INTERNATIONAL LABOUR MARKET REGULATION AND ECONOMIC GROWTH WITH CREATIVE DESTRUCTION

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Abstract

A multi-country Schumpeterian growth model is constructed when there is world-wide externality in technological knowledge. Households can enter the labour force as workers or become engineers at some cost. Production employs both workers and engineers while R&D uses only engineers. Workers are unionized and labour market regulation supports union power in wage bargaining. It is shown that international coordination of labour market policy increases the growth rate and the level of welfare. When the interest-rate elasticity of consumption in the world is low (high), the simultaneous regulation (deregulation) of the labour market in all countries increases welfare.

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1 Introduction

Labour market regulation (deregulation) – i.e. the strengthening (weakening) of the workers' position in wage bargaining – may have strong effects on the level of employment, the growth rate and the level of welfare. This leads to the following problems. To what extent should a single country, which is dependent of technological knowledge in the other countries, regulate its labour market? Should labour market policy be internationally coordinated or should the countries be left alone to compete with each other by labour market deregulation? Should, for instance, the European Union be given a greater importance in labour market policy or should this be left for the national governments? This study tries to answer these questions.

In Jerger (2002), regulation and social standards are endogenously determined by politicians who have to solve a trade-off between equity and efficiency and whose utility is a quadratic function of some macroeconomic variables. In contrast, this study ignores such trade-off by assuming that the households in a country are similar and the government maximizes a household's welfare. It is shown that when technological change is properly incorporated into the model, efficiency can alone explain why a rational and benevolent government exercises labour market regulation.

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 investment on $R\&D$. The study takes here a similar 'Schumpeterian' approach, but instead of a competitive labour market it assumes that unions and employers bargain over wages. The wages are then determined by a two-player game in which the parties are long-sighted enough to observe the effect of wages on the firms' investment policy.

Palokangas (1996, 2000) introduces collective bargaining into Romer's (1990) product-variety model with two labour inputs, skilled and unskilled workers, and obtains the following results. Higher bargaining power for unions leads to higher wages for unskilled workers, higher unemployment for both skilled and unskilled workers in production, a lower wage for skilled workers, a larger amount of $R\&D$ which uses skilled labour, and a higher growth rate. If the unions are not initially too strong, this increase in the growth rate is welfare enhancing. The product-variety models, however, ignore the uncertainty that is embodied in technological change. To eliminate this shortcoming, the study uses a model of creative destruction.

In the model, there is a fixed number J of countries that are interdependent through international technology transfer. Each country j contains a fixed number κ of households.[1] All households are modelled as dynastic families whose size remains unchanged over time. They are risk averters, share identical preferences and supply two labour inputs: *workers*, who are employed only in production, and *engineers*, who are employed in both production and *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 to become engineers or enter the labour force as workers. A single family takes prices, wages, profits, the level of employment and aggregate labour supply as given.

Research firms can adopt ideas from each other. A single firm has technology which is a random variable but the probability of an improvement of its technology 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 countries, this study assumes that there is no international trade in goods or factors and each intermediate product is specific to the country in which it is used and produced.[2] Given this assumption, each country can have a separate stochastic process that characterizes its technological change and the growth rates can differ across the countries.

The structure of a single country can be characterized as follows:

(i) A large number of competitive firms produces final goods from the intermediate good and some indivisible factor of production.[3]

(ii) One monopolist at a time produces the intermediate good by workers and engineers. Several firms do *R&D* by using engineers and finance their expenditure by issuing shares. As soon as any of these firms

[1] It is necessary for the analysis that each country contains a large but finite number of households. The model would be a bit more complicated but the results still the same if the number of households differed across the countries.

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

[3] It is assumed, for simplicity, only one intermediate good for each country. With some complication, the same results can be derived even with many intermediate goods.

completes a new innovation, it takes over the whole production of the intermediate good and drives the old producer out of the market.

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

(iv) All workers are unionized.[4] The labour union, which maximizes the discounted value of the flow of the workers' wage bill, and the employer federation, which maximizes the discounted value of the flow of the employers' profit, bargain over the workers' wages. The labour union has also the option to refuse from bargaining, in which case the workers' wage is competitively determined.

(v) The government determines the relative bargaining power of the labour union by its labour market policy. When the policy measures increase (decrease) the labour union's relative bargaining power, we say that the labour market is regulated (deregulated).

Section 3 considers households deciding on consumption and saving. This is a problem of stochastic dynamic programming and leads to the savings and investment functions for the countries. The study focuses entirely on the households' stationary equilibrium in which the allocation of resources is invariable across technologies, and ignores the behaviour of the system during the transitional period before the equilibrium is reached. Section 4 examines collective bargaining in the households' stationary state. Finally, section 5 considers the national governments which act as Stackelberg leaders with respect to the other agents. Two cases are examined: either the governments play Nash among themselves or they cooperate in labour market policy.

[4]This study assumes that the engineers are not unionized, for simplicity. In the larger version of this paper [Palokangas (2002)], both workers and engineers belong to the same union. Then, in line with Palokangas (1996) and (2000), it is shown that because a higher employment for engineers yields higher profits and higher labour income, the union and the employer will always make such wage contracts that the engineers will be fully employed. Given the full employment of engineers, the other results are the same as in this study.

2 Firms

(a) Final-good producers. The representative final-good firm in country j makes output y_j from some indivisible factor of production and intermediate input x_j through a Cobb-Douglas function

$$y_j = B_j x_j^{1-\beta}/(1-\beta) \text{ with } 0 < \beta < 1, \tag{1}$$

where B_j is the productivity parameter and β a constant. It maximizes profit

$$\Pi_j \doteq P_j y_j - p_j x_j = P_j B_j x_j^{1-\beta}/(1-\beta) - p_j x_j \tag{2}$$

by intermediate input x_j, taking the input price p_j and the output price P_j as fixed. This implies the inverse demand function for input x_j,

$$p_j = P_j B_j x_j^{-\beta}. \tag{3}$$

(b) Intermediate-good producers. Input x_j is produced through technology

$$x_j = X(m_j, n_j), \quad X_m \doteq \partial X/\partial m_j > 0, \quad X_n \doteq \partial X/\partial n_j > 0, \tag{4}$$

where m_j (n_j) is the demand for engineers (workers) in production. Assuming that technology (4) is of CES form, the unit cost ψ_j is determined by

$$\psi_j = \Psi(w_j, v_j) \doteq \left[\delta w_j^{1-\varepsilon} + (1-\delta) v_j^{1-\varepsilon}\right]^{1/(1-\varepsilon)}, \ 0 < \delta < 1, \ 0 < \varepsilon < 1, \tag{5}$$

where w_j (v_j) is the wage for engineers (workers), ε the constant elasticity of substitution, and δ the constant relative weight of engineers. Assumption $\varepsilon < 1$ is the Inada condition for CES technology: there cannot be output without both of the inputs. By duality, the following conditions must hold:

$$\begin{aligned} m_j &= \frac{\partial \Psi}{\partial w_j} x_j = \delta \Big(\frac{\psi_j}{w_j}\Big)^{\varepsilon} x_j, \quad n_j = \frac{\partial \Psi}{\partial v_j} x_j = (1-\delta)\Big(\frac{\psi_j}{v_j}\Big)^{\varepsilon} x_j, \\ X_m/X_n &= w_j/v_j, \quad x_j = X_m m_j + X_n n_j. \end{aligned} \tag{6}$$

