 2)X + (1 - \beta)(\delta - 1)]^{-2} \\
&\left(\frac{[\beta(X + \delta - 2)X + (1 - \beta)(\delta - 1)][\beta(X + \delta - 1)X_w + \beta XX_w] - [\beta(X + \delta - 1)X + (1 - \beta)(\delta - 1)][\beta(X + \delta - 2)X_w + \beta XX_w]}{[\beta(X + \delta - 2)X + (1 - \beta)(\delta - 1)]^2} \right) \\
&= \frac{-\beta X_w \left[\beta \left(1 + \delta \gamma \frac{K}{L} \right)^2 - (1 - \beta)(\delta - 1) \right]}{[\beta(X + \delta - 2)X + (1 - \beta)(\delta - 1)]^2},
\end{aligned} \tag{B5}$$

where $X_w = \frac{\delta \gamma}{L} \left(\frac{\delta w^{-\delta-1} K}{L} \right) = \eta \frac{\delta \gamma K}{wL} > 0$.

By using (B3) and (B5) the equation (B1) can be expressed as follows

$$\begin{aligned}
\frac{dw^N}{dK} &= \frac{\frac{A_K w}{A}}{1 - \frac{A_w w}{A}} = \frac{\left(\frac{\beta X_K w \left[\beta \left(1 + \delta \gamma \frac{K}{L} \right)^2 - (1 - \beta)(\delta - 1) \right]}{\left[\beta(X + \delta - 2)X + (1 - \beta)(\delta - 1) \right] \left[\beta(X + \delta - 1)X + (1 - \beta)(\delta - 1) \right]} \right)}{1 + \frac{\left(\frac{\beta X_w w \left[\beta \left(1 + \delta \gamma \frac{K}{L} \right)^2 - (1 - \beta)(\delta - 1) \right]}{\left[\beta(X + \delta - 2)X + (1 - \beta)(\delta - 1) \right] \left[\beta(X + \delta - 1)X + (1 - \beta)(\delta - 1) \right]} \right)}{\left(\frac{\beta X_K w \left[\beta \left(1 + \delta \gamma \frac{K}{L} \right)^2 - (1 - \beta)(\delta - 1) \right]}{\left[\beta(X + \delta - 2)X + (1 - \beta)(\delta - 1) \right] \left[\beta(X + \delta - 1)X + (1 - \beta)(\delta - 1) \right]} \right)}} \\
&= \frac{-\beta X_K w \left[\beta \left(1 + \delta \gamma \frac{K}{L} \right)^2 - (1 - \beta)(\delta - 1) \right]}{\left[\beta(X + \delta - 2)X + (1 - \beta)(\delta - 1) \right] \left[\beta(X + \delta - 1)X + (1 - \beta)(\delta - 1) \right] + \beta X_w w \left[\beta X^2 - (1 - \beta)(\delta - 1) \right]}
\end{aligned} \tag{B6}$$

By using $X_w w = (X + \delta - 1)(X - 1)$ the denominator of (B6) can be expressed as follows

$$\begin{aligned}
D &= \beta^2 (X + \delta - 2)(X + \delta - 1)X^2 + (1 - \beta)^2 (\delta - 1)^2 + \\
&\beta^2 (X + \delta - 1)X^2 (X - 1) + \beta(1 - \beta)(\delta - 1)(1 + (X + \delta - 2)X) > 0, \quad \text{since } X > 1.
\end{aligned}$$

Thus, we can draw the conclusion that

$$\frac{dw^N}{dK} \begin{cases} < \\ = \\ > \end{cases} 0 \text{ as } \beta \begin{cases} > \\ = \\ < \end{cases} \frac{\delta - 1}{\left[1 + \delta \gamma \frac{K}{L} \right]^2 + (\delta - 1)}. \tag{B7}$$

In particular, from (B6) we can infer that $\lim_{\beta \rightarrow 0^+} \frac{dw^N}{dK} > 0$ verifying that K has an increasing effect on the negotiated wage for small values of β . **QED.**

Appendix C: Data

The sample data consists of roughly 28 years of quarterly time series observations for the following OECD countries. Australia (AU), Belgium (BE), Canada (CA), Denmark (DK), Finland (FI), France (FR), Ireland (IR), Italy (IT), Japan (JP), the Netherlands (NL), Norway (NO), new Zealand (NZ), Spain (SP), Sweden (SE), the UK, the US. The variable definitions and sources are reported here.

