International Labour Union Policy and Growth with Creative Destruction

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Abstract

A multi-economy Schumpeterian growth model is constructed. Regions are interdependent through technology transfer. Households can stay as workers or become researchers at some cost. Workers are employed in production and researchers in *R&D*. Workers are unionized and union power depends on the government's protection. The main findings are as follows. If international technological dependence increases, then the workers' wages, the growth rate and the level of welfare fall. The international coordination of labour market policy raises the workers' wages and promotes growth and welfare.

Journal of Economic Literature: $O40$, $J50$, $F02$

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1 Introduction

This paper examines the role of labour unions in a number of economies which benefit from each other's technological knowledge. The basic questions are as follows. To what extent should a single economy support or suppress its labour unions? Should labour market policy be internationally coordinated or should the economies compete with each other by such policy?

Labour unions and employer federations have two roles which are often mixed in economic debates: (*i*) they bargain over wages and (*ii*) lobby the government for a number of issues (e.g. pension schemes, hiring and firing costs, restrictions on hours of work). To avoid confusion in this matter, this study concentrates wholly on role (*i*) and assumes that labour unions and employer federations try to increase their income through wage settlement. Political lobbying is ignored here and the author considers it elsewhere.[1]

The microfoundations of labour market policy are as follows. When the labour union and the employer federation alternate in making offers to each other, they behave so as to maximize a weighed geometric average of their utilities.[2] The weights of such an average, which reflect the relative bargaining power of the parties, depend on government regulations (e.g. restrictions in starting a dispute, the intermediation of disputes). On the other hand, the employer's reference income in wage bargaining hinges on how many of the workers will participate in a strike.[3] The number of non-striking workers, too, depends on government regulations.

Grossman and Helpman (1991) (in ch. 4), Aghion and Howitt (1998), and Wälde (1999) examine economic growth from the viewpoint of creative destruction in which firms can step forward in the quality ladders of technology by *R&D*. We take a similar 'Schumpeterian' approach, but instead of a competitive labour market we assume wage bargaining. The parties in bargaining observe the effect of wages on both employment and investment.

Expensive labour may give rise to a higher growth rate. Cahuc and Michel (1996) (using an *OLG* model) and Agell and Lommerud (1997) (using an

[1]Using a common agency framework, Palokangas (2003) considers unions and employers as lobbies trying to influence the self-interested government.

[2]Cf. Binmore, Rubinstein and Wolinsky (1986) or Palokangas (2000), Chapter 1.

[3]In the limit case where all workers will take part in a strike, the results are the same as in the case of a monopoly union whose relative bargaining power is unity.

extensive game model) show that a minimum wage may create an incentive for workers to accumulate human capital. Palokangas (1996, 2000) introduces wage bargaining into Romer's (1990) product-variety model with skilled and unskilled workers. He obtains that higher union bargaining power raises wages for unskilled workers, decreases production, lowers wages for skilled workers, decreases $R\&D$ costs and boosts economic growth. All these models, however, ignore the uncertainty that is embodied in technological change. To eliminate this shortcoming, we use here a model of creative destruction.

Because it is difficult to measure union power, there is still very little empirical evidence on the effects of union power on $R\&D$ and economic growth.[4] Some papers explain $R\&D$ by the unionization rate, i.e. the ratio of unionized to all workers,[5] but this is a different issue.[6]

This paper is organized as follows. Section 2 explains the institutional background of the model. Final-good, intermediate-good and research firms are modelled in section 3 and households in section 4. Section 5 examines wage bargaining. Finally, section 6 considers governments in two cases: either they play Nash or cooperate in labour market policy.

2 The setting

There is a fixed number J of economies that are interdependent through technology transfer. Each economy j contains a fixed number of similar

[4]Beitnes and Søraas (2003) present some indirect support to a positive dependence of $R\&D$ on union power. They show that the end of deunionization in South Korea in 1987 increased sharply real wages, $R\&D$ and the accumulation of total factor productivity.

[5]Addison and Wagner (1994) find a positive cross-sectional correlation, but Menezes-Filho et.al. (1998) find little correlation in a panel of firms, between $R\&D$ and the unionization rate in the UK. On the other hand, Connolly et.al. (1986), Hirsch (1990), (1992), Bronars et.al. (1994) find a negative cross-sectional correlation between these in the USA, and Betts et.al. (2001) in Canada. Hence, the results are highly institution-specific.

[6]The unionization rate is not a proper proxy for union power in wage bargaining. In many European countries it tells nothing about union power, because the contract made by the representative union is extended to cover all employers and employees in the industry. In some other countries (e.g. USA, Canada), unions can make agreements only for their members and a unionized worker can be easily replaced by a non-unionized worker. This imposes an additional constraint for the union in wage bargaining, but does not necessarily affect the relative bargaining power of the parties.

households.[7] All households are modelled as dynastic families which are risk averters and share identical preferences. The members of such a family can be either *workers*, who are employed in production, or *researchers*, who are employed in *R&D*. Family-optimization considerations determine the evolution of consumption expenditure over time, the allocation of savings across shares in different firms, and the decision whether a family member becomes a researcher or enters the labour force as a worker. A single family takes prices, wages, profits, employment and aggregate labour supply as given.

Research firms can adopt ideas from other firms everywhere in the world. A single firm's technology is a random variable but the probability of its improvement in one unit of time is an increasing function of both its and the other firms' *R&D*. To focus on this technological transfer as the main connection between economies, we assume that there is no international trade in goods or factors and each intermediate product is specific to the economy in which it is used and produced.[8] In such a case, the price levels of the economies are independent and we can choose a separate numeraire for each economy. Technological change in each economy is characterized by a separate stochastic process and the growth rates can differ across the economies.

The structure of single economy j can be characterized as follows:

(i) Competitive firms produce the final good from the intermediate good according to decreasing returns to scale.

(ii) One monopolist at a time produces the intermediate good by workers. Several firms do *R&D* by using researchers and finance their expenditure by issuing shares. As soon as any of these completes a new innovation, it takes over the whole production of the intermediate good and drives the old producer out of the market. Innovations are *non-drastic*, i.e. the previous incumbent could make a positive profit if the current one charged the monopoly price.[9] Hence, the current incumbent sets the maximum price that gives the previous one non-positive profits.

[7] The purpose of this admittedly strong assumption is to allow us to make welfare comparisons, which would be extremely problematic with heterogeneous households.

[8] Howitt (2000) makes the same assumption for the same reason.

[9] If innovations were *drastic*, the intermediate-good producer would not be constrained by potential competition from other producers. This would complicate the analysis.