Given the demand function (3), the producer maximizes its profit

$$\pi_j \doteq p_j x_j - \psi_j x_j = P_j B_j x_j^{1-\beta} - \psi_j x_j = P_j B_j x_j^{1-\beta} - \psi_j x_j \tag{7}$$

by its output x_j, taking its unit cost ψ_j and the price for the final good, P_j, as fixed. Given (2)-(7), this yields

$$\psi_j = (1-\beta) P_j B_j x_j^{-\beta}, \quad \frac{\pi_j}{\psi_j x_j} = \frac{\beta}{1-\beta}, \quad \frac{\Pi_j}{\psi_j x_j} = \frac{\beta}{(1-\beta)^2}. \tag{8}$$

(c) Research firms. Because only engineers are used in *R&D*, investment expenditure in country j is equal to labour cost $w_j l_j$, where l_j is the engineers' labour input in *R&D*. When a research firm in country 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.

Country j is subject to technological change which is characterized by a Poisson process q_j as follows. During a short time interval dt, there is an innovation $dq_j = 1$ with probability $\Lambda_j dt$, and no innovation $dq_j = 0$ with probability $1 - \Lambda_j dt$, where Λ_j is the arrival rate of innovations in the research process. It is assumed that the arrival rate Λ_j is in fixed proportion λ to a Cobb-Douglas function Z_j of research input in the country j, l_j, and the average research input in the rest of the world, l_{-j}:

$$\Lambda_j = \lambda Z_j(l_j, l_{-j}, \mu) \text{ with } Z_j(l_j, l_{-j}, \mu) \doteq l_j^{1-\mu} l_{-j}^{\mu}, \quad l_{-j} \doteq \frac{1}{J-1} \sum_{k \neq j} l_k,$$
$$0 < \mu < 1, \quad \partial Z_j / \partial \mu = 0 \text{ and } \partial^2 Z_j / (\partial l_j \partial \mu) = -1 < 0 \text{ for } l_j = l_{-j}. \tag{9}$$

The higher parameter μ is, the more the countries are technologically dependent on each other. Each new generation of products provides exactly $\gamma > 1$ times as many services as the product of the generation before it. Hence, the level of productivity B_j is determined by the currently most advanced technology t. The invention of a new technology raises t by one and the level of productivity by $\gamma > 1$, so that

$$B_j^t = B_j^0 \gamma^t. \tag{10}$$

Because $\ln B_j^{t+1} - \ln B_j^t = (\ln \gamma) \chi(t)$, where $\chi(t)$ is the number of innovations between t and $t+1$, and $\chi(t)$ is Poisson distributed with parameter λZ_j, the average growth rate of the level of productivity B_j in the stationary state is in fixed proportion to Z_j as $E[\log B_j^{t+1} - \log B_j^t] = \lambda Z_j \log \gamma$, where E is the expectation operator.[5] This result shows that research inputs $Z_j \doteq l_j^{1-\mu} l_{-j}^{\mu}$ can be used as proxies of the average growth rates of the countries $j \in \{1, ..., J\}$.

3 Households

Households make two choices separately: (a) they decide their occupation on the basis of prospective income; and (b) they determine the flow of savings given the flow of income. The outcome of these choices are as follows.
(a) Labour supply. Because each family can change its members' occupation from a worker to an engineer at some cost and the abilities of all individuals in country j differ, we can introduce a decreasing and convex transformation function between the number of workers, N_j, and the number of engineers, L_j, as follows:

$$N_j = N(L_j), \quad N' < 0, \quad N'' < 0. \tag{11}$$

More and more workers must be transformed in order to create one more engineering input. Engineers are always fully employed. Because the workers are used only in production, their full employment constraint is given by

$$n_j \leq N_j = N(L_j), \tag{12}$$

where n_j is the level of employment and N_j the labour supply. A worker's expected wage $v_j^e \doteq v_j n_j / N_j$ is equal to the wage v_j times the probability of employment, n_j/N_j. Since the supply of the engineers is always equal to the demand for them, $L_j = l_j + m_j$, their expected wage is the wage w_j.

Because households must choose their combination of labour supply before entering the labour market, this choice is based on the transformation function (11) and the expected wages (w_j, v_j^e), which the household takes as given. This equilibrium is found by maximizing expected income $w_j L_j + v_j^e N_j = w_j L_j + v_j^e N(L_j)$ by L_j, which yields the first order condition $w_j / v_j^e = -N'(L_j)$. This, (11) and definition $v_j^e \doteq v_j n_j / N_j$, yield

$$-\frac{N'(l_j + m_j)}{N(l_j + m_j)} = -\frac{N'(L_j)}{N(L_j)} = \frac{w_j}{v_j^e N_j} = \frac{w_j}{v_j n_j}. \tag{13}$$

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

(b) Saving. The utility for household $\iota \in \{1, ..., \kappa\}$ in country j from an infinite stream of consumption beginning at time τ takes the form

$$U(C_{j\iota}, \tau) = E \int_{\tau}^{\infty} C_{j\iota}^{\sigma} e^{-\rho(\theta-\tau)} d\theta \text{ with } 0 < \sigma < 1 \text{ and } \rho > 0, \qquad (14)$$

where θ is time, E the expectation operator, $C_{j\iota}$ the index of consumption, ρ the rate of time preference and $1/(1-\sigma)$ is the constant relative risk aversion. Aggregate expenditure in the whole world is used as the numeraire:

$$\sum_{j=1}^{J} \sum_{\iota=1}^{\kappa} P_j C_{j\iota} = \sum_{j=1}^{J} P_j \sum_{\iota=1}^{\kappa} C_{j\iota} = 1, \qquad (15)$$

where P_j is the price for the final good in country j.

When household ι 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 $s_{j\iota}$ be the true profit share of household ι when the uncertainty of the outcome of the projects are taken into account. Following Wälde (1999), we assume that the change in this share, $ds_{j\iota}$, is a function of the increment dq_j of a Poisson process q_j as follows:

$$ds_{j\iota} = (i_{j\iota} - s_{j\iota}) dq_j \text{ with } i_{j\iota} \doteq S_{j\iota}/(w_j l_j), \qquad (16)$$

where $S_{j\iota}$ is saving by household ι in country j. When a household does not invest in the upcoming vintage, her 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.