Variable definitions and sources			
Var.	Exceptions	Definition	Source ^{*)}
$u_{j,t}$	-	Unemployment rate.	OECD1
$c_{j,t}$	-	Log of total economy real capital stock.	OECD2
$w_{j,t}$		Log of real private sector wage rate.	OECD2
	BE, DK	Log of the real hourly wage rate in manufacturing.	OECD1
	SP, NZ	Log of real hourly earnings in all activities.	OECD1
	IR	Log of total economy real compensation rate.	OECD2
$a_{j,t}$	-	Log of real gross domestic product (GDP) divided by total employment.	OECD2
$p_{j,t}$	-	Log of consumer price index (2005 = 100).	OECD2
$\eta_{j,t}$	-	Log of ratio between consumer and producer prices.	OECD1, OECD2
$\tilde{y}_{j,t}$	-	Log of ratio between real and production function based potential GDP	OECD2
	BE, SP	Log of ratio between real GDP and HP-filtered GDP.	-
k_j		Average of log capital labor ratio.	-
β_{j1}		Indicator: Wage-setting, enforcement of minimum wage policies, wage arrears, prevalence of child labour, gender discrimination.	CF
β_{j2}		Indicator: Legal and economic position of unions.	CF
β_{j3}		Indicator: Nature and frequency of industrial disputes, institutions for resolving labour conflicts.	CF
β_{j4}		Indicator: Effect of regulations and collective bargaining on labour contracts, work hours, hiring and firing decisions.	CF
β_{j5}		Indicator: Pension schemes, sickness benefits, unemployment insurance.	CF

^{*)} OECD main economic indicators (OECD1), OECD Economic Outlook (OECD2), Chor and Freeman (2005) (CF).

Regression and cointegration results						
j	$\partial u_{j,t}^N / \partial c_{j,t}$		Regression summary			
	ζ_{jK}	t -value	Sample	h	Excl.	t -ADF, $\varepsilon_{j,t}^N$
AU	-0.062	-3.88	80:1-08:2	2	$\mu_{j,t}, \Delta p_{j,t}$	-3.58
BE	1.765	0.27	80:1-08:2	3	-	-2.52
CA	0.059	2.35	80:1-08:1	5	$\tilde{y}_{j,t}, \Delta p_{j,t}$	-5.17
DK	0.375	1.44	80:1-08:1	5	$\Delta p_{j,t}$	-2.95
FI	0.068	2.32	80:1-08:2	4	-	-2.9
FR	-0.057	-1.71	80:1-08:2	2	$\Delta p_{j,t}$	-4.43
IR	0.021	1.96	80:1-08:2	2	-	-3.75
IT	0.008	0.18	81:1-08:2	2	$\tau_{j,t}, \Delta p_{j,t}$	-3.28
JP	0.082	2.06	80:1-08:2	2	$w_{j,t}, \tau_{j,t}, \Delta p_{j,t}$	-1.86
NL	-0.033	-1.69	80:1-08:2	2	$\tau_{j,t}, \Delta p_{j,t}$	-3.65
NO	-0.003	-0.36	80:1-08:2	2	$\tau_{j,t}$	-3.33
NZ	0.038	1.14	80:1-08:2	2	$w_{j,t}, a_{j,t}$	-4.01
SP	-0.013	-0.01	80:1-08:2	2		-2.6
SE	-0.079	-3.23	82:1-08:2	2	$\tilde{y}_{j,t}, \tau_{j,t}, \Delta p_{j,t}$	-4.09
UK	-0.139	-3.4	80:1-08:1	5	$a_{j,t}, \tau_{j,t}, \Delta p_{j,t}$	-3.84
US	0.036	1.44	80:1-08:2	2	$\tau_{j,t}, \Delta p_{j,t}$	-4.11

Table 1: Estimates of ζ_{jK} and regression summaries.

The column labeled "Excl." reports variables that were excluded from $x_{j,t}$. Boldface values indicate rejection at the 5% significance level (note that the ADF-test has a non-standard distribution).

Cross country regressions of ζ_{jK} on k_j and β_j						
Var.	$k_j, \bar{\beta}_j$	k_j, β_{j1}	k_j, β_{j2}	k_j, β_{j3}	k_j, β_{j4}	k_j, β_{j5}
ψ_1	-0.19 (-0.384)	-0.17 (-0.360)	-0.29 (-0.599)	-0.22 (-0.453)	-0.20 (-0.416)	-0.14 (-0.278)
ψ_2	-0.15 (-0.114)	-0.36 (-0.252)	0.41 (0.327)	0.03 (0.026)	-0.17 (-0.131)	-0.32 (-0.375)

Table 2: Cross country regressions of ζ_{jK} on k_j and β_j .

The numbers in parenthesis are t-values.