(iii) The households decide on their labour supply before entering the labour market. They save in shares in research firms of their own economies.

(iv) The workers are unionized. The labour union can control the whole of the intermediate good industry, including potential entrants, so that the change of the incumbent producer does not affect the union's bargaining position. There is, however, a fixed number β_j of (employed or unemployed) workers who shall not or cannot take part in strikes. In wage bargaining, the labour union maximizes the discounted value of the flow of the workers' wages and the employer federation the discounted value of the flow of the employers' profits.[10] Government regulations influence both the relative bargaining power of the parties (which we denote α_j) and the number β_j of non-striking workers.

(v) Direct subsidy to $R\&D$ is commonly non-feasible.[11] Given this, the government regulates union power as a second-best policy.

The growth model is based on a Poisson process. We focus entirely on the households' stationary equilibrium in which the allocation of resources is invariable across technologies, and ignore the behaviour of the system during the transitional period before the equilibrium is reached. If the initial state is chosen outside a stationary equilibrium, then the model would most likely generate cycles, which are technically extremely difficult to cope with.

[10] Some papers assume that the expected wage outside the firm is the union's reference point, but this is not quite in line with the microfoundations of the alternating offers game. Binmore, Rubinstein and Wolinsky (1986) state (pp. 177, 185-6) that the the reference income should not be identified with the outside option point. Rather, despite the availability of these options, it remains appropriate to identify the reference income with the income streams accruing to the parties in the course of the dispute. For example, if the dispute involves a strike, these income streams are the employee's income from temporary work, union strike funds, and similar sources, while the employer's income might derive from temporary arrangements that keeps the business running.

[11] It is commonly suggested that in order to eliminate the externality due to $R\&D$, the government should directly subsidize $R\&D$. In reality, however, $R\&D$ is mostly carried out by research departments of companies that are also producing other goods, so that the government cannot completely distinguish between inputs being used in $R\&D$ and production. If $R\&D$ were subsidized, then it were in the interests of both employers and labour unions to hide costs of production under $R\&D$ expenditure and share the subsidy. For this discussion, see Palokangas (2000), chapter 8.

3 Firms

(a) Producers in the high-tech sector. The representative final-good firm in economy j makes output y_j from intermediate input n_j through technology

$$y_j = B_j f(n_j), \quad f' > 0, \quad f'' < 0, \tag{1}$$

where B_j is the productivity parameter. It maximizes profit $\Pi_j \doteq P_j y_j - p_j n_j$ by intermediate input n_j, taking the input price p_j and the output price P_j as fixed. This implies the equilibrium price and the equilibrium profit as

$$p_j = P_j B_j f'(n_j), \quad \Pi_j = P_j B_j [f(n_j) - n_j f'(n_j)]. \tag{2}$$

One unit of intermediate good is produced from one unit of workers' labour, but each new generation of the good provides constant $\epsilon > 1$ times as many services as the product of the generation before it. There is one firm at a time as the incumbent producer, who maximizes its profit

$$\pi_j \doteq p_j n_j - w_j n_j \tag{3}$$

by its input n_j, given the demand function p_j in (2). Without potential competition from other firms, the first-order condition $\partial \pi_j / \partial n_j = 0$ yields the monopoly price $p_j^m = w_j / [1 + n_j f''(n_j)/f'(n_j)]$. The previous incumbent, whose productivity is $1/\epsilon$ times the productivity of the current incumbent, makes a positive profit $\pi_j = (1/\epsilon) p_j n_j - w_j n_j > 0$ for prices $p_j > \epsilon w_j$. To make innovations non-drastic, $p_j^m > \epsilon w_j$, we assume

$$n_j f''(n_j)/f'(n_j) < 1/\epsilon - 1.$$

The producer then sets $p_j = \epsilon w_j$ to prevent the others from entering the market. We normalize the value of the high-tech good, $P_j y_j$, at unity for all economies j. Given this, $\epsilon > 1$, $p_j = \epsilon w_j$, (1), (2) and (3), we obtain

$$\begin{gathered} P_j y_j = 1, \quad P_j B_j = \frac{1}{f(n_j)}, \quad w_j = \frac{p_j}{\epsilon} = \frac{f'(n_j)}{\epsilon f(n_j)}, \quad \Pi_j = 1 - n_j \frac{f'(n_j)}{f(n_j)}, \\ w_j n_j = x(n_j) \doteq \frac{n_j f'(n_j)}{\epsilon f(n_j)}, \quad \pi_j = (\epsilon - 1) x(n_j), \quad w_j n_j + \pi_j + \Pi_j = 1. \end{gathered} \tag{4}$$

(b) Research firms. Because only researchers are used in *R&D*, investment expenditure in economy j is equal to labour cost $v_j l_j$, where l_j is the researchers' labour input and v_j their wage. When a research firm in economy

j is successful, it uses its new technology to drive the old producer out and starts producing good j itself. Its profits are then distributed among those who had financed it. When $R\&D$ is not successful for a firm, there is no profit and the *ex post* value of a share of the firm is zero.

Region j is subject to technological change which is characterized by a Poisson process q_j as follows. During a short time interval $d\theta$, there is an innovation $dq_j = 1$ with probability $\Lambda_j d\theta$, and no innovation $dq_j = 0$ with probability $1 - \Lambda_j d\theta$, where Λ_j is the arrival rate of innovations in the research process. We assume that the arrival rate Λ_j depends on research input both in the economy j, l_j, and elsewhere, l_{-j} as follows:

$$\Lambda_j = \lambda z_j(l_j, l_{-j}, \mu) \text{ with } z_j(l_j, l_{-j}, \mu) \doteq l_j^{1-\mu} l_{-j}^{\mu}, \quad l_{-j} \doteq \frac{1}{J-1} \sum_{k \neq j} l_k,$$
$$0 < \mu < 1, \quad \partial z_j / \partial \mu = 0 \text{ and } \partial^2 z_j / (\partial l_j \partial \mu) = -1 < 0 \text{ for } l_j = l_{-j}, \quad (5)$$

where λ and μ are positive constants. The higher parameter μ is, the more the economies are technologically dependent on each other.

We denote the serial number of technology in economy j by t_j. Because the invention of a new technology raises t_j by one and the level of productivity by $\epsilon > 1$, the level of productivity corresponding to technology t_j is given by

$$B_j^{t_j} = B_j^0 \epsilon^{t_j}. \quad (6)$$

The average growth rate of the level of productivity B_j in the stationary state is in fixed proportion $\lambda \log \epsilon$ to z_j.[12] Hence, research inputs $z_j \doteq l_j^{1-\mu} l_{-j}^{\mu}$ can be used as proxies of the growth rates in economies $j \in \{1, ..., J\}$.