Total labour income in country j, I_j is equal to labour expenditure in production, $\psi_j x_j$, and in *R&D*, $w_j l_j$,

$$I_j \doteq w_j l_j + \psi_j x_j. \qquad (17)$$

The total income of household ι in country j, $A_{j\iota}$, consists of an equal share $1/\kappa$ of both labour income I_j and the profit of the final-good firm, Π_j, and the share $s_{j\iota}$ of the total profits of the intermediate-good firm, π_j,

$$A_{j\iota} \doteq (I_j + \Pi_j)/\kappa + s_j \pi_j = (w_j l_j + \psi_j x_j + \Pi_j)/\kappa + s_{j\iota} \pi_j. \qquad (18)$$

The budget constraint of household ι in country j is given by

$$A_{j\iota} = P_j C_{j\iota} + S_{j\iota}, \tag{19}$$

where $C_{j\iota}$ is consumption and P_j the consumption price. Household ι chooses its saving $S_{j\iota}$ and takes labour income I_j, profits Π_j and π_j, investment expenditure $w_j l_j$ and aggregate research input Z_j as given.

(c) Optimization. We denote the value of receiving a share $s_{j\iota}$ of the profits of the monopolists using current technology t by $\Omega(s_{j\iota}, t)$, and the value of receiving a share $i_{j\iota}$ of the profits of the monopolists of the next generation by $\Omega(i_{j\iota}, t+1)$. Household ι maximizes its utility (14) subject to stochastic process (16) and the budget constraint (19) by its saving $S_{j\iota}$, given I_j, Π_j, π_j, $w_j l_j$ and Z_j. This maximization leads to the Bellman equation[6]

$$\rho\Omega(s_{j\iota}, t) = \max_{S_{j\iota}} \Big\{ C_{j\iota}^{\sigma} + \Lambda_j [\Omega(i_{j\iota}, t+1) - \Omega(s_{j\iota}, t)] \Big\}, \tag{20}$$

where $C_{j\iota} = (A_{j\iota} - S_{j\iota})/P_j$ and $\Lambda_j = \lambda Z_j = \lambda l_j^{1-\mu} l_{-j}^{\mu}$ by (9) and (19). The first order condition associated with the Bellman equation (20) is

$$\lambda Z_j \frac{d}{dS_{j\iota}} [\Omega(i_{j\iota}, t+1) - \Omega(s_{j\iota}, t)] = \sigma C_{j\iota}^{\sigma-1}/P_j. \tag{21}$$

We try the solution that consumption expenditure $P_j C_{j\iota}$ is a share $0 \le 1/h_{j\iota} \le 1$ out of income $A_{j\iota}$, and that the value function is of the form $\Omega = (A_{j\iota}/h_{j\iota})^{\sigma}/r_{j\iota}$, where the income-consumption ratio $h_{j\iota}$ and the (subjective) interest rate $r_{j\iota}$ are independent of income $A_{j\iota}$. Inserting these guesses into (20) and (21), it is shown in Appendix A that the interest rate r_j and the ratio of the labour costs in the two sectors for country j are given by[7]

$$r_{j\iota} = r_j \doteq \rho + (1 - \gamma^{\sigma})\lambda Z_j, \tag{22}$$

$$w_j l_j / (\psi_j x_j) = \varpi [h(Z_j) - 1], \quad h' > 0 \text{ and } \varpi > 0 \text{ constant}. \tag{23}$$

4 Employment and wage bargaining

In the system of six differentiable equations (4), (5), (6), (13) and (23), there are six endogenous variables – the unit cost ψ_j, the engineers' and workers'

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

[7]Note that this definition of the interest rate r_j contains also the expected growth of consumption through technological change (10).

wages, w_j and v_j, the intermediate input x_j and the employment of engineers and workers in production, m_j and n_j – and two exogenous variables – the employment of engineers in $R\&D$, l_j, and the level of $R\&D$, Z_j. This system defines the following differentiable functions (see Appendix B):

$$\begin{aligned} &w_j = w(l_j, Z_j), \quad v_j = v(l_j, Z_j), \quad m_j = m(l_j, Z_j), \quad n_j = n(l_j, Z_j), \\ &x_j = x(l_j, Z_j), \quad \partial x_j/\partial l_j < 0. \end{aligned} \tag{24}$$

Result $\partial x_j/\partial l_j < 0$ means that the increase of resources in $R\&D$ (i.e., a higher l_j) deprives resources from production and yields lower output x_j. Given functions (24), the full employment constraint (12) takes the form

$$N\big(l_j + m(l_j, Z_j)\big) \geq n(l_j, Z_j). \tag{25}$$

In each country j, the workers' wage v_j is determined by collective bargaining between labour union j, which represents the workers, and employer federation j, which represents firms that employ workers. It is assumed, for simplicity, that these both are risk neutral and have the same rate of time preference $\varrho > 0$. Union j attempts then to maximize the expected value of the stream of the workers' real wage bill $v_j n_j/P_j$, $\mathcal{U}_j$, while employer federation j attempts to maximize the expected value of the stream of real profits π_j/P_j, $\mathcal{F}_j$.[8] Given the stochastic technological progress explained in part (c) of section 2, these targets take the form:[9]

$$\begin{aligned} \mathcal{U}_j(l_j, l_{-j}, \alpha_j, \mu) &\doteq E\int_0^\infty e^{-\varrho\theta}\Big(\frac{v_j n_j}{P_j}\Big)d\theta = \Big(\frac{B_j^0 v_j n_j}{B_j P_j}\Big)\frac{1}{\varrho + (1-\gamma)\lambda Z_j}, \\ \mathcal{F}_j(l_j, l_{-j}, \alpha_j, \mu) &\doteq E\int_0^\infty e^{-\varrho\theta}\Big(\frac{\pi_j}{P_j}\Big)d\theta = \Big(\frac{B_j^0 \pi_j}{B_j P_j}\Big)\frac{1}{\varrho + (1-\gamma)\lambda Z_j}. \end{aligned} \tag{26}$$

Union j has always the possibility of refusing from collective bargaining in which case the workers' wage v_j is determined by supply and demand and there is full employment. That is why union j cannot make an agreement that

[8]Because the workers and the employers consume the final good, their real income is defined by the final-good price P_j. If the employer federation represented also the final-goods firms, then it would maximize the discounted value of the stream of the real profits $(\pi_j + \Pi_j)/P_j$ of both the intermediate and final-goods firms rather than the discounted value of the stream of π_j/P_j. However, because in the model Π_j is in fixed proportion to π_j, the results were the same.

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

produces a lower welfare for its members than in full employment. Denoting the level of employment corresponding to full employment $n_j = N_j$ by l_j^f and noting (26), this incentive constraint can be written as follows:

$$\mathcal{U}_j(l_j, l_{-j}, \alpha_j, \mu) \geq \mathcal{U}_j(l_j^f, l_{-j}, \alpha_j, \mu). \tag{27}$$

In bargaining, union j (employer federation j) maximizes its welfare $\mathcal{U}_j$ ($\mathcal{F}_j$) by the workers' wage v_j subject to the employment constraints (25) and the union's incentive constraint (27), taking the number of engineers devoted to *R&D* elsewhere, l_{-j}, as given. Because there is one-to-one correspondence from v_j to l_j through (24), in the model v_j can be replaced by l_j as the instrument of bargaining. The outcome of bargaining is then obtained through the maximization of the Generalized Nash Product of the parties' targets, $\mathcal{U}_j^{\alpha}\mathcal{F}_j^{1-\alpha}$, where constant $0 < \alpha < 1$ is the union's relative bargaining power, by l_j, subject to (25) and (27), taking l_{-j} as given. This maximization yields the following results (Appendix C):

Proposition 1 ***(i)*** *With unemployment for the workers, $N_j > n_j$, the employment of engineers in R&D, l_j, is above its level $l_j^f(l_{-j}, \mu)$ that corresponds to the workers' full employment $N_j = n_j$.*
(ii) *When the number of engineers in R&D elsewhere in the world, l_{-j}, is held constant, labour market regulation in country j (i.e., a higher α_j) fosters R&D and growth in that country, $\partial l_j/\partial \alpha_j > 0$.*
(iii) *Simultaneous labour market regulation in all countries (i.e., a higher $\alpha_j = \alpha$ for all j) increases the world growth rate $l_j = l_{-j} = Z_j = Z$.*

These result are explained in the final section.

