EQUILIBRIUM UNEMPLOYMENT WITH CAPITAL INVESTMENTS UNDER LABOUR MARKET IMPERFECTIONS[*]

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We study the effects of labour market imperfections and the capital stock on equilibrium unemployment. With an exogenous capital-labour ratio, stronger labour market imperfections promote equilibrium unemployment. However, 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. Empirically we find dispersed long-run effects of capital on unemployment, using 28 years of quarterly data, in 16 OECD countries. A significant part of this dispersion can be explained by differences in labour market conditions among the countries. (JEL: E22, E24, J51, L11)

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1. Introduction

Faced with persistent unemployment, governments in many European countries have frequently been advised to conduct structural reforms of the labour market institutions. And indeed, microeconomic research focusing on labour economics has given strong theoretical foundations for such policies. For example, Nickell, Nunziata and Ochel (2005) present empirical evidence on the importance of labour market institutions as an explanation for differences in employment performance across countries. An alternative approach, advocated by, for example, Rowthorn (1999), emphasizes the role of capital accumulation and interest rates as an additional factor with significant effects on unemployment.

The employment consequences of long-term investments have been controversial in economics for a long time. The issue underlies many disputes between firm owners and labour unions. In some influential models of imperfectly competitive labour markets, for example Layard, Nickell and Jackman (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.

Our theoretical model establishes novel systematic interaction effects between long-term investments and equilibrium unemployment in the presence of labour market imperfections. The model 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 higher capital stocks decrease (increase) equilibrium unemployment if the relative bargaining power of the labour union is sufficiently strong (weak). Furthermore, we find theoretically that increases in the bargaining power of the union or the benefit replacement ratio promote equilibrium unemployment. These results complement those of Rowthorn (1999), who emphasizes the importance of the elasticity of substitution between capital and labour in the production function as a significant determinant of the effects of investments on equilibrium unemployment. Furthermore, we also demonstrate that our qualitative results regarding the crucial role of the labour market institutions for the relationship between long-term investments and equilibrium unemployment hold true for a CES production function under the empirically relevant configuration where the elasticity of substitution between capital and labour is below one.

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, Baddeley and Sawyer (2007) and Karanassou, Sala and Salvador (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: First, 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 the one between capital and unemployment. Second, we present empirical cointegration analyses on these relationships for a broader set of countries than has previously been analyzed.

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 2 presents the basic structure of the model with the time sequence of the decisions. Labour demand is studied in section 3, and wage determination through Nash bargaining is analyzed in section 4. Section 5 analyzes equilibrium unemployment and characterizes the long-run effects of capital on equilibrium unemployment. We present empirical evidence in section 6 and discuss our results in section 7. Finally, we present concluding comments in Section 8.

2. 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 present analysis our goal is to characterize the effects of the capital stock on equilibrium unemployment. For that purpose we are primarily interested in the comparative static effects of the capital stock on wage formation, and thereby on employment. Consistent with this goal we do not endogenize capital investments.

The 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

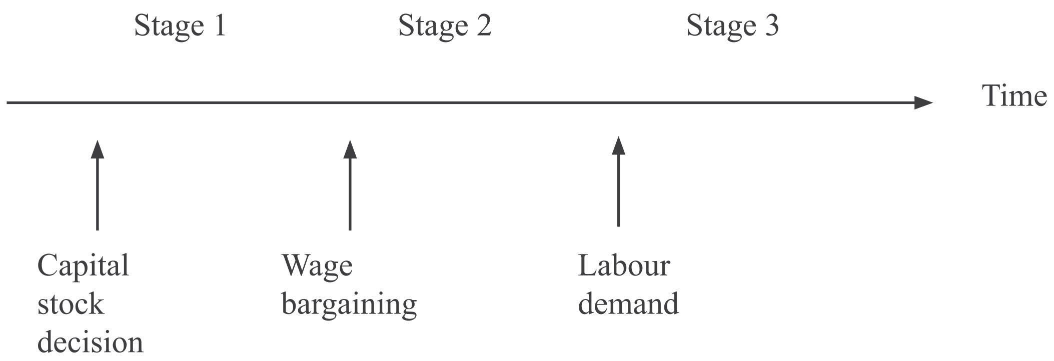

Figure 1. Time sequence of decisions

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).

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.

3. Labour demand

We assume that the production function satisfies

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

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. In Section 7 we will discuss how more general specifications of the production function will affect our results. In particular, we show that the qualitative properties relevant for an evaluation of the effects of the capital stock on equilibrium unemployment are robust when shifting our attention from the production function (1) to a CES-production function with the elasticity of substitution between capital and labour confined to the empirically relevant region between zero and one.

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 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

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

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

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

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

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

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

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

As (5) shows, the wage elasticity of labour demand, $\eta(K/L,w)>1$, 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.

4. 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 threat 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

(6)

$$\underbrace{Max}_{w}\ \Omega = \left[L\,(w-b)\right]^{\beta}\left[R(L, K) - wL\right]^{1-\beta} - (1+r)K,$$

subject to labour demand ($\pi_L = 0$). 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

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

where

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

and

(9)

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

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

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

From this equation we find the following Nash bargaining solution

(10)

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

We refer to Appendix A for the crucial steps in the derivation of (10). According to (10), the negotiated wage is proportional to the outside option with the mark-up factor

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

This mark-up factor strictly exceeds one if $0 < \beta \le 1$ 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

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

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

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

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 $\mathrm{d}w/\mathrm{d}K = A_K b/(1-A_w b)$ 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)