4 Households

Households (a) decide their occupation as workers or reseachers on the basis of prospective income, and (b) determine the flow of consumption and savings given the flow of income. These choices are determined as follows.

(a) Labour supply. Because each family can change its members' occupation from a worker to an researcher at some cost and the abilities of all individuals

[12] For this, see Aghion and Howitt (1998), p. 59.

in economy j differ, there is a decreasing and convex transformation function between the supply of workers, N_j, and the supply of researchers, L_j, as:

$$N_j = N(L_j), \quad N' < 0, \quad N'' < 0. \tag{7}$$

More and more workers must be transformed in order to create one more research input. A worker's expected wage is equal to the wage w_j times the likelihood of employment, n_j/N_j:

$$w_j^e \doteq (n_j/N_j)w_j, \tag{8}$$

Because researchers are not unionized, they are always fully employed $l_j = L_j$ and their expected wage is equal to the wage v_j.

Because households must choose their combination (L_j, N_j) of labour supply before entering the labour market, this choice is based on the transformation function (7) and the expected wages (v_j, w_j^e) which the household takes as given. This equilibrium is found by maximizing expected income $v_jL_j + w_j^eN_j = v_jL_j + w_j^eN(L_j)$ by L_j, which yields the first order condition $v_j/w_j^e = -N'(L_j)$. This condition, $l_j = L_j$, (7) and (8) yield

$$-\frac{N'(l_j)}{N(l_j)} = -\frac{N'(L_j)}{N(L_j)} = \frac{v_j}{w_j^eN_j} = \frac{v_j}{w_jn_j}. \tag{9}$$

(b) Saving. Region j contains a fixed number κ_j of similar households which consist of both workers and researchers.[13] The utility for household $\ell \in \{1, ..., \kappa_j\}$ in economy j from an infinite stream of consumption beginning at time τ takes the form

$$U_j(C_{j\ell}, \tau) = E\int_\tau^\infty C_{j\ell}^\sigma e^{-\rho(\theta-\tau)}d\theta \text{ with } 0 < \sigma < 1 \text{ and } \rho > 0, \tag{10}$$

where θ is time, E the expectation operator, $C_{j\ell}$ consumption, ρ the rate of time preference and $1/(1-\sigma)$ is the constant rate of relative risk aversion.

When household ℓ has financed a successful *R&D* project, it acquires the right to a certain share of profits the successful firm earns in the production of final goods. Since the old producer is driven out of the market, all shares held in it lose their value. Let $s_{j\ell}$ be the true profit share of household ℓ when the uncertainty of the outcome of the projects are taken into account.

[13]See footnote 7.

Following Wälde (1999), we assume that the change in this share, $ds_{j\ell}$, is a function of the increment dq_j of a Poisson process q_j as follows:

$$ds_{j\ell} = (i_{j\ell} - s_{j\ell})dq_j \text{ with } i_{j\ell} \doteq S_{j\ell}/(v_j l_j), \tag{11}$$

where $S_{j\ell}$ is saving by household ℓ in economy j. When a household does not invest in the upcoming vintage, its share holdings are reduced to zero in the case of research success $dq_j = 1$. If it invests, then the amount of share holdings depends on its relative investment in the vintage.

Labour income in economy j, I_j, is equal to wages paid in production, $w_j n_j$, and in *R&D*, $v_j l_j$,

$$I_j \doteq v_j l_j + w_j n_j. \tag{12}$$

The total income of household $\ell \in \{1, ..., \kappa_j\}$ in economy j, $A_{j\ell}$, consists of an equal share $1/\kappa_j$ of labour income I_j and the profit of the final-good firm, Π_j, and the share $s_{j\ell}$ of the total profits of the intermediate-good firm, π_j,

$$A_{j\ell} \doteq (I_j + \Pi_j)/\kappa_j + s_j\pi_j = [v_j l_j + w_j n_j + \Pi_j]/\kappa_j + s_{j\ell}\pi_j. \tag{13}$$

The budget constraint of household ℓ in economy j is given by

$$A_{j\ell} = P_j C_{j\ell} + S_{j\ell}, \tag{14}$$

where $C_{j\ell}$ is consumption, $S_{j\ell}$ saving and P_j the consumption price.

(c) Optimization. We denote the value of receiving a share $s_{j\ell}$ of the profits of the monopolists using current technology t_j by $\Omega(s_{j\ell}, t_j)$, and the value of receiving a share $i_{j\ell}$ of the profits of the monopolists of the next generation by $\Omega(i_{j\ell}, t_j + 1)$. Household ℓ maximizes its utility (10) subject to stochastic process (11) and the budget constraint (14) by its saving $S_{j\ell}$, given labour income I_j, profits Π_j and π_j, total investment expenditure $v_j l_j$ and aggregate research input z_j. This maximization leads to the Bellman equation[14]

$$\rho\Omega(s_{j\ell}, t_j) = \max_{S_{j\ell}} \Big\{ C_{j\ell}^{\sigma} + \Lambda_j[\Omega(i_{j\ell}, t_j + 1) - \Omega(s_{j\ell}, t_j)] \Big\}, \tag{15}$$

where $C_{j\ell} = (A_{j\ell} - S_{j\ell})/P_j$ and $\Lambda_j = \lambda z_j$. The first order condition associated with the Bellman equation (15) is given by

$$\lambda z_j \frac{d}{dS_{j\ell}}[\Omega(i_{j\ell}, t_j + 1) - \Omega(s_{j\ell}, t_j)] = \sigma C_{j\ell}^{\sigma-1}/P_j. \tag{16}$$

[14]Cf. Dixit and Pindyck (1994).