5 The governments

Because country j consumes its output, $y_j = \sum_{\iota=1}^{\kappa} C_{j\iota}$ obtains. Given the symmetry across the households in country j, this takes the form $C_{j\iota} = y_j/\kappa$. A household's consumption $C_{j\iota}$ relative to the level of productivity, γ^t, is given by $c_j \doteq \gamma^{-t} C_{j\iota}$. This, $C_{j\iota} = y_j/\kappa$, (1), (10) and (24) produce

$$\begin{aligned} c_j(l_j, Z_j) &\doteq \gamma^{-t} C_{j\iota} = \gamma^{-t} y_j/\kappa = \gamma^{-t} B_j x_j^{1-\beta}/[(1-\beta)\kappa] \\ &= B_j^0 x(l_j, Z_j)^{1-\beta}/[(1-\beta)\kappa] \text{ with } \partial c_j/\partial l_j < 0. \end{aligned} \tag{28}$$

Noting (28), the utility function (14) takes the form

$$U(C_{j\iota},\tau) = E\int_{\tau}^{\infty} c_j(l_j, Z_j)^{\sigma}\gamma^{\sigma}e^{-\rho(\theta-\tau)}d\theta. \tag{29}$$

According to proposition 1(*i*), the full employment constraint takes the form $l_j \geq l_j^f(l_{-j},\mu)$. Given proposition 1(*ii*), the government in country j (hereafter government j) can increase (decrease) the number of engineers in $R\&D$, l_j, by labour market regulation (deregulation). If the government is benevolent, it maximizes social welfare (29) by l_j subject to $l_j \geq l_j^f(l_{-j},\mu)$, given the number of engineers devoted to $R\&D$ elsewhere, l_{-j}. Denoting the value of the state of technology t for government j by $\Upsilon_j(t)$, the Bellman equation for the government's optimization can be written as follows:

$$\begin{aligned}
&\rho\Upsilon_j(t) = \max_{l_j \geq l_j^f(l_{-j},\mu)} \mathcal{B}_j, \quad \text{where} \\
&\mathcal{B}_j \doteq c_j\big(l_j, Z_j(l_j, l_{-j},\mu)\big)^{\sigma}\gamma^{\sigma t} + \lambda Z_j(l_j, l_{-j},\mu)[\Upsilon_j(t+1) - \Upsilon_j(t)].
\end{aligned} \tag{30}$$

Noting (9) and (30), we obtain the partial derivative of $\mathcal{B}_j$ as follows:

$$\frac{\partial\mathcal{B}_j}{\partial l_j} = \sigma c_j^{\sigma-1}\gamma^{\sigma t}\left[\frac{\partial c_j}{\partial l_j} + \frac{\partial c_j}{\partial Z_j}\frac{\partial Z_j}{\partial l_j}\right] + \lambda[\Upsilon_j(t+1) - \Upsilon_j(t)]\frac{\partial Z_j}{\partial l_j}. \tag{31}$$

We try the solution that the value function is of the form $\Upsilon_j(t) = \vartheta c_j^{\sigma}\gamma^{\sigma t}$, where ϑ is independent of the endogenous variables of the system. In Appendix D, this solution yields the following proposition:

Proposition 2 ***(i)*** *If labour market regulation is carried out at the level of single country and the dependence on the rest of the world increases (i.e., μ rises), then the employment of engineers in R&D falls, $dl_j/d\mu < 0$.* ***(ii)*** *If the elasticity of consumption with respect to the interest rate, $\eta \doteq (r/c)dc/dr$, is smaller (greater) than $1/\sigma$, where $1/(1-\sigma)$ is a household's rate of risk aversion, then it is welfare enhancing to regulate (deregulate) the labour market simultaneously in all countries j.*

A government faces a trade-off between rapid technological change and low income. When technological change in a country depends less on foreign $R\&D$ and more on domestic $R\&D$ (i.e, a higher μ), it is more attractive for the government to speed up technological change through lower income and consequently, there will be more engineers in $R\&D$. In a stationary equilibrium the level of utility (14) takes the form $U_j = c_j^\sigma / r_j$. If the interest rate r_j (as being a function of the growth rate l_j) is chosen to maximize utility U_j, the first-order condition $\partial U_j / \partial r_j = 0$ implies $\eta \doteq (r_j/c_j)\partial c_j / \partial r_j = 1/\sigma$.

When labour market regulation is coordinated across countries $1, ..., J$, we obtain the Pareto optimum for the whole world. The governments then behave as if there were only one government in the world and $\mu \to 0$ holds. Because $l_j|_{\mu=0} > l_j|_{\mu>0}$ by proposition $2(i)$, there will be more engineers and consequently a higher growth rate $l_j = l_{-j} = Z_j = Z$ than with independent governments. From proposition $1(ii)$ it follows that to increase l_j to the level corresponding to the Pareto optimum, each independent government j should increase its α_j. Hence, the following corollary is established:

Proposition 3 *The international coordination of labour market policy speeds up economic growth (i.e., increases Z). Independent national governments tend to overly deregulate their labour markets (i.e., to choose too low α_j).*

This result is explained in the final section.

6 Conclusions

This paper examined a world that has the following properties. First, growth is generated by creative destruction: a firm creating the newest technology by a successful $R\&D$ project crowds out the other firms with older technologies from the market so that the latter lose their value. Second, wages are determined by collective bargaining. Third, the firms finance their $R\&D$ by selling shares, and the households save only by buying these shares. Fourth, the households choose optimally their supply two primary inputs: engineers which are used both in production and $R\&D$; and workers which are employed only in production. The main findings of the paper were as follows.

Labour market deregulation, which weakens the unions and increases the employment of the workers, slows down economic growth in two ways. First, with lower unemployment for the workers, the households will more likely to remain workers and less likely to become engineers. Second, because the two labour inputs are complements in production, a higher level of employment for the workers increases also the demand for engineers in the production sector. Since the former effect reduces the supply of engineers and the latter transfers these from $R\&D$ into production, the number of engineers devoted to $R\&D$ will fall. With a lower level of $R\&D$, there will be less innovations and the growth rate will fall. Correspondingly, it can be shown that labour market regulation, which strengthens the unions and decreases the employment of the workers, speeds up growth. From these results it follows that if the growth rate is above (below) the optimal growth rate of the economy, then the labour market should be deregulated (regulated).