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

where

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

and

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

so that

(16) $$\frac{dw^N}{dK} = \frac{\frac{A_K w}{A}}{1-\frac{A_w w}{A}} \begin{Bmatrix} < \\ = \\ > \end{Bmatrix} 0 \quad \textit{if and only if}$$

$$\beta \begin{Bmatrix} > \\ = \\ < \end{Bmatrix} \frac{\delta-1}{(1+\delta\gamma\frac{K}{L})^2+(\delta-1)}.$$

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 $\mathrm{d}w^N/\mathrm{d}K\big|_{\beta=1} < 0$, which means that capital investments always moderate wages in a labour market with a monopoly union. Furthermore, it holds true that $\mathrm{d}w^N/\mathrm{d}K\big|_{\beta=1} = 0$. Thus, in the absence of any labour market imperfections there is no relationship between the capital stock and wage formation. This makes sense, because 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. First, a higher capital stock increases the wage elasticity of labour demand (5), inducing discipline and thereby a negative effect on the wage mark-up. Second, as capital and labour are substitutes a higher capital stock will moderate the profit-reducing effect π_w/π of a wage increase. From (10), 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.

5. The effect of capital investment on equilibrium unemployment

We now move on to explore the determinants of equilibrium unemployment in a general equilibrium framework. Our main focus is on the structural effects of an increased capital stock on long-run equilibrium unemployment for an economy consisting of a large number of identical industries. In this framework, we do not attempt to analyze the short-run path that unemployment takes as it adjusts toward the long run equilibrium.

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

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

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 $q = B/w^N$ ratio and substituting (17) for b into the Nash bargaining solution (10) yields the equilibrium unemployment

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

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 find that

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

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

$$\frac{du^N}{dq} = \frac{1}{(1-q)^2}\left[1-\frac{1}{A}\right] > 0.$$

Intuitively, result (19) means that higher investments are required in countries with stronger trade unions in order to reduce equilibrium unemployment. 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.

6. Capital stock and equilibrium unemployment: empirical evidence

In this section we investigate the relationship between capital and unemployment from an empirical perspective. Our model yields at least two testable empirical predictions. First, the (long-term) equilibrium unemployment rate should be dependent on the capital stock. Second, the sign of the partial derivative of equilibrium unemployment with respect to capital should be determined by three factors: the bargaining power of the union, the capital-labour ratio and the parameters of the production function. In particular, from (19), i.e.

$$\frac{\mathrm{d}u^N}{\mathrm{d}K} \begin{Bmatrix} < \\ = \\ > \end{Bmatrix} 0 \quad \text{if and only if} \quad \beta \begin{Bmatrix} > \\ = \\ < \end{Bmatrix} \frac{\delta - 1}{(1+\delta\gamma\frac{K}{L})^2 + (\delta - 1)},$$

we see that capital is more likely to have a negative impact on wages if the bargaining power or the capital-labour ratio is high. Hence, as labour market institutions and capital-labour shares exhibit substantial differences across countries, our theory seems to imply country-specific relationships between the capital stock and unemployment.

The first prediction can be tested as the hypothesis that capital is a significant determinant of equilibrium unemployment. The second prediction can be tested in two complementary ways, (a) either by allowing the partial derivative of the equilibrium unemployment rate with respect to capital to be a time-varying function of the capital-labour ratio and union bargaining power, or (b) by investigating if potential cross-country differences in this partial derivative can be explained by the same variables. We will exclusively focus on the latter approach and apply it to data from several OECD countries. The primary reason is that, although there are notable changes over time with respect to both labour market institutions and capital-labour ratios for some of the countries in our sample, cross-country differences between these variables are nevertheless of much larger magnitude. Moreover, for the countries displaying substantial changes in labour market institutions (Australia, Ireland, the UK, and New Zealand) or capital-labour ratios (Belgium, Denmark, France, Japan, and the US), we experimented by estimating the equilibrium unemployment relationship (see below) using a smooth transition regression (STR) model, where the partial derivative is allowed to depend on the aforementioned variables. While we found some evidence of significant, albeit small, changes in the magnitude of this derivative within these countries, its *sign* remained intact in all cases.[1] Hence, the value added of incorporating this feature seems small compared to the cost of increased technical complication.

An additional benefit of focusing on the cross-sectional, rather than temporal, variation in the partial derivative with respect to capital is that it enables us to test our theoretical predictions in two distinct steps. In the first step, we estimate the effect of capital on equilibrium unemployment and test its significance separately for each country in our sample. In the second step, we ask whether or not potential cross-country differences in the estimated derivatives can be explained by cross-country differences with respect to union bargaining power and capital-labour ratios. We begin by discussing the details associated with the first step.

We approximate the equilibrium unemployment relationship separately for each country, j, by the estimated steady state (cointegration relationship) derived from a standard autoregressive distributed lag model of the form

(20)

$$u_{j,t} = \sum_{i=1}^{h} \zeta_{j0i} u_{j,t-i} + \sum_{i=0}^{h} \zeta_{j1i} c_{j,t-i} + \sum_{i=0}^{h} \zeta'_{j2i} x_{j,t-i} + \zeta'_{j3} d_{j,t} + \varepsilon_{j,t}$$

where $u_{j,t}$ is the observed unemployment rate, $c_{j,t} = \log(K_{j,t})$ is the (log of the) real capital stock, $x_{j,t}$ is a vector containing the wage rate, $w_{j,t}$, and other explanatory variables, $d_{j,t}$ is a vector consisting of a constant and centered seasonal dummies, and the error term is assumed to be *i.i.d.* The role of $x_{j,t}$ is to control for factors which may be important for unemployment determination, but are not explicitly treated within our theoretical framework. In line with previous empirical studies on unemployment

[1] *In the STR models, we used yearly trade union density data (obtained from the CESifo DICE database) interpolated to the quarterly frequency as a proxy for the union bargaining power. The results from these estimations are available upon request.*

(e.g., Marcellino and Mizon 2001 and Nymoen and Rødseth 2003) we include (the log of) average labour 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, Jansen and Nymoen 2003) and a measure of the output gap, $\tilde{y}_{j,t}$,[2] as a proxy for the cyclical component in economic activity. Hence, $x_{j,t} = (w_{j,t}, \alpha_{j,t}, \Delta p_{j,t}, \tau_{j,t}, \tilde{y}_{j,t})$ for each country. Our sample data consist of roughly 28 years (1980:1–2008:2 for most countries) with quarterly time series observations on the variables in (20) for 16 OECD-countries. Appendix C provides detailed definitions and descriptions of the data.