We try the solution that consumption expenditure $P_j C_{j\ell}$ is a share $0 \leq 1/h_{j\ell} \leq 1$ out of income $A_{j\ell}$, and the value function is of the form $\Omega = (A_{j\ell}/h_{j\ell})^\sigma / r_{j\ell}$, where the income-consumption ratio $h_{j\ell}$ and the (subjective) interest rate $r_{j\ell}$ are independent of income $A_{j\ell}$. Inserting that solution into (15) and (16), we obtain the following results for economy j (Appendix A). First, every innovation that replaces technology t_j by $t_j + 1$ raises consumption y_j and decreases the consumption price P_j in economy j as follows:

$$P_j^{t_j} / P_j^{t_j+1} = y_j^{t_j+1} / y_j^{t_j} = \epsilon > 1. \tag{17}$$

Second, the interest rate r_j and $R\&D$ costs in economy j, $v_j l_j$, are given by[15]

$$r_{j\ell} = r_j \doteq \rho + (1 - \epsilon^\sigma)\lambda z_j, \quad v_j l_j = \zeta_j\big(x(n_j), z_j\big), \ \frac{\partial}{\partial x}\Big(\frac{\zeta_j}{x}\Big) < 0, \ \frac{\partial \zeta_j}{\partial z_j} > 0. \tag{18}$$

5 Employment and wage bargaining

From (4), (9) and (18) it follows that

$$-l_j \frac{N'(l_j)}{N(l_j)} = \frac{v_j l_j}{w_j n_j} = \frac{\zeta_j\big(x(n_j), z_j\big)}{x(n_j)}. \tag{19}$$

Given (7) and (18), this equation defines the function

$$n_j(l_j, z_j), \quad \partial n_j / \partial l_j < 0 \ \Leftrightarrow \ \partial n_j / \partial z_j > 0 \ \Leftrightarrow \ x' > 0. \tag{20}$$

In each economy j, the workers' wage w_j is determined by bargaining between a union representing workers in economy j and a federation representing employers of these workers. We assume, for simplicity, that these both are risk neutral and have the same rate of time preference $\varrho > 0$. The union controls the whole of the intermediate-good industry inclusive of the possible entrants, but there is a fixed number β_j of workers who cannot go on strike or who are willing to work even during strikes. This means that the reference income is zero for the union and $\pi_j|_{n_j=\beta_j}$ for the federation.[16] The union attempts then to maximize the expected value $\mathcal{U}_j$ of the stream of

[15]Note that this definition of the interest rate r_j contains also the expected growth of consumption through technological change (6).

[16]See footnote 10.

workers' real wages $w_j n_j / P_j$, while the federation attempts to maximize the expected value $\mathcal{F}_j$ of the stream of employers' real profits over the reference income, $[\pi_j - \pi_j|_{n_j=\beta_j}]/P_j$.[17] Given the result (17) and the stochastic technological progress (see part (*b*) in section 3), these targets take the form:[18]

$$\mathcal{U}_j(l_j, l_{-j}, \mu) \doteq E \int_0^\infty e^{-\varrho\theta} \frac{w_j n_j}{P_j} d\theta = \frac{w_j n_j}{P_j^0[\varrho + (1-\epsilon)\lambda z_j]},$$
$$\mathcal{F}_j(l_j, l_{-j}, \mu) \doteq E \int_0^\infty e^{-\varrho\theta} \frac{\pi_j - \pi_j|_{n_j=\beta_j}}{P_j} d\theta = \frac{\pi_j - \pi_j|_{n_j=\beta_j}}{P_j^0[\varrho + (1-\epsilon)\lambda z_j]}. \tag{21}$$

The union (federation) maximizes its welfare $\mathcal{U}_j$ ($\mathcal{F}_j$) by workers' wage w_j, taking the supply of research work elsewhere, l_{-j}, as given. Because there is one-to-one correspondence from w_j to l_j through (20), w_j can be replaced by l_j as the instrument of bargaining. The outcome of bargaining is then obtained through maximizing the Generalized Nash Product $\mathcal{U}_j^{\alpha_j}\mathcal{F}_j^{1-\alpha_j}$, where constant $\alpha_j \in [0,1]$ is relative union bargaining power (hereafter shortly 'union power'), by l_j, taking l_{-j} as given. This yields (Appendix *B*):

$$\begin{aligned} &l_j(l_{-j}, \alpha_j, \beta_j, \mu), \quad \partial l_j/\partial\alpha_j > 0, \quad \partial l_j/\partial\beta_j < 0 \;\Leftrightarrow\; x'(\beta_j) > 0, \\ &[\partial l_j/\partial\mu]_{l_j=l_{-j}} < 0, \quad x'[dn_j/dl_j] < 0, \quad \lim_{\alpha_j\to 1} l_j = \lim_{\beta_j\to 0} l_j. \end{aligned} \tag{22}$$

Results (22) can then be rephrased as:

Proposition 1 *Given the research work elsewhere, l_{-j}, lower union power (i.e. a smaller α_j) or higher technological dependence on other economies (i.e. a higher μ) slows down R&D and growth in economy j.*

With higher union power, workers' wage w_j increases, but their employment l_j and expected wage w_j^e falls. With a lower relative expected wage for a worker, more households choose to become researchers rather than workers. A higher number of researchers promotes *R&D* and economic growth. When technological change in an economy depends more on foreign *R&D* and less on domestic *R&D* (i.e. if μ increases), an equal decrease in workers' expected wage yields a smaller increase in the growth rate. Because the union has then less incentives to decrease workers' current income and to boost growth through higher wage claims, the equilibrium growth rate must be lower.

[17] Because workers and shareholders spend their income in consumption, their nominal income must be divided by the consumption price P_j.

[18] For this, see e.g. Aghion and Howitt (1998), p. 61.

6 The governments

The symmetry across the households in economy j yields $C_{j\ell} = y_j/\kappa_j$. Given (1), (6), (7), (17), (20) and (22), we can define

$$\begin{aligned}
&C_{j\ell} = y_j/\kappa_j = f(n_j)B_j/\kappa_j = B_j^0 f\big(n_j(l_j, z_j)\big)\epsilon^{t_j}/\kappa_j \doteq c(l_j, z_j)\epsilon^{t_j},\\
&\partial c/\partial l_j < 0 \;\;\Leftrightarrow\;\; \partial c/\partial z_j > 0 \;\;\Leftrightarrow\;\; x' > 0, \quad (dc/dl_j)x' < 0.
\end{aligned} \tag{23}$$

The utility function (10) takes then the form

$$U_j = E\int_\tau^\infty c(l_j, z_j)^\sigma \epsilon^{\sigma t} e^{-\rho(\theta-\tau)} d\theta. \tag{24}$$

The government in economy j maximizes social welfare (24) by union power α_j, given the number of researchers elsewhere, l_{-j}.[19] Because l_j depends positively on α_j (see (22)), union power α_j can be replaced by the number of researchers, l_j, as the instrument of maximization. Denoting the value of the state of technology t_j for this government by $\Upsilon_j(t_j)$, and noting (5) and (22), we obtain the Bellman equation for this policy as follows:

$$\begin{aligned}
&\rho\Upsilon_j(t_j) = \max_{l_j} \mathcal{B}_j, \quad \text{where}\\
&\mathcal{B}_j \doteq c\big(l_j, z_j(l_j, l_{-j}, \mu)\big)^\sigma \epsilon^{\sigma t} + \lambda z_j(l_j, l_{-j}, \mu)[\Upsilon_j(t_j+1) - \Upsilon_j(t_j)].
\end{aligned} \tag{25}$$