If the countries regulate their labour markets independently, then increased dependence of countries slows down but international coordination of labour market policy speeds up economic growth. This is because a government faces a trade-off between rapid technological change and low current income. When technological change in a country depends more on foreign $R\&D$ and less on domestic $R\&D$, the trade-off becomes more restrictive and the government must slow down technological change through deregulation. With international coordination, the externality caused by the dependence of countries can be internalized. The trade-off then becomes less restrictive for the governments taken together, which means that these can speed up technological change through regulation. In other words, independent local governments will overly deregulate the labour market when compared to the case of international cooperation.

Finally, the world can be divided into regulation and deregulation regimes as follows. If the elasticity of consumption with respect to the interest rate is below (above) some critical level, then regulation (deregulation) that increases (decreases) the unions' bargaining power in the labour market is welfare enhancing. The interest rate is a function of the growth rate. Because in a stationary state the level of utility is equal to some function of consumption (which correspond instantaneous utility), divided by the interest rate,[10] there exists utility-maximizing levels for the interest rate and the growth rate, at which the interest-elasticity of consumption is equal to the critical

[10]Because we have chosen the households' aggregate spending as the numeraire, current expenditure on consumption is equal to future expenditure. This means that utilities can be discounted by the interest rate.

level. If the interest-elasticity of consumption is below the critical level, then the growth rate is above its utility-maximizing level and the labour markets should be deregulated to slow down growth.

While a great deal of caution should be exercised when a highly stylized growth model is used to draw conclusions about the effects of public policy, the following judgement nevertheless seems to be justified. With greater international externality in technological change, it is a good idea to increase international cooperation in labour market policy.

Appendix A

Let us denote variables depending on technology t by superscript t. Since according to (18) income $A^t_{j\iota}$ depends directly on the share $s^t_{j\iota}$, we denote $A^t_{j\iota}(s^t_{j\iota})$. Guessing that $h_{j\iota}$ is invariant across technologies, we obtain

$$P^t_j C^t_{j\iota} = A^t_{j\iota}(s^t_{j\iota})/h_{j\iota}, \quad S^t_{j\iota} = (1 - 1/h_{j\iota})A^t_{j\iota}(s^t_{j\iota}). \tag{32}$$

The share in the next producer $t+1$ is determined by investment under technology t, $s^{t+1}_{j\iota} = i^t_{j\iota}$. The value functions are then given by

$$\Omega(s^t_{j\iota}, t) = (C^t_{j\iota})^\sigma / r_{j\iota}, \quad \Omega(i^t_{j\iota}, t+1) = (C^{t+1}_{j\iota})^\sigma / r_{j\iota}. \tag{33}$$

Given this, we obtain

$$\partial\Omega(s^t_{j\iota}, t)/\partial S^t_{j\iota} = 0. \tag{34}$$

From (16), (18), (32) and (33) it follows that

$$\begin{aligned} &\frac{\partial i^t_{j\iota}}{\partial S^t_{j\iota}} = \frac{1}{w^t_j l^t_j}, \quad \frac{\partial [A^{t+1}_{j\iota}(i^t_{j\iota})]}{\partial i^t_{j\iota}} = \frac{\partial [A^{t+1}_{j\iota}(s^{t+1}_{j\iota})]}{\partial s^{t+1}_{j\iota}} = \pi^{t+1}_j, \\ &\frac{\partial \Omega(i^t_{j\iota}, t+1)}{\partial S^t_{j\iota}} = \frac{\sigma}{r_{j\iota}} (C^{t+1}_{j\iota})^{\sigma-1} \frac{\partial C^{t+1}_{j\iota}}{\partial A^{t+1}_{j\iota}} \frac{\partial A^{t+1}_{j\iota}}{\partial i^t_{j\iota}} \frac{\partial i^t_{j\iota}}{\partial S^t_{j\iota}} = \sigma \frac{(C^{t+1}_{j\iota})^{\sigma-1} \pi^{t+1}_j}{r_{j\iota} h_{j\iota} P^{t+1}_j w^t_j l^t_j}. \end{aligned} \tag{35}$$

We focus on a stationary equilibrium where the allocation of labour, $(l^t_j, m^t_j, n^t_j, x^t_j)$ and a household's expenditure share, $C^t_{j\iota}/y^t_j$,[11] are invariant

[11] The domestic households consume the domestic output.

across technologies. Given (5), (6), (8), (9), (18) and (32), this implies

$$\begin{aligned}&l_j^t = l_j,\;\; n_j^t = n_j,\;\; m_j^t = m_j,\;\; x_j^t = x_j,\;\; Z_j^t = Z_j,\;\; \psi_j^t = \psi_j,\;\; v_j^t = v_j,\\ &w_j^t = w_j,\;\; \Pi_j^t = \Pi_j,\;\; \pi_j^t = \pi_j,\;\; P_j^t y_j^t = P_j^{t+1} y_j^{t+1},\;\; A_{j\iota}^t = A_{j\iota},\;\; S_{j\iota}^t = S_{j\iota},\\ &C_{j\iota}^t / y_j^t = C_{j\iota}^{t+1}/y_j^{t+1},\end{aligned} \tag{36}$$

for all j. From (1), (10) and (36) it then follows that

$$P_j^t/P_j^{t+1} = y_j^{t+1}/y_j^t \;= C_{j\iota}^{t+1}/C_{j\iota}^t \;= B_j^{t+1}/B_j^t \;= \gamma. \tag{37}$$

Inserting (32), (33) and (37) into equation (20), we obtain

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

This leads to the function

$$r_j = r_{j\iota} = \rho + (1-\gamma^\sigma)\lambda Z_j. \tag{38}$$

Inserting (8) and (34)-(38) into (21) yields

$$\begin{aligned}0 &= \lambda Z_j \frac{\partial \Omega(i_{j\iota}^t, t+1)}{\partial S_{j\iota}^t} - \sigma \frac{(C_{j\iota}^t)^{\sigma-1}}{P_j^t} = \lambda Z_j \sigma \frac{(C_{j\iota}^{t+1})^{\sigma-1}\pi_j}{r_j h_{j\iota} P_j^{t+1} w_j l_j} - \sigma \frac{(C_{j\iota}^t)^{\sigma-1}}{P_j^t}\\ &= \sigma \frac{(C_{j\iota}^t)^{\sigma-1}}{h_{j\iota} P_j^t}\Big[\lambda Z_j \frac{\gamma^\sigma \pi_j}{r_j w_j l_j} - h_{j\iota}\Big] = \sigma \frac{(C_{j\iota}^t)^{\sigma-1}}{h_{j\iota} P_j^t}\Big[\frac{\beta\lambda\gamma^\sigma}{1-\beta}\frac{\psi_j x_j}{r_j w_j l_j} Z_j - h_{j\iota}\Big]\end{aligned}$$

and

$$h_{j\iota} = h_j \doteq \frac{\beta\lambda\gamma^\sigma}{1-\beta}\frac{\psi_j x_j}{r_j w_j l_j} Z_j. \tag{39}$$