The steady state relationship for unemployment implied by (20) is given by

(21)

$$u^N_{j,t} = \zeta_{jK} c_{j,t} + \zeta'_{jx} x_{j,t} + \zeta'_{jd} d_{j,t},$$

where the relationships between the parameters in (20) and (21) are given by

$$\zeta_{jK} = \left(\sum_{i=0}^{h} \zeta_{j1i}\right) \Big/ \left(1 - \sum_{i=1}^{h} \zeta_{j0i}\right),$$

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

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

Hence, our estimate of the partial derivative of equilibrium unemployment with respect to capital, $\partial u^N_{j,t} / \partial c_{j,t}$, is given by ζ_{jK}. 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 $(u_{j,t-1} - \zeta_{jK} c_{j,t-1} - \zeta_{jx} x_{j,t-1}) \equiv \varepsilon^N_{j,t}$ is $I(0)$, whereas it is zero in a statistical sense otherwise. The set of variables in $x_{j,t}$ 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 principle, it will be difficult to reconcile an upward trending capital stock with the unemployment rate in an equation like (21) without specifying equations for the remaining endogenous variables (see Karanassou et al. 2008), such as wages. However, when the data are approximately difference stationary, as turns out to be the case in our study, the steady states for a system of equations take the form of a cointegration space which may not yield a unique estimate of ζ_{jK}. The reason is that both capital and unemployment may appear in several cointegration relationships for specific rotations of the cointegration space. Therefore, it is more convenient to focus solely on the unemployment equation, as this generates an unambiguous estimate of ζ_{jK} derived in a uniform way for the different countries. This also seems justified in light of our assumed time sequence, according to which unemployment is endogenous relative to all other variables, which implies that the unemployment equation can be consistently estimated in isolation. However, we deal with the issue pertaining to growth trends, by linearly detrending both the capital and labour productivity series prior to estimation.

Table 1 reports the estimates of ζ_{jK} with corresponding t-values and summarizes the main empirical findings from the regressions (20). The full parameter estimates, ζ_{jK} and ζ_{jx}, of the equilibrium unemployment equation (21) are reported in Table 3 of Appendix D. The lag length, *h*, is chosen based

[2] Some of the variables in $x_{j,t}$, such as the output gap, may be stationary (albeit sometimes highly persistent) and cannot, hence, be cointegrated with unemployment in (21). However, this is not problematic as cointegration relationships are invariant to the inclusion of stationary information.

on standard information criteria. Moreover, standard F-tests were used to exclude variables in $x_{j,t}$ for which all coefficients in (20) are jointly insignificant (the column "Excl." in Table 1). As a precaution, we also checked that none of the excluded variables were significant in (21). 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 $\varepsilon^N_{j,t}$ is rejected for most countries. For the few countries where cointegration is not found, i.e. Belgium, Japan and Spain, unemployment rates contained components that were nearly *I(2)*, 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 half of the countries, capital is insignificant as a determinant of unemployment in the long run. In four countries (Australia, the Netherlands, 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 results can be compared with those reported in Arestis et al. (2007), who estimate cointegrated systems for wages and unemployment in nine Euro area countries. Their results

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).

Regression and cointegration results						
$\partial u^N_{j,t} / \partial c_{j,t}$			Regression summary			
j	ζ_{jK}	t-value	Sample	h	Excl.	t-ADF, $\varepsilon^N_{j,t}$
AU	–0.062	**–3.88**	80:1–08:2	2	$\tau_{j,t}$, $\Delta p_{j,t}$	**–3.58**
BE	1.765	0.27	80:1–08:2	3	-	–2.52
CA	0.059	**2.35**	80:1–08:1	5	$a_{j,t}$, $\Delta p_{j,t}$	**–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	–0.017	**–4.03**	80:1–08:2	2	$w_{j,t}$, $a_{j,t}$	**–4.59**
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	**–3.46**	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**

differ from ours in the sense that they obtain negative long-run relationships between capital and unemployment for each country in their sample.[3] Malley and Moutos (2001) and Alexiou and Pitelis (2003) also find significant relationships between capital and unemployment. However, it is difficult to make direct comparisons between their results and ours, as they use non-linear specifications and panel techniques, respectively, on samples which are substantially different with respect to both length and included countries.

The 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 should be visible.

We next investigate whether we can explain the different country-specific estimates of ζ_{jK} by capital-labour ratios, k_j, and proxies of the bargaining power of labour unions, β_j, as suggested by (19). We initially make the simplifying assumptions that the parameters δ and γ, related to the production function, are identical for each country in the sample. Under this assumption the derivative of equilibrium unemployment with respect to capital becomes

$$(22)\ \frac{\partial u^N_{j,t}}{\partial c_{j,t}} = \zeta_{jK} = \zeta_K(\underset{-}{k_j},\underset{-}{\beta_j},\underset{+}{\delta},\underset{-}{\gamma}).$$

Linearizing this equation yields

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

where the error vj depends on the following four factors: (i) the degree of non-linearities in $\zeta_K(.)$, (ii) estimation errors in ζ_{jK}, (iii) technological differences between countries, and (iv) measurement errors in k_j and β_j.