Noting (5), we obtain the first-order condition corresponding to (25) as:

$$\frac{\partial \mathcal{B}_j}{\partial l_j} = \sigma c^{\sigma-1}\epsilon^{\sigma t}\Big[\frac{\partial c}{\partial l_j} + \frac{\partial c}{\partial z_j}\frac{\partial z_j}{\partial l_j}\Big] + \lambda[\Upsilon_j(t_j+1) - \Upsilon_j(t_j)]\frac{\partial z_j}{\partial l_j} = 0. \tag{26}$$

We try the solution that the value function is of the form $\Upsilon_j(t_j) = \vartheta c^\sigma \epsilon^{\sigma t}$, where ϑ is independent of the endogenous variables of the system. This solution yields the following proposition (Appendix C):

Proposition 2 *If the local governments are rational and can influence union power (through either α_j or β_j), then technological dependence on other economies (i.e. a higher μ) decreases workers' wage w_j, the growth rate $l_j = l(\mu)$ and the level of welfare, $B_j = B$, in all economies j, $dw_j/d\mu < 0$, $dl/d\mu < 0$ and $dB/d\mu < 0$.*

[19] The 'more symmetric' assumption that the government takes union power elsewhere, α_k for $k \neq j$, as given, leads to a more complicated model. It is also more natural to think that the government takes the observable variable l_{-j} rather than unobservable variables α_k for $k \neq j$ as given.

When labour market policy is coordinated across economies $1, ..., J$, the governments behave as if there were only one government in the world and $\mu \to 0$ holds. According to proposition 2, coordination $\mu \to 0$ increases union power. Hence, the following corollary is established:

Proposition 3 *The coordination of labour market policy, $\mu \to 0$, increases workers' wages, the growth rate and the level of welfare.*

Propositions 2 and 3 are explained in the final section.

7 Conclusions

This paper examines a world with the following properties. First, growth is generated by creative destruction. A firm creating the latest technology through a successful $R\&D$ project crowds the other firms with older technologies out of the market so that they lose their value. Second, there is a world-wide externality in technological knowledge. Third, the households save by buying shares in $R\&D$ projects. Fourth, the households decide whether their members are researchers who are used in $R\&D$ or workers who are employed in production. A change of occupation involves a cost. Fifth, direct subsidy to $R\&D$ is commonly non-feasible. Sixth, wages are determined by bargaining. The main findings are as follows.

Union power has a positive impact on economic growth, but not necessarily on welfare. With higher union power, workers' wages increase, but their employment and expected wage falls, and more households choose to become researchers rather than workers. With a larger number of researchers, there will be more innovations and a higher growth rate. When technological change in an economy depends more on technology spillovers from abroad and less on domestic $R\&D$, an equal decrease in workers' expected wage yields a smaller increase in the growth rate. In such a case, labour unions have less incentives to decrease workers' current income and to boost growth through higher wage claims, so that the equilibrium growth rate is lower.

If governments can influence union power, international technological dependence tend to slow down economic growth. There is a trade-off between high current consumption and a high growth rate. If technological change depends less on domestic and more on foreign $R\&D$, then an equal decrease in consumption produces a smaller increase in the growth rate. This makes a rational government to transfer resources from $R\&D$ to consumption through a decrease in union power and the growth rate falls. Once the externality due to technological dependence is internalized by uniform labour market policy, welfare and the growth rate increase.

While a great deal of caution should be exercised when a highly stylized dynamic model is used to explain the relationship of growth, wage bargaining and public policy, the following judgement nevertheless seems to be justified. It is known that globalization increases international technological dependence. Without international cooperation, this change will decrease workers' wages, the growth rate and the level of welfare. Either labour unions reduce their wage claims or governments weaken labour unions in their jurisdiction.

Appendix A

Let us denote variables depending on technology t_j by superscript t_j. Since according to (13) income $A_{j\ell}^{t_j}$ depends directly on the share $s_{j\ell}^{t_j}$, we denote $A_{j\ell}^{t_j}(s_{j\ell}^{t_j})$. Guessing that $h_{j\ell}$ is invariant across technologies, we obtain

$$P_j^{t_j} C_{j\ell}^{t_j} = A_{j\ell}^{t_j}(s_{j\ell}^{t_j})/h_{j\ell}, \quad S_{j\ell}^{t_j} = (1 - 1/h_{j\ell}) A_{j\ell}^{t_j}(s_{j\ell}^{t_j}). \tag{27}$$

The share in the next producer $t_j + 1$ is determined by investment under technology t_j, $s_{j\ell}^{t_j+1} = i_{j\ell}^{t_j}$. The value functions are then given by

$$\Omega(s_{j\ell}^{t_j}, t_j) = (C_{j\ell}^{t_j})^\sigma / r_{j\ell}, \quad \Omega(i_{j\ell}^{t_j}, t_j + 1) = (C_{j\ell}^{t_j+1})^\sigma / r_{j\ell}. \tag{28}$$

Given this, we obtain

$$\partial\Omega(s_{j\ell}^{t_j}, t_j)/\partial S_{j\ell}^{t_j} = 0. \tag{29}$$

From (11), (13), (27) and (28) it follows that

$$\begin{aligned} &\frac{\partial i_{j\ell}^{t_j}}{\partial S_{j\ell}^{t_j}} = \frac{1}{v_j^{t_j} l_j^{t_j}}, \quad \frac{\partial [A_{j\ell}^{t_j+1}(i_{j\ell}^{t_j})]}{\partial i_{j\ell}^{t_j}} = \frac{\partial [A_{j\ell}^{t_j+1}(s_{j\ell}^{t_j+1})]}{\partial s_{j\ell}^{t_j+1}} = \pi_j^{t_j+1}, \\ &\frac{\partial\Omega(i_{j\ell}^{t_j}, t_j + 1)}{\partial S_{j\ell}^{t_j}} = \frac{\sigma}{r_{j\ell}} (C_{j\ell}^{t_j+1})^{\sigma-1} \frac{\partial C_{j\ell}^{t_j+1}}{\partial A_{j\ell}^{t_j+1}} \frac{\partial A_{j\ell}^{t_j+1}}{\partial i_{j\ell}^{t_j}} \frac{\partial i_{j\ell}^{t_j}}{\partial S_{j\ell}^{t_j}} = \sigma \frac{(C_{j\ell}^{t_j+1})^{\sigma-1} \pi_j^{t_j+1}}{r_{j\ell} h_{j\ell} P_j^{t_j+1} v_j^{t_j} l_j^{t_j}}. \end{aligned} \tag{30}$$