Because the shares in domestic firms are the only assets for the households, in equilibrium $w_j l_j = \sum_{\iota=1}^{\kappa} S_{j\iota}$ must hold. This, $\sum_{\iota=1}^{\kappa} s_{j\iota} = 1$, (8), (18), (32) and (39) produce

$$\frac{h_j w_j l_j}{h_j - 1} = \frac{h_j}{h_j - 1}\sum_{\iota=1}^{\kappa} S_{j\iota} = \sum_{\iota=1}^{\kappa} A_{j\iota} = w_j l_j + \psi_j x_j + \Pi_j + \pi_j$$

and

$$w_j l_j/(\psi_j x_j) = (h_j - 1)(\psi_j x_j + \Pi_j + \pi_j)/(\psi_j x_j) = \varpi(h_j - 1), \tag{40}$$

where $\varpi \doteq 1 + \beta/(1-\beta) + \beta/(1-\beta)^2 > 0$. Noting (39), (40) and (38),

$$(h_j - 1)h_j = \frac{h_j}{\varpi}\frac{w_j l_j}{\psi_j x_j} = \frac{1}{\varpi}\frac{\beta\lambda\gamma^\sigma}{1-\beta}\frac{Z_j}{r_j} = \frac{1}{\varpi}\frac{\beta\lambda\gamma^\sigma}{1-\beta}\frac{1}{\rho/Z_j + (1-\gamma^\sigma)\lambda} \tag{41}$$

obtains. Because $h_j > 1$, equation (41) defines a function $h_j = h(Z_j) > 1$ with $h' > 0$. Inserting this into (40) produces (23).

Appendix B

We omit subscripts j, for convenience. Equations (6) yield

$$\frac{w}{v} = \left(\frac{\delta}{1-\delta}\right)^{1/\varepsilon}\left(\frac{n}{m}\right)^{1/\varepsilon}, \quad \frac{w}{\psi} = \delta^{1/\varepsilon}\left(\frac{x}{m}\right)^{1/\varepsilon}.$$

Substituting these into (13) and (23), we obtain

$$-\frac{N'(l+m)}{N(l+m)} = \frac{w}{vn} = \left(\frac{\delta}{1-\delta}\right)^{1/\varepsilon}\left(\frac{n}{m}\right)^{1/\varepsilon}\frac{1}{n} = \left(\frac{\delta}{1-\delta}\right)^{1/\varepsilon} n^{1/\varepsilon-1} m^{-1/\varepsilon},$$
$$\varpi[h(Z) - 1] = (l/x)w/\psi = \delta^{1/\varepsilon} x^{1/\varepsilon-1} m^{-1/\varepsilon} l.$$

Taking a logarithm of these and noting (4), we obtain a system of three equations,

$$\log[-N'(l+m)] - \log N(l+m) + (1/\varepsilon)\log m + (1-1/\varepsilon)\log n = \text{constants},$$
$$(1/\varepsilon - 1)\log x - (1/\varepsilon)\log m + \log l - \log[h(Z) - 1] = \text{constants},$$
$$X(m,n) - x = 0, \tag{42}$$

with endogenous variables m, n and x and exogenous variables l and Z. Given $0 < \varepsilon < 1$, (6) and (13), the Jacobian of the system (42) is

$$\begin{aligned}
\mathcal{A} &= \left(1 - \frac{1}{\varepsilon}\right)\frac{1}{x}\left[\left(\frac{N''}{N'} - \frac{N'}{N} + \frac{1}{\varepsilon m}\right)X_n + \left(\frac{1}{\varepsilon} - 1\right)\frac{1}{n}X_m - \frac{x}{nm\varepsilon}\right] \\
&= \left(1 - \frac{1}{\varepsilon}\right)\frac{1}{x}\left[\left(\frac{N''}{N'} - \frac{N'}{N} + \frac{1}{\varepsilon m}\right)X_n + \left(\frac{1}{\varepsilon} - 1\right)\frac{1}{n}X_m - \frac{X_m m + X_n n}{nm\varepsilon}\right] \\
&= \left(1 - \frac{1}{\varepsilon}\right)\frac{1}{x}\left[\left(\frac{N''}{N'} - \frac{N'}{N}\right)X_n - \frac{1}{n}X_m\right] \\
&= \left(1 - \frac{1}{\varepsilon}\right)\frac{X_n}{x}\left[\frac{N''}{N'} - \frac{N'}{N} - \frac{1}{n}\frac{w}{v}\right] = \left(1 - \frac{1}{\varepsilon}\right)\frac{X_n}{x}\frac{N''}{N'} < 0.
\end{aligned}$$

By the comparative statics of the system (42), we obtain

$$\frac{\partial x}{\partial l} = \frac{1}{\mathcal{A}l}\left[\frac{X_n l}{\varepsilon n}\left(\frac{N''}{N'} - \frac{N'}{N}\right) + \left(\frac{N''}{N'} - \frac{N'}{N} + \frac{1}{\varepsilon m}\right) X_n + \left(\frac{1}{\varepsilon} - 1\right)\frac{X_m}{n}\right] < 0.$$

Appendix C

From (9) and (25) it follows that in full employment there is

$$N(l_j + m(l_j, Z_j(l_j, l_{-j}, \mu))) = N_j = n_j = n(l_j, Z_j(l_j, l_{-j}, \mu)).$$

This equation defines the function $l_j = l_j^f(l_{-j}, \mu)$. Given (5), (6), (8), (9), (24) and (26), the logarithm of the product $\mathcal{U}_j^\alpha \mathcal{F}_j^{1-\alpha}$ takes the form

$$\begin{aligned}
&\Gamma_j(l_j, l_{-j}, \alpha_j, \mu) \doteq \alpha_j \log \mathcal{U}_j + (1-\alpha_j)\log \mathcal{F}_j \\
&= \log B_j^0 + \alpha_j \log\Big(\frac{v_j n_j}{P_j B_j}\Big) + (1-\alpha_j)\log\Big(\frac{\pi_j}{P_j B_j}\Big) - \log[\varrho + (1-\gamma)\lambda Z_j] \\
&= \alpha_j \log\Big(\frac{v_j n_j}{\psi_j x_j}\Big) + \log \frac{\psi_j x_j}{P_j B_j} - \log[\varrho + (1-\gamma)\lambda Z_j] + \Theta \\
&= \alpha_j \log(\psi_j/v_j)^{\varepsilon-1} + \log x_j^{1-\beta} - \log[\varrho + (1-\gamma)\lambda Z_j] + \Theta \\
&= -\alpha_j \log[\delta(w_j/v_j)^{1-\varepsilon} + 1 - \delta] + (1-\beta)\log x_j - \log[\varrho + (1-\gamma)\lambda Z_j] + \Theta \\
&= -\alpha_j \log\Big\{\Big[\frac{w(l_j, Z_j)}{v(l_j, Z_j)}\Big]^{1-\varepsilon} + 1 - \delta\Big\} + (1-\beta)\log x(l_j, Z_j) \\
&\qquad - \log[\varrho + (1-\gamma)\lambda Z_j] + \Theta, \qquad (43)
\end{aligned}$$

where Θ consists of terms that are independent of l_j.