The fact that capital is insignificant in the equilibrium unemployment relationship (21) generates a minor technical problem when estimating (23). The reason is that the absolute value of ζ_{jK} can fluctuate quite substantially in these cases due to the unit-root trends, since there is no tendency for insignificant parameters to converge to any specific value in particular when $1-\sum_{i=1}^{h}\zeta_{j0i}$ is small. Hence, it is not sensible to compare the insignificant ζ_{jK} with the significant ones in terms of their absolute values (see for instance the Danish and Australian coefficients in Table 1). For this reason we normalize the estimated ζ_{jK} by their standard errors, i.e. we use the t-values in Table 1, to ensure that they are of comparable size across countries, prior to estimating (23). We use the average capital-labour ratio in US dollars as a measure of k_j in each country. As a proxy for the bargaining power of labour unions we take the arithmetic mean of five indices (each ranging in value from 1 to 7), obtained from Chor and Freeman (2005), which capture various structural aspects of the labour market, such as enforcement of minimum wages, the

[3] *Arestis et al. (2007) interpret their cointegration vectors as defining either wage or unemployment relationships. However, both of these variables enter both relationships with signs and magnitudes that vary across the different countries. Hence, the net effect of the capital stock is ambiguous and cannot be inferred from either relationship in isolation. This may account for the seemingly different results reported in their paper compared to the ones reported here.*

legal position of unions, and the effect of collective bargaining on labour contracts.[4]

Since we only have observations from 16 countries the results from estimating (23) will necessarily be imprecise and should be viewed with a great deal of caution. To economize on degrees of freedom, we begin by exclusively focusing on the association between the capital labour ratio, k_j, and the normalized ζ_{jK}, i.e. we set $\psi_2 = 0$ in (23). The second column of Table 2 reports the results. As is evident from this table, the estimated coefficients are insignificant and R^2 is virtually zero, indicating very low explanatory power. Similar results are obtained in the third column of the table, where we focus on β_j instead, i.e. we estimate (23) with $\psi_1 = 0$. These results are perhaps not surprising in light of the many sources of error and the size of the sample. Figure 2 plots the cross-correlations between normalized ζ_{jK} and k_j (upper panel), as well as between normalized ζ_{jK} and β_j (lower panel). As can be seen from Figure 2, there are some indications that countries with low capital-labour ratios and union bargaining powers define different groups with respect to the intercept in (23), compared to countries with high values for these variables.

One potential reason for the pattern in the upper panel of Figure 2 is that the countries with low capital labour-ratios have higher

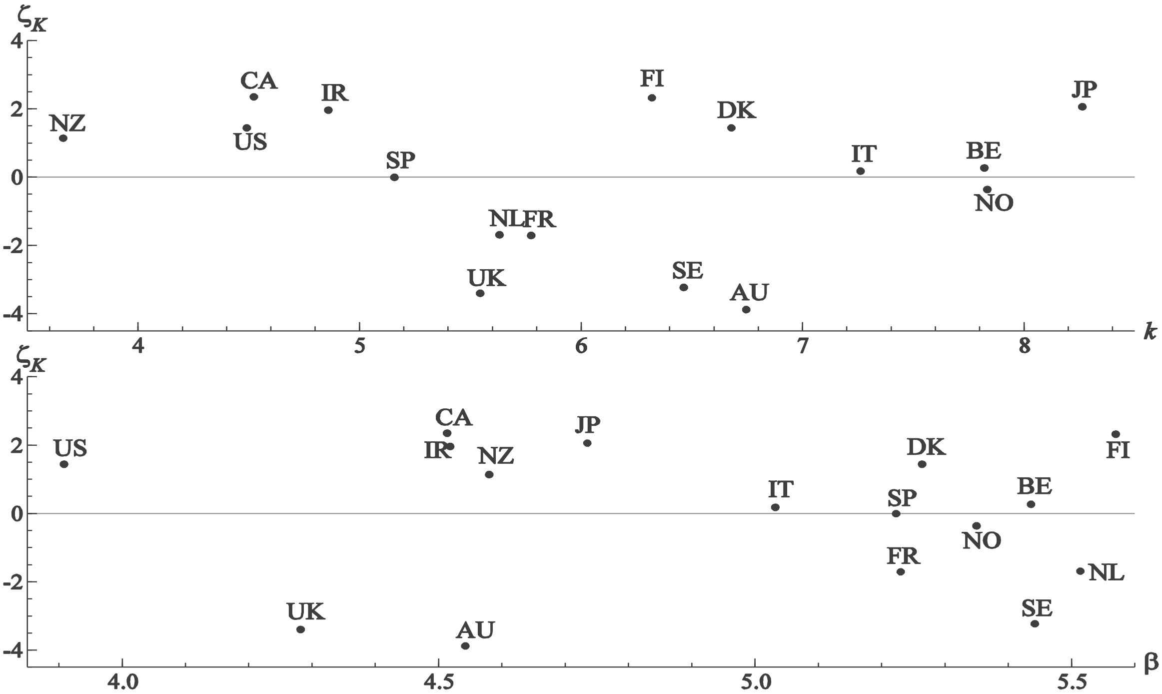

Figure 2. Cross correlations between normalized ζ_{jK} and k_j (upper panel), as well as between normalized ζ_{jK} and β_j (lower panel)