We focus on a stationary equilibrium where the allocation of labour, $(l_j^{t_j}, m_j^{t_j}, n_j^{t_j}, n_j^{t_j})$ and a household's expenditure share, $C_{j\ell}^{t_j}/y_j^{t_j}$, are invariant across technologies. Given (4), (5), (7), (9), (13) and (27), this implies

$$\begin{aligned}
&l_j^{t_j} = l_j,\ \ n_j^{t_j} = n_j,\ \ z_j^{t_j} = z_j,\ \ w_j^{t_j} = w_j,\ \ N_j = N(L_j) = N(l_j),\ \ \pi_j^{t_j} = \pi_j,\\
&\Pi_j^{t_j} = \Pi_j,\ \ P_j^{t_j} y_j^{t_j} = 1,\ \ v_j^{t_j} = v_j,\ \ A_{j\ell}^{t_j} = A_{j\ell},\ \ S_{j\ell}^{t_j} = S_{j\ell}. \qquad (31)
\end{aligned}$$

From (1), (6) and (31) it then follows that

$$P_j^{t_j}/P_j^{t_j+1} = y_j^{t_j+1}/y_j^{t_j} = C_{j\ell}^{t_j+1}/C_{j\ell}^{t_j} = B_j^{t_j+1}/B_j^{t_j} = \epsilon > 1. \qquad (32)$$

Inserting (27), (28) and (32) into equation (15), we obtain

$$\begin{aligned}
0 &= (\rho + \Lambda_j)\Omega(s_{j\ell}^{t_j}, t_j) - (C_{j\ell}^{t_j})^\sigma - \Lambda_j \Omega(i_{j\ell}^{t_j}, t_j + 1)\\
&= (\rho + \Lambda_j)(C_{j\ell}^{t_j})^\sigma / r_{j\ell} - (C_{j\ell}^{t_j})^\sigma - \Lambda_j (C_{j\ell}^{t_j+1})^\sigma / r_j\\
&= (C_{j\ell}^{t_j})^\sigma [\rho + \Lambda_j - r_{j\ell} - \epsilon^\sigma \Lambda_j]/r_{j\ell} = (C_{j\ell}^{t_j})^\sigma [\rho - r_{j\ell} + (1 - \epsilon^\sigma)\lambda z_j]/r_{j\ell}.
\end{aligned}$$

This leads to the function

$$r_j = r_{j\ell} = \rho + (1 - \epsilon^\sigma)\lambda z_j. \qquad (33)$$

Inserting (4), (5) and (29)-(33) into (16) yields

$$\begin{aligned}
0 &= \Lambda_j \frac{\partial \Omega(i_{j\ell}^{t_j}, t_j + 1)}{\partial S_{j\ell}^{t_j}} - \sigma \frac{(C_{j\ell}^{t_j})^{\sigma-1}}{P_j^{t_j}} = \lambda z_j \sigma \frac{(C_{j\ell}^{t_j+1})^{\sigma-1} \pi_j}{r_j h_{j\ell} P_j^{t_j+1} v_j l_j} - \sigma \frac{(C_{j\ell}^{t_j})^{\sigma-1}}{P_j^{t_j}}\\
&= \sigma \frac{(C_{j\ell}^{t_j})^{\sigma-1}}{h_{j\ell} P_j^{t_j}} \left[\lambda z_j \frac{\epsilon^\sigma \pi_j}{r_j v_j l_j} - h_{j\ell} \right]
\end{aligned}$$

and

$$h_{j\ell} = h_j \doteq \lambda z_j \frac{\epsilon^\sigma \pi_j}{r_j v_j l_j} = \frac{(\epsilon - 1)\lambda \epsilon^\sigma x(n_j) z_j}{v_j l_j [\rho + (1 - \epsilon^\sigma)\lambda z_j]}. \qquad (34)$$

Given $\sum_{\ell=1}^{\kappa_j} i_{j\ell}^{t_j} = 1$, (4), (11), (13), (27) and (34), we obtain $v_j l_j = \sum_{\ell=1}^{\kappa_j} S_{j\ell}$,

$$\begin{aligned}
\frac{h_j v_j l_j}{h_j - 1} &= \frac{h_j}{h_j - 1} \sum_{\ell=1}^{\kappa_j} S_{j\ell} = \sum_{\ell=1}^{\kappa_j} \frac{h_{j\ell}}{h_{j\ell} - 1} S_{j\ell} = \sum_{\ell=1}^{\kappa_j} A_{j\ell} = v_j l_j + w_j n_j + \Pi_j + \pi_j\\
&= v_j l_j + w_j n_j + \Pi_j + \pi_j = v_j l_j + 1
\end{aligned}$$

and

$$v_j l_j = h_j - 1. \tag{35}$$

Noting (33), (34) and (35), we obtain

$$(h_j - 1)h_j = v_j l_j h_j = \frac{(\epsilon - 1)\lambda\epsilon^\sigma x(n_j) z_j}{\rho + (1 - \epsilon^\sigma)\lambda z_j} = \frac{(\epsilon - 1)\lambda\epsilon^\sigma x(n_j)}{\rho/z_j + (1 - \epsilon^\sigma)\lambda},$$

which defines the function

$$h_j\big(x(n_j), z_j\big), \quad \frac{\partial h_j}{\partial x} = \frac{1}{x(n_j)}\Big(\frac{1}{h_j - 1} + \frac{1}{h_j}\Big)^{-1}, \quad \frac{\partial h_j}{\partial z_j} > 0.$$

Inserting this into (35) produces $v_j l_j = \zeta_j\big(x(n_j), z_j\big) \doteq h_j\big(x(n_j), z_j\big) - 1$ with

$$\frac{\partial \zeta_j}{\partial z_j} > 0, \quad \frac{1}{\zeta_j}\frac{\partial \zeta_j}{\partial x} = \frac{1}{(h_j - 1)x}\Big(\frac{1}{h_j - 1} + \frac{1}{h_j}\Big)^{-1} < \frac{1}{x} \text{ and}$$
$$\frac{\partial}{\partial x}\Big(\frac{\zeta_j}{x}\Big) = \frac{1}{x}\frac{\partial \zeta_j}{\partial x} - \frac{\zeta_j}{x^2} = \frac{\zeta_j}{x}\Big(\frac{1}{\zeta_j}\frac{\partial \zeta_j}{\partial x} - \frac{1}{x}\Big) < 0.$$