Because a logarithm is an increasing transformation, the outcome of bargaining is obtained by maximizing the function (43) by l_j, subject to (25) and (27), taking l_{-j} as given. The Lagrangean of this problem is given by

$$\begin{aligned}
\mathcal{L} &\doteq \Gamma_j(l_j, l_{-j}, \alpha_j, \mu) + \xi[N(l_j + m(l_j, Z_j)) - n(l_j, Z_j)] \\
&\quad + \varphi[\mathcal{U}_j(l_j, l_{-j}, \alpha_j, \mu) - \mathcal{U}_j(\tilde{l}_j, l_{-j}, \alpha_j, \mu)] \quad \text{with} \quad Z_j = l_j^{1-\mu} l_{-j}^{\mu}, \qquad (44)
\end{aligned}$$

where multipliers ξ and φ satisfy Kuhn-Tucker conditions

$$\begin{aligned}
&\xi[N(l_j + m(l_j, Z_j)) - n(l_j, Z_j)] = 0, \quad \xi \geq 0, \\
&\varphi[\mathcal{U}_j(l_j, l_{-j}, \alpha_j, \mu) - \mathcal{U}_j(\tilde{l}_j, l_{-j}, \alpha_j, \mu)] = 0, \quad \varphi \geq 0. \qquad (45)
\end{aligned}$$

The first-order conditions of this maximization are (45) and

$$\frac{\partial \mathcal{L}}{\partial l_j} = \frac{\partial \Gamma_j}{\partial l_j} + \varphi \frac{\partial \mathcal{U}_j}{\partial l_j} + \xi \frac{\partial (N_j - n_j)}{\partial l_j} = 0, \tag{46}$$

where

$$\partial (N_j - n_j)/\partial l_j = N'(l_j + m_j)[1 + \partial m/\partial l_j] - \partial n/\partial l_j.$$

Subresult: $\partial^2 \Gamma_j/(\partial l_j \partial \alpha_j) > 0$ *holds when there is unemployment* $N_j > n_j$.

Assume on the contrary that $\partial^2 \Gamma_j/(\partial l_j \partial \alpha_j) \leq 0$ holds. Because $\lim_{\alpha \to 1} \Gamma_j = \log \mathcal{U}_j$ by (43), this assumption implies

$$\frac{1}{\mathcal{U}_j} \frac{\partial \mathcal{U}_j}{\partial l_j} = \frac{\partial \log \mathcal{U}_j}{\partial l_j} = \left. \frac{\partial \Gamma_j}{\partial l_j} \right|_{\alpha_j = 1} \leq \left. \frac{\partial \Gamma_j}{\partial l_j} \right|_{\alpha_j < 1}. \tag{47}$$

To prove $\partial (N_j - n_j)/\partial l_j < 0$, assume on the contrary that

$$\partial (N_j - n_j)/\partial l_j \geq 0, \tag{48}$$

This and the full employment constraint (12) yield

$$l_j \geq l_j^f. \tag{49}$$

Given (45)-(48), we obtain

$$0 \geq -\xi \frac{\partial (N_j - n_j)}{\partial l_j} = \left[\frac{\partial \Gamma_j}{\partial l_j} + \varphi \frac{\partial \mathcal{U}_j}{\partial l_j} \right]_{l_j = l_j^f} \geq \left(\frac{1}{\mathcal{U}_j} + \varphi \right) \left. \frac{\partial \mathcal{U}_j}{\partial l_j} \right|_{l_j = l_j^f}$$

and $[\partial \mathcal{U}_j/\partial l_j]_{l_j = l_j^f} \leq 0$. This and (49) yield

$$\mathcal{U}_j(l_j, l_{-j}, \alpha_j, \mu)\big|_{l_j > l_j^f} < \mathcal{U}_j(l_j^f, l_{-j}, \alpha_j, \mu),$$

which is in contradiction with (27). So there must be

$$\partial (N_j - n_j)/\partial l_j < 0. \tag{50}$$

From (50) and and the full employment constraint (12) it follows that

$$l_j \leq l_j^f. \tag{51}$$

Given (45), (46), (47) and (50), we obtain

$$0 < -\xi \frac{\partial(N_j - n_j)}{\partial l_j} = \left[\frac{\partial \Gamma_j}{\partial l_j} + \varphi \frac{\partial \mathcal{U}_j}{\partial l_j}\right]_{l_j = l_j^f} \leq (1 + \varphi \mathcal{U}_j) \frac{\partial \Gamma_j}{\partial l_j}\bigg|_{l_j = l_j^f}$$

and $[\partial \Gamma_j / \partial l_j]_{l_j = l_j^f} > 0$. This and (51) yield

$$\Gamma_j(l_j, l_{-j}, \alpha_j, \mu)\big|_{l_j < l_j^f} < \Gamma_j(l_j^f, l_{-j}, \alpha_j, \mu).$$

This means that if the function (43) is maximized by l_j, then there must be $l_j = l_j^f$ and full employment. Hence, $\partial^2 \Gamma_j / (\partial l_j \partial \alpha_j) \leq 0$ cannot hold with unemployment $l_j \neq l_j^f$, and the subresult is proven.

Result (i). Given (5), (43) and the subresult, we obtain

$$\frac{\partial^2 \Gamma_j}{\partial l_j \partial \alpha_j} = \frac{(\varepsilon - 1)\delta(w_j/v_j)^{-\varepsilon}}{\delta(w_j/v_j)^{1-\varepsilon} + 1 - \delta} \frac{\partial(w_j/v_j)}{\partial l_j} > 0 \text{ with } l_j \neq l_j^f, \tag{52}$$

$$\frac{1}{\mathcal{U}_j} \frac{\partial \mathcal{U}_j}{\partial l_j} = \frac{\partial \log \mathcal{U}_j}{\partial l_j} = \frac{\partial \Gamma_j}{\partial l_j}\bigg|_{\alpha_j = 1} > \frac{\partial \Gamma_j}{\partial l_j}\bigg|_{\alpha_j < 1}. \tag{53}$$