[4] *Detailed descriptions of these indices are provided in Appendix C. Using each index separately, (23) does not yield qualitatively different results. Du Caju, Gautier, Momferatou and Ward-Warmedinger (2008) study institutional features of wage bargaining and report considerable heterogeneity between 23 European countries, the US and Japan in the levels at which wage bargaining is conducted. Stockhammer and Klär (2011) find strong effects of capital accumulation and the real interest rate on unemployment, but only moderate and non-robust effects of labour market institutions in a panel analysis based on 20 OECD countries.*

productivity of capital relative to labour, γ, which according to (19) would amplify the role of k_j in (23). Thus, to control for this possibility, we need to relax the assumption of homogenous production function parameters to some extent. To this end, we construct a dummy variable (Dum1), which takes the value one for countries with comparatively low labour productivities, based on estimates in Hall and Jones (1999), and zero otherwise.[5] Similarly, we note that the countries with low β_j in the lower panel of Figure 2 are predominantly Anglo-Saxon economies with relatively low degrees of unionization. To control for this aspect, we construct a dummy variable (Dum2), which takes the value one for countries in which, on average, less than 50% of the labor force is covered by collective agreements. The results of augmenting the estimated equations in columns 2 and 3 with Dum1 and Dum2, respectively, are reported in columns 4 and 5 of Table 2. As can be seen, there are radical increases in explanatory power (R^2 increases from 0.02 to 0.50 in the first case and from 0.01 to 0.21 in the second case). More important, the coefficient on k_j is now negative and significant, whereas the coefficient on β_j is negative and close to being significant, in line with the predictions of our theoretical model. These results are by and large preserved in an estimate of the full version of (23) with both dummies included, as reported in the last column of Table 3. The only difference is a slight loss of precision due to the lower degrees of freedom. These results are broadly consistent with our theoretical framework.

7. Discussion

As already emphasized in the introduction, some influential models of imperfectly competitive labour markets, for example Layard et al. (1991), have argued that

Table 2. Cross country regressions of normalized ζ_{jK} on k_j and β_j, the numbers in parenthesis are t-values

Cross country regressions of ζ_{jK} on k_j and β_j					
The dependent variable is normalized ζ_{jK}					
Constant	0.88 (0.31)	3.44 (0.58)	3.98 (1.71)	15.31 (1.76)	12.13 (1.64)
k_j	– 0.18 (–0.39)	–	– 0.92 (–2.25)	–	– 0.67 (–1.41)
β_j	–	– 0.74 (–0.62)	–	– 2.97 (–1.77)	– 1.86 (–1.18)
Dum1	–	–	3.72 (3.38)	–	3.38 (2.73)
Dum2	–	–	–	– 3.39 (–1.78)	– 1.41 (–0.81)
R^2	0.01	0.03	0.47	0.21	0.53
DF	14	14	13	13	11

[5] *In particular, based on the estimates in Hall and Jones (1999), the selected countries have less than 75% efficiency of human capital or labour productivity, as well as a low score on the product of these two terms, compared to the US.*

investments have no effect on equilibrium unemployment. This hypothesis is correct if the wage elasticity of labour demand is independent of the capital-labour ratio and it 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, Fazzari and Meyer (2004), Antras (2004)). Also empirical evidence from international data seems to consistently yield estimates of similar magnitudes and these do not lie in conformity with the Cobb-Douglas specification (see e.g. Rowthorn (1995, 1999), Berthold, Fehn and Thode (2002), Duffy and Papageorgiou (2000), Chirinko (2008), Juselius (2008) and Driver and Munoz-Bugarin (2010)). In particular, Rowthorn (1999) forcefully argues for the view that the elasticity of substitution between labour and capital is well below one based on a systemic review of a large number of empirical studies.

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

$$(24)\quad R(K,L)=\left[(1-a)K^{\frac{\sigma-1}{\sigma}}+aL^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma\rho}{\sigma-1}},$$

where $0 < a < 1$ is the distribution parameter (see e.g. Arrow, Chenery, Minhas and Solow (1961)), whereas σ is the elasticity of substitution between capital and labour and $0<\rho<1$ captures decreasing returns to scale in production.

With the CES production function (24) the firm decides on employment by taking the capital stock and wage as given in order to solve

$$\underbrace{Max}_{L}\ \pi=\left[(1-a)K^{\frac{\sigma-1}{\sigma}}+aL^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma\rho}{\sigma-1}}-wL\ .$$

Straightforward calculations establish that the wage elasticity of labour demand can be written as

$$(25)\quad \eta\equiv-\frac{L_w w}{L}=\frac{\sigma\left[1+\frac{1-a}{a}\left(\frac{K}{L}\right)^{\frac{\sigma-1}{\sigma}}\right]}{\left[\sigma(1-\rho)+\frac{1-a}{a}\left(\frac{K}{L}\right)^{\frac{\sigma-1}{\sigma}}\right]}$$

and this implies, under the reasonable assumption $\sigma(1-\rho)-1<0$, that

(26)

$$\eta_K=\frac{\left((\sigma-1)\frac{1-a}{a}(\frac{K}{L})^{-\frac{1}{\sigma}}\left[\sigma(1-\rho)-1\right]\frac{\sigma(1-\rho)}{L}\right)}{\left[\sigma(1-\rho)+\frac{1-a}{a}\left(\frac{K}{L}\right)^{\frac{\sigma-1}{\sigma}}\right]^2}\begin{Bmatrix}>\\=\\<\end{Bmatrix}0$$

as

$$\sigma\begin{Bmatrix}<\\=\\>\end{Bmatrix}1.$$

Analysis of the wage negotiations in a way completely analogous to Section IV, we find that the negotiated wage with this production function is given by

(27)

$$w^N\Big|_{\sigma\neq1}=\frac{\beta\eta\left((1-a)(\frac{K}{L})^{\frac{\sigma-1}{\sigma}}+(1-\rho)\right)+(1-\beta)\rho a}{\beta(\eta-1)\left((1-a)(\frac{K}{L})^{\frac{\sigma-1}{\sigma}}+(1-\rho)\right)+(1-\beta)\rho a}\,b.$$