Appendix B

Given (4), (5), (19), (20) and (21), the logarithm of the Generalized Nash product $\mathcal{U}_j^\alpha \mathcal{F}_j^{1-\alpha}$ takes the form

$$\begin{aligned}
&\Gamma_j(l_j, l_{-j}, \alpha_j, \beta_j, \mu) \doteq \alpha_j \log \mathcal{U}_j + (1 - \alpha_j)\log \mathcal{F}_j \\
&= \alpha_j \log(w_j n_j) + (1 - \alpha_j)\log\big(\pi_j - \pi_j|_{n_j=\beta_j}\big) - \log P_j^0 - \log[\varrho + (1 - \epsilon)\lambda z_j] \\
&= (1 - \alpha_j)\log\big[1 - x(\beta_j)/x(n_j(l_j, z_j))\big] + \log x(n_j(l_j, z_j)) - \log\, P_j^0 \\
&\qquad - \log[\varrho + (1 - \epsilon)\lambda z_j] + (1 - \alpha_j)\log(\epsilon - 1) \\
&\text{with } \; z_j = l_j^{1-\mu} l_{-j}^\mu \; \text{ and } \; \varrho + (1 - \epsilon)\lambda z_j > 0.
\end{aligned} \tag{36}$$

Because a logarithm is an increasing transformation, the outcome of bargaining is obtained through maximizing the function (36) by l_j, taking l_{-j} as given. This leads to the first-order condition

$$\frac{\partial \Gamma_j}{\partial l_j} = \left[\frac{(1 - \alpha_j)x(\beta_j)/x(n_j)}{1 - x(\beta_j)/x(n_j)} + 1\right]\frac{x'(n_j)}{x(n_j)}\frac{dn_j}{dl_j} + \frac{(\epsilon - 1)\lambda}{\varrho + (1 - \epsilon)\lambda z_j}\frac{\partial z_j}{\partial l_j} = 0. \tag{37}$$

Note that if all workers are controlled by the union and can take part in a strike, $\beta_j \to 0$, then $x(\beta_j) \to 0$ by (4), and we obtain the same outcome as in the case of a monopoly union, $\alpha \to 1$.

In equilibrium, there must be $\pi_j > \pi_j|_{n_j=\beta_j}$ and $n_j > \beta_j$. This and (4) yield $x(n_j) > x(\beta_j)$. Noting this, $\epsilon > 1$ and (5), we obtain from (37) that

$$\begin{aligned}
\frac{x'(n_j)}{x(n_j)}\frac{dn_j}{dl_j} &= \left[\frac{(1-\alpha_j)x(\beta_j)/x(n_j)}{1-x(\beta_j)/x(n_j)}+1\right]^{-1}\frac{(1-\epsilon)\lambda}{\varrho+(1-\epsilon)\lambda z_j}\frac{\partial z_j}{\partial l_j} < 0,\\
\frac{\partial^2\Gamma_j}{\partial l_j\partial\alpha_j} &= -\frac{x(\beta_j)/x(n_j)}{1-x(\beta_j)/x(n_j)}\frac{x'(n_j)}{x(n_j)}\frac{dn_j}{dl_j} > 0,\\
\frac{\partial^2\Gamma_j}{\partial l_j\partial\beta_j} &= \frac{(1-\alpha_j)x'(\beta_j)x(n_j)}{[x(n_j)-x(\beta_j)]^2}\frac{x'(n_j)}{x(n_j)}\frac{dn_j}{dl_j} < 0 \;\;\Leftrightarrow\;\; x'(\beta_j) > 0,\\
\left.\frac{\partial^2\Gamma_j}{\partial l_j\partial\mu}\right|_{l_j=l_{-j}} &= \frac{(\epsilon-1)\lambda}{\varrho+(1-\epsilon)\lambda z_j}\left.\frac{\partial^2 z_j}{\partial l_j\partial\mu}\right|_{l_j=l_{-j}} < 0.
\end{aligned}$$

Given this and the second-order condition $\partial^2\Gamma_j/\partial l_j^2 < 0$, the comparative statics of the equation (37) produce the function $l_j(l_{-j},\alpha_j,\mu)$ with

$$\frac{\partial l_j}{\partial\alpha_j} = -\frac{\partial^2\Gamma_j}{\partial l_j^2}\Big/\frac{\partial^2\Gamma_j}{\partial l_j\partial\alpha_j} > 0,\quad \left.\frac{\partial l_j}{\partial\mu}\right|_{l_j=l_{-j}} = -\left[\frac{\partial^2\Gamma_j}{\partial l_j\partial\mu}\Big/\frac{\partial^2\Gamma_j}{\partial l_j^2}\right]_{l_j=l_{-j}} < 0.$$

Appendix C

From $\Upsilon_j(t_j+1) > \Upsilon_j(t_j)$, (4), (5), (22), (23) and (26) it follows that

$$\begin{aligned}
&\frac{dc}{dl_j} = \frac{\partial c}{\partial l_j} + \frac{\partial c}{\partial z_j}\frac{\partial z_j}{\partial l_j} = c^{1-\sigma}\epsilon^{-\sigma t}\frac{\lambda}{\sigma}[\Upsilon_j(t_j)-\Upsilon_j(t_j+1)]\frac{\partial z_j}{\partial l_j} < 0,\quad x' > 0,\\
&\frac{dn_j}{dl_j} < 0,\quad \frac{dw_j}{dl_j} = w_j\Big(\frac{f''}{f'}-\frac{f'}{f}\Big)\frac{dn_j}{dl_j} > 0,\quad \frac{\partial c}{\partial l_j} < 0,\quad \frac{\partial c}{\partial z_j} > 0. \qquad (38)
\end{aligned}$$

For a large class of production functions $f(n_j)$ in (1) – e.g. CES functions with a fixed factor of production – it is true that $x'(\beta_j) > 0$ holds if and only if $x'(n_j) > 0$. This, (22) and (38) yield $\partial l_j/\partial\beta_j < 0$. In such a case, a decrease in the number of non-striking workers, β_j, has the same effect as an increase in union power α_j: they both support unions in bargaining and increase the amount of research work, l_j, and the growth rate. Consequently, α_j and β_j are complements as government instruments.