According to (26), the capital stock elasticity of labour demand is constant with a Cobb-Douglas production function, that is, when the elasticity of substitution between capital and labour is one. More generally, (26) shows how the elasticity of substitution between capital and labour affects the capital stock elasticity of labour demand. In this respect the analysis based on the CES production function with the empirically relevant configuration with $\sigma<1$ generates qualitative properties similar to those predicted by our original production function (1), thereby supporting the robustness of the results achieved within this simpler and more transparent setting.[6]

Irrespectively of whether the formal analysis is founded on production function (1) or (24), the effect of the capital stock on equilibrium unemployment is determined by the bargaining power of the trade union, as well as the capital-labour ratio, and it depends crucially on the sign of the derivative of the wage elasticity of labour demand with respect to capital, η_K. Compared to the current approach based on production function (1), the CES production function highlights the important role played by technology, more precisely the elasticity of substitution between capital and labour. However, with the CES specification the relationship between capital investments and equilibrium unemployment is very complex and cannot be explicitly characterized. The advantage of our present study, based on production function (1), is that we can obtain an explicit representation of this relationship. This tractability is achieved at the expense of a detailed description of the impact of technological factors on the relationship between capital investments and equilibrium unemployment.

8. Conclusions

We explore the long-term effects of capital on equilibrium unemployment in a model of labour market imperfections. The formal 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 establish 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 find 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 support 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. Our theory implies country-specific relationships between the capital stock and wages as well as between the capital stock and unemployment. Our empirical investigation explores the relationship between capital and unemployment by using quarterly observations for roughly 28 years in 16 OECD-countries. We detect a great deal of disparity between the countries regarding the

[6] *An unpublished predecessor of the present paper (Kauppi, Koskela and Stenbacka (2004)) presents further details of the much more tedious analysis of the effects of the capital stock on equilibrium unemployment with the CES production function. Also Kaas and von Thadden (2003) have analyzed how employment, capital and income shares respond to wage-setting shocks by showing, in a dynamic equilibrium model, that adjustment dynamics depend decisively on the magnitude of the elasticity of substitution between capital and labour.*

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 not monotonic and determined by three factors: the bargaining power, the capital-labour ratio and production function parameters. Moreover, we find that a large part of the dispersion in the long-run effects can be explained by indicators of labour market conditions and capital-labour ratios.

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.[7] Within such a richer context it might be possible to characterize qualitatively different interaction patterns between capital investments and employment across the different labour market segments.

[7] *Goldin and Katz (1998) have analyzed the origins of technology-skill complementarity both theoretically and empirically. Krusell, Ohanian, Rios-Rill and Violante (2000) have provided a theoretical framework to explain the skill premium in terms of the relative wages of skilled and unskilled labor. Duffy, Papageorgiou and Perez-Sebastian (2004) have studied the capital-skill complementarity hypothesis at the aggregate production level by using a time-series cross-section panel of 73 developed and less developed countries over a 25-year period. Riley and Young (2007) have studied empirically the relationship between skill heterogeneity and equilibrium unemployment by using data from the UK.*

Appendix A. The Nash bargaining solution for wage

Taking labour demand (4) into account we find that

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

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

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

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 the wage and capital stock yields

$$\frac{\mathrm{d}w}{\mathrm{d}K}=\frac{A_K b}{1-A_w b}$$

and substituting $b = w/A$ gives

$$\text{(B1)}\quad \frac{\mathrm{d}w^N}{\mathrm{d}K}=\frac{\dfrac{A_K w}{A}}{1-\dfrac{A_w w}{A}}.$$

By introducing the notation $X = 1+\delta\gamma(K/L)$ we can rewrite the mark-up as follows

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

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

(B3)

$$A_K=\left[\beta(X+\delta-2)X+(1-\beta)(\delta-1)\right]^{-2}$$
$$\begin{pmatrix}\left[\beta(X+\delta-2)X+(1-\beta)(\delta-1)\right]\left(\beta(X+\delta-1)X_K+\beta XX_K\right)- \\ \left[\beta(X+\delta-1)X+(1-\beta)(\delta-1)\right]\left(\beta(X+\delta-2)X_K+\beta XX_K\right)\end{pmatrix}$$

$$=\frac{-\beta X_K\left[\beta(1+\delta\gamma\frac{K}{L})^2-(1-\beta)(\delta-1)\right]}{\left[\beta(X+\delta-2)X+(1-\beta)(\delta-1)\right]^2}\begin{Bmatrix}<\\=\\>\end{Bmatrix}0 \text{ as } \beta\begin{Bmatrix}>\\=\\<\end{Bmatrix}\frac{\delta-1}{\left[1+\delta\gamma\frac{K}{L}\right]^2+(\delta-1)}$$

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

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

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

(B5)

$$A_w = \left[\beta(X+\delta-2)X+(1-\beta)(\delta-1)\right]^{-2}$$
$$\begin{pmatrix}\left[\beta(X+\delta-2)X+(1-\beta)(\delta-1)\right]\left[\beta(X+\delta-1)X_w+\beta XX_w\right]- \\ \left[\beta(X+\delta-1)X+(1-\beta)(\delta-1)\right]\left[\beta(X+\delta-2)X_w+\beta XX_w\right]\end{pmatrix}$$

$$= \frac{-\beta X_w\left[\beta(1+\delta\gamma\frac{K}{L})^2-(1-\beta)(\delta-1)\right]}{\left[\beta(X+\delta-2)X+(1-\beta)(\delta-1)\right]^2},$$