Inserting the value functions $\Upsilon_j(t_j) = \vartheta c^\sigma \epsilon^{\sigma t}$ and $\Upsilon_j(t_j+1)/\Upsilon_j(t_j) = \epsilon^\sigma$ into the Bellman equation (25) and noting (18) produce

$$\begin{aligned}0 &= c^\sigma \epsilon^{\sigma t} + (\epsilon^\sigma - 1)\Upsilon_j(t_j)\lambda z_j - \rho\Upsilon_j(t_j)\\ &= \Upsilon_j(t_j)\big[1/\vartheta - \rho - (1-\epsilon^\sigma)\lambda z_j\big] = \Upsilon_j(t_j)\big[1/\vartheta - r_j\big]\end{aligned}$$

and $\vartheta = 1/r_j > 0$. Given $\vartheta = 1/r_j > 0$, (5), (26), $\Upsilon_j(t_j) = \vartheta c^\sigma \epsilon^{\sigma t}$ and $\Upsilon_j(t_j+1)/\Upsilon_j(t_j) = \epsilon^\sigma$, we obtain

$$\begin{aligned}\frac{1}{\Upsilon_j(t_j)}\frac{\partial \mathcal{B}_j}{\partial l_j} &= \frac{\sigma c^{\sigma-1}\epsilon^{\sigma t}}{\Upsilon_j(t_j)}\left[\frac{\partial c}{\partial l_j} + \frac{\partial c}{\partial z_j}\frac{\partial z_j}{\partial l_j}\right] + \lambda\left[\frac{\Upsilon_j(t_j+1)}{\Upsilon_j(t_j)} - 1\right]\frac{\partial z_j}{\partial l_j}\\ &= \frac{\sigma}{c\vartheta}\left[\frac{\partial c}{\partial l_j} + \frac{\partial c}{\partial z_j}\frac{\partial z_j}{\partial l_j}\right] + \lambda(\epsilon^\sigma - 1)\frac{\partial z_j}{\partial l_j}\\ &= \frac{\sigma}{c\vartheta}\frac{\partial c}{\partial l_j} + \left[\frac{\sigma}{c\vartheta}\frac{\partial c}{\partial z_j} + \lambda(\epsilon^\sigma - 1)\right]\frac{\partial z_j}{\partial l_j}\\ &= \frac{\sigma r_j}{c}\frac{\partial c}{\partial l_j} + (1-\mu)\left[\frac{\sigma r_j}{c}\frac{\partial c}{\partial z_j} + \lambda(\epsilon^\sigma - 1)\right]\left(\frac{l_{-j}}{l_j}\right)^\mu = 0. \qquad (39)\end{aligned}$$

Given (5), (18) and (23), the functions c, r_j, $\partial c/\partial z_j$ and $\partial c/\partial l_j$ are independent of μ for $l_j = l_{-j}$. This, (5), (38) and (39) yield

$$\left.\frac{\partial^2 \mathcal{B}_j}{\partial l_j \partial \mu}\right|_{l_j = l_{-j}} = \lambda(1-\epsilon^\sigma) - \frac{\sigma r_j}{c}\frac{\partial c}{\partial z_j} = \frac{\sigma r_j}{(1-\mu)c}\frac{\partial c}{\partial l_j} < 0. \qquad (40)$$

Differentiating the first-order condition (39) and noting (40) and the second-order condition $\partial^2\mathcal{B}_j/\partial l_j^2 < 0$, we obtain the functions

$$l_j = \Theta(l_{-j}, \mu), \quad \left.\frac{\partial \Theta}{\partial \mu}\right|_{l_j = l_{-j}} = -\left[\frac{\partial^2 \mathcal{B}_j}{\partial l_j \partial \mu}\Big/\frac{\partial^2 \mathcal{B}_j}{\partial l^2}\right]_{l_j = l_{-j}} < 0. \qquad (41)$$

Given the functions (41), we define a system of equations

$$\mathcal{A}_j = l_j - \Theta(l_{-j}, \mu) = 0 \quad (j = 1, ..., J), \qquad (42)$$

with endogenous variables $l_1, ..., l_J$. Differentiating this system, we obtain the coefficient matrix $\big(\partial \mathcal{A}_j/\partial l_k\big)_{J\times J}$. The reaction function of economy j is given by (42). The sufficient conditions for the stability of the equilibrium require that the coefficient matrix $\big(\partial \mathcal{A}_j/\partial l_k\big)_{J\times J}$ is subject to diagonal dominance.[20]

[20]See footnote **??**.

Noting (5), (41) and (42), this dominance can be rephrased as:

$$0 < \frac{\partial \mathcal{A}_j}{\partial l_j} \pm \sum_{k \neq j} \frac{\partial \mathcal{A}_j}{\partial l_k} = 1 \pm \frac{\partial \Theta}{\partial l_{-j}} \sum_{k \neq j} \frac{\partial l_{-j}}{\partial l_k} = 1 \pm \frac{\partial \Theta}{\partial l_{-j}}.$$

This implies $\partial\Theta/\partial l_{-j} < 1$. With symmetry $l_j = l$ for all j, we can transform relations (41) into $l = \Theta(l, \mu)$. Differentiating this equation totally and noting (41), we obtain $l_j = l(\mu)$ with $dl/d\mu = (\partial\Theta/\partial\mu)/[1 - \partial\Theta/\partial l_{-j}] < 0$.

Inserting $l_k = l(\mu)$ for all k into (25) and (26), and noting (5) yield

$$B = c(l(\mu), l(\mu))^\sigma \epsilon^{\sigma t} + \lambda l[\Upsilon_j(t_j + 1) - \Upsilon_j(t_j)],$$
$$\sigma c^{\sigma-1} \epsilon^{\sigma t}[\partial c/\partial l_j + (1-\mu)\partial c/\partial z_j] + (1-\mu)\lambda[\Upsilon_j(t_j+1) - \Upsilon_j(t_j)] = 0.$$

The effect of μ on $B_j = B$ is then given by

$$\begin{aligned} dB/d\mu &= \left\{\sigma c^{\sigma-1}\epsilon^{\sigma t}[\partial c/\partial l_j + \partial c/\partial z_j] + \lambda[\Upsilon_j(t_j+1) - \Upsilon_j(t_j)]\right\} dl/d\mu \\ &= \left\{\sigma c^{\sigma-1}\epsilon^{\sigma t}\mu\, \partial c/\partial z_j + \mu\lambda[\Upsilon_j(t_j+1) - \Upsilon_j(t_j)]\right\} dl/d\mu < 0. \end{aligned}$$

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