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

(B6)

$$\frac{\mathrm{d}w^N}{\mathrm{d}K} = \frac{\frac{A_K w}{A}}{1-\frac{A_w w}{A}} = \left(\frac{-\frac{\beta X_K w\left[\beta(1+\delta\gamma\frac{K}{L})^2-(1-\beta)(\delta-1)\right]}{\left[\beta(X+\delta-2)X+(1-\beta)(\delta-1)\right]\left[\beta(X+\delta-1)X+(1-\beta)(\delta-1\right]}}{1+\frac{\beta X_w w\left[\beta(1+\delta\gamma\frac{K}{L})^2-(1-\beta)(\delta-1)\right]}{\frac{\beta X_K w\left[\beta(1+\delta\gamma\frac{K}{L})^2-(1-\beta)(\delta-1)\right]}{\left[\beta(X+\delta-2)X+(1-\beta)(\delta-1)\right]\left[\beta(X+\delta-1)X+(1-\beta)(\delta-1\right]}}}\right)$$

$$= \frac{-\beta X_K w\left[\beta(1+\delta\gamma\frac{K}{L})^2-(1-\beta)(\delta-1)\right]}{\left[\beta(X+\delta-2)X+(1-\beta)(\delta-1)\right]\left[\beta(X+\delta-1)X+(1-\beta)(\delta-1)\right]+\beta X_w w\left[\beta X^2-(1-\beta)(\delta-1)\right]}$$

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

$$D = \beta^2(X+\delta-2)(X+\delta-1)X^2+(1-\beta)^2(\delta-1)^2+$$
$$\beta^2(X+\delta-1)X^2(X-1)+\beta(1-\beta)(\delta-1)(1+(X+\delta-2)X) > 0,$$

since $X > 1$.

Thus, we can draw the conclusion that

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

In particular, from (B6) we can infer that

$$\lim_{\beta \to 0^+} \frac{d\,w^N}{d\,K} > 0$$

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_j		Arithmetic average of β_{ji}, for $i = 1,...,5$, described below	
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).

Appendix D. Estimated equilibrium unemployment equations

Table D1. Estimated coefficients in the equilibrium unemployment relationships. The expected sings are indicated in the third row from the top. Deviations from the expected sign occur in three cases: the coefficients on $\alpha_{j,t}$, for j = IT, SE, and $\tau_{j,t}$, for j = CA.

Estimated steady state coefficients from Equation (21) for $u^N_{j,t}$						
j	$c_{j,t}$	$w_{j,t}$	$\alpha_{j,t}$	$\tilde{y}_{j,t}$	$\tau_{j,t}$	$\Delta p_{j,t}$
Exp. Sign:	+/–	+	–	–	+	–
AU	**–0.062**	**0.042**	0.003	**–0.154**	–	–
t-value	**–3.88**	**7.17**	0.28	**–7.90**	–	–
BE	1.765	–0.246	1.124	–0.622	–0.126	17.579
t-value	0.27	–0.27	0.29	–0.24	–0.19	0.28
CA	**0.059**	–0.026	–	**–0.714**	**–3.403**	–
t-value	**2.35**	–1.78	–	**–3.80**	**–2.78**	–
DK	0.375	0.170	0.071	–0.081	0.095	–
t-value	1.44	2.13	0.461	–0.49	1.73	–
FI	**0.068**	–0.042	0.030	**–0.206**	0.011	0.072
t-value	**2.32**	–1.74	0.932	**–10.3**	0.531	0.408
FR	–0.057	–0.023	0.066	**–0.148**	**0.040**	–
t-value	–1.71	–1.01	1.46	**–1.99**	**2.28**	–
IR	**0.021**	0.050	**–0.125**	0.039	–0.028	**–0.398**
t-value	**1.96**	1.39	**–4.70**	1.18	–1.54	**–3.63**
IT	0.008	–0.005	**0.061**	**–0.128**	–	–
t-value	0.18	–0.468	**4.50**	**–2.82**	–	–
JP	0.082	–	**–0.093**	–0.059	–	–
t-value	2.06	–	**–2.18**	–1.02	–	–
NL	**–0.017**	–	–	**–0.130**	0.004	0.039
t-value	**–4.03**	–	–	**–1.94**	0.50	0.195
NO	–0.003	–0.005	–0.008	**–0.071**	–	–0.017
t-value	–0.36	–0.451	–1.83	**–4.71**	–	–0.26
NZ	0.038	–	–	–0.053	**0.062**	**–0.329**
t-value	1.14	–	–	–1.21	**3.00**	**–2.82**
SP	–0.013	–0.083	0.895	–0.810	0.327	23.863
t-value	–0.01	–0.11	0.17	–0.11	0.099	0.123
SE	**–0.079**	–0.011	**0.206**	–	–	–
t-value	**–3.23**	–0.67	**7.04**	–	–	–
UK	**–0.139**	**0.032**	–	**–0.129**	–	–
t-value	**–3.46**	**2.42**	–	**–4.10**	–	–
US	0.036	–0.015	0.033	**–0.110**	–	–
t-value	1.44	–0.458	1.11	**–5.11**	–	–

References

Alexiou, C., and C. Pitelis (2003). “On Capital Shortages and European Unemployment: A Panel Data Investigation.” *Journal of Post Keynesian Economics* 25, 613–640.

Anderson, S.P., and M.B. Devereux (1991). “The Trade-Off Between Precommitment and Flexibility in Trade Union Wage Setting.” *Oxford Economic Papers* 43, 549–569.

Antras, P. (2004). “Is the U.S. Aggregate Production Function Cobb-Douglas: New Estimates of the Elasticity of Substitution.” *Contributions to Macroeconomics* 4, Article 4.

Arestis, P., M. Baddeley, and M. Sawyer (2007). “The Relationship Between Capital Stock, Unemployment and Wages in Nine EMU Countries.” *Bulletin of Economic Research* 59, 125–148.

Arrow, K. J., H.B. Chenery, B.S. Minhas, and R.M. Solow (1961). “Capital-Labor Substitution and Economic Efficiency.” *Review of Economics and Statistics* XLIII, 225–250.

Berthold, N., Fehn, R. and E. Thode (2002). “Falling Labor Share and Rising Unemployment: Long-Run Consequences of Institutional Shocks.” *German Economic Review* 3, 431–459.

Bårdsen, G. (1989). “The Estimation of Long Run Coefficients from Error Correction Models.” *Oxford Bulletin of Economics and Statistics* 51, 345–350.

Bårdsen, G., E.S. Jansen, and R. Nymoen (2003). “Econometric Inflation Targeting.” *Econometrics Journal* 6, 430–460.

Cahuc, P., and A. Zylberberg (2004). *Labor Economics.* MIT Press.

Chirinko, R.S. (2008). “S : The Long and Short of It.” *Journal of Macroeconomics* 30, 671–686.

Chirinko, R.S. (2002). “Corporate Taxation, Capital Formation, and the Substitution Elasticity Between Labor and Capital.” *National Tax Journal* LV, 339–355.

Chirinko, R.S., S.M. Fazzari, and A.P. Meyer (2004). That Elusive Elasticity: A Long-Panel Approach to Estimating the Capital-Labor Substitution Elasticity. CESifo working paper No. 1240.

Chor, D., and R. Freeman (2005). The 2004 Global Labor Survey: Workplace Institutions and Practices Around the World. NBER Working Paper No. 11598.

Driver, C., and J. Munoz-Bugarin (2010). “Capital Investment and Unemployment in Europe: Neutrality or Not?” *Journal of Macroeconomics* 32, 492–496.

Du Caju, P., E. Gautier, Momferatou, and M. Ward-Warmedinger (2008). Institutional Features of Wage Bargaining in 23 European Countries, the US and Japan. IZA DP No. 3867.

Duffy, J., and C. Papageorgiou (2000). “A Cross-Country Empirical Investigation of the Aggregate Production Function Specification.” *Journal of Economic Growth* 5, 87–129.

Duffy,J., C. Papageorgiou, and F. Perez-Sebastian (2004). “Capital-Skill Complementary? Evidence from a Panel of Countries.” *The Review of Economics and Statistics* 86, 327–344.

Goldin, C., and L.F. Katz (1998). “The Origins of Technology-Skill Complementarity.” *Quarterly Journal of Economics* 113, 693–732.

Hall, R.E., and C.I. Jones (1999). “Why Do Some Countries Produce So Much More Output Per Worker Than Others?” *Quarterly Journal of Economics* 114, 83–116.

Juselius, M. (2008). “Long-Run Relationships Between Labor and Capital: Indirect Evidence on the Elasticity of Substitution.” *Journal of Macroeconomics* 30, 739–756.

Karanassou, M., H. Sala, and P.F. Salvador (2008). “Capital Accumulation and Unemployment: New Insights on the Nordic Experience.” *Cambridge Journal of Economics* 32, 977–1001.

Kaas, L., and L. von Thadden (2003). “Unemployment, Factor Substitution and Capital Formation.” *German Economic Review* 4, 475–495.

Kauppi, H., E. Koskela, and R. Stenbacka (2004). Equilibrium Unemployment and Capital Intensity Under Product and Labor Imperfections. HECER Discussion Paper No. 24.

Krusell, P., L.E. Ohanian, J.V. Rios-Rill, and G.L. Violante (2000). “Capital-Skill Complementarity and Inequality: A Macroeconomic Analysis.” *Econometrica*, 68, 1029–1053.

Layard, R., S.J. Nickell, and R. Jackman (1991). *Unemployment: Macroeconomic Performance and Labour Markets.* Oxford University Press.

Lucas, R. (1969). “Labor-Capital Substitution in US Manufacturing.” In *The Taxation of Income from Capital*, 223–274. Eds. A. Harberger and M. Bailey. Washington: The Brookings Institution.

Malley, J., and T. Moutos (2001). “Capital Accumulation and Unemployment: A Tale of Two Countries.” *The Scandinavian Journal of Economics* 103, 79–99.

Marcellino, M., and G. Mizon (2001). “Small-System Modelling of Real Wages, Inflation, Unemployment and Output per Capita in Italy 1970-1994.” *Journal of Applied Econometrics*, 16, 359–370.

Nickell, S. and R. Layard (1999). “Labor Market Institutions and Economic Performance.” In *Handbook of Labor Economics*, Volume 3C, 3029–3084. Eds. O. Ashelfelter and D. Card.

Nickell, S., L. Nunziata, and W. Ochel (2005). “Unemployment in the OECD since the 1960s. What do we Know?” *The Economic Journal* 115, 1–27.

Nymoen, R., and A. Rødseth (2003). “Explaining Unemployment: Some Lessons from Nordic Wage Formation.” *Labour Economics* 10, 1–29.

Riley, R., and G. Young (2007). “Skill Heterogeneity and Equilibrium Unemployment.” *Oxford Economic Papers* 59, 702–725.

Rowthorn, R. (1995). “Capital Formation and Unemployment.” *Oxford Review of Economic Policy* 11, 26–39.

Rowthorn, R. (1999). “Unemployment, Wage Bargaining and Capital-Labour Substitution.” *Cambridge Journal of Economics* 23, 413–425.

Stockhammer, E., and E. Klär (2011). “Capital Accumulation, Labour Market Institutions and Unemployment in the Medium Run.” *Cambridge Journal of Economics* 35, 437–457.