To prove $\partial(N_j - n_j)/\partial l_j > 0$, assume on the contrary that

$$\partial(N_j - n_j)/\partial l_j \leq 0 \tag{54}$$

holds. This and the employment constraint (12) imply

$$l_j \leq l_j^f. \tag{55}$$

Given (45), (46), (53) and (54), we obtain

$$0 \leq -\xi \frac{\partial(N_j - n_j)}{\partial l_j} = \left[\frac{\partial \Gamma_j}{\partial l_j} + \varphi \frac{\partial \mathcal{U}_j}{\partial l_j}\right]_{l_j = l_j^f} < \left(\frac{1}{\mathcal{U}_j} + \varphi\right) \frac{\partial \mathcal{U}_j}{\partial l_j}\bigg|_{l_j = l_j^f}$$

and $[\partial \mathcal{U}_j / \partial l_j]_{l_j = l_j^f} > 0$. This and (55) yield

$$\mathcal{U}_j(l_j, l_{-j}, \alpha_j, \mu)\big|_{l_j < l_j^f} < \mathcal{U}_j(l_j^f, l_{-j}, \alpha_j, \mu),$$

which is in contradiction with (27). Hence, inequality (54) cannot hold and

$$\partial(N_j - n_j)/\partial l_j > 0 \tag{56}$$

is true. Given (25) and (56), l_j cannot be below $l_j^f(l_{-j}, \mu)$.
Result (ii). Assume unemployment $N_j > n_j$ and $l_j > l_j^f$. The union's incentive constraint (27) is then a strict inequality and the first-order conditions (45) and (46) take the form $\partial\Gamma_j/\partial l_j = 0$. Given (52) and the second-order condition $\partial^2\Gamma_j/\partial l_j^2 < 0$, the comparative statics of $\partial\Gamma_j/\partial l_j = 0$ produce

$$l_j = l_j^*(l_{-j}, \alpha_j, \mu), \qquad \frac{\partial l_j^*}{\partial \alpha_j} = -\frac{\partial^2\Gamma_j}{\partial l_j} \Big/ \frac{\partial^2\Gamma_j}{\partial l_j \partial \alpha_j} > 0. \tag{57}$$

Results (iii). Now we examine the equilibrium of the world in the case $\alpha_j = \alpha$ for all j, in which all countries $j \in [0, 1]$ are in symmetric position. Given the functions (57), we define a system of equations

$$\Delta_j = l_j - l_j^*(l_{-j}, \alpha, \mu) = 0 \text{ for all } j, \tag{58}$$

with endogenous variables l_j for all j. Differentiating system (58), we obtain the coefficient matrix $(\partial\Delta_j/\partial l_k)$. The reaction function of country j is given by (58). The sufficient conditions for the stability of the equilibrium require that the coefficient matrix $(\partial\Delta_j/\partial l_k)$ is subject to diagonal dominance.[12] Noting (9), (58) and the symmetry over j, we obtain the diagonal dominance in the form

$$0 < \frac{\partial\Delta_j}{\partial l_j} \pm \sum_{k \neq j} \frac{\partial\Delta_j}{\partial l_k} = 1 \pm \frac{\partial l_j^*}{\partial l_{-j}} \sum_{k \neq j} \frac{\partial l_{-j}}{\partial l_k} = (J-1)\frac{\partial l_j^*}{\partial l_{-j}} \frac{\partial l_{-j}}{\partial l_k} = 1 \pm \frac{\partial l_j^*}{\partial l_{-j}}.$$

This implies $\partial l_j^*/\partial l_{-j} < 1$. Because of symmetry $l_j = l_{-j} = l$ obtains, and we can transform relations (57) into $l = l_j^*(l, \alpha, \mu)$. Differentiating this totally and noting (57) and $\partial l_j^*/\partial l_{-j} < 1$ yield

$$l_j = l(\alpha, \mu) \text{ with } \partial l/\partial\alpha = (\partial l_j^*/\partial\alpha_j)/[1 - l_j^*/\partial l_{-j}] > 0.$$

Appendix D

Assume first that there is unemployment, $l_j > l_j^f(l_{-j}, \mu)$. Inserting the value function $\Upsilon_j(t) = \vartheta c_j^\sigma \gamma^{\sigma t}$ and $\Upsilon_j(t+1)/\Upsilon_j(t) = \gamma^\sigma$ into the Bellman

[12]See, for example, Dixit (1986), p. 117. Here, the diagonal term $\partial\Delta_j/\partial l_j = 1$ is positive so that the sum of each row must be greater than zero.

equation (30) and noting (22) produce

$$
\begin{aligned}
0 &= c_j^{\sigma}\gamma^{\sigma t} + (\gamma^{\sigma} - 1)\Upsilon_j(t)\lambda Z_j - \rho\Upsilon_j(t) \\
&= \Upsilon_j(t)\big[1/\vartheta - \rho - (1-\gamma^{\sigma})\lambda Z_j\big] = \Upsilon_j(t)\big[1/\vartheta - r_j\big]
\end{aligned}
$$

and $\vartheta = 1/r_j > 0$. Given $\vartheta = 1/r_j > 0$, (9), (31), $\Upsilon_j(t) = \vartheta c_j^{\sigma}\gamma^{\sigma t}$ and $\Upsilon_j(t+1)/\Upsilon_j(t) = \gamma^{\sigma}$, we obtain

$$
\begin{aligned}
\frac{1}{\Upsilon_j(t)}\frac{\partial \mathcal{B}_j}{\partial l_j} &= \frac{\sigma c_j^{\sigma-1}\gamma^{\sigma t}}{\Upsilon_j(t)}\left[\frac{\partial c_j}{\partial l_j} + \frac{\partial c_j}{\partial Z_j}\frac{\partial Z_j}{\partial l_j}\right] + \lambda\left[\frac{\Upsilon_j(t+1)}{\Upsilon_j(t)} - 1\right]\frac{\partial Z_j}{\partial l_j} \\
&= \frac{\sigma}{c_j\vartheta}\left[\frac{\partial c_j}{\partial l_j} + \frac{\partial c_j}{\partial Z_j}\frac{\partial Z_j}{\partial l_j}\right] + \lambda(\gamma^{\sigma} - 1)\frac{\partial Z_j}{\partial l_j} \\
&= \frac{\sigma r_j}{c_j}\left[\frac{\partial c_j}{\partial l_j} + \frac{\partial c_j}{\partial Z_j}\frac{\partial Z_j}{\partial l_j}\right] + \lambda(\gamma^{\sigma} - 1)\frac{\partial Z_j}{\partial l_j} \\
&= \frac{\sigma r_j}{c_j}\frac{\partial c_j}{\partial l_j} + \left[\frac{\sigma r_j}{c_j}\frac{\partial c_j}{\partial Z_j} + \lambda(\gamma^{\sigma} - 1)\right]\frac{\partial Z_j}{\partial l_j} \\
&= \frac{\sigma r_j}{c_j}\frac{\partial c_j}{\partial l_j} + (1-\mu)\left[\frac{\sigma r_j}{c_j}\frac{\partial c_j}{\partial Z_j} + \lambda(\gamma^{\sigma} - 1)\right]\left(\frac{l_{-j}}{l_j}\right)^{\mu}. \qquad (59)
\end{aligned}
$$

Given $\gamma^{\sigma} > 1$ and (59), the first-order condition $\partial\mathcal{B}_j/\partial l_j = 0$ yields

$$
\frac{\partial c_j}{\partial l_j} + \frac{\partial c_j}{\partial Z_j}\frac{\partial Z_j}{\partial l_j} = \frac{(1-\gamma^{\sigma})\lambda c_j}{\sigma r_j}\frac{\partial Z_j}{\partial l_j} < 0. \qquad (60)
$$

From (9), (22), (24) and (28) one can see that the functions x_j, c_j, r_j, $\partial c_j/\partial Z_j$ and $\partial c_j/\partial l_j$ are independent of μ for $l_j = l_{-j}$. This, (28) and (59) yield

$$
\frac{\partial^2 \mathcal{B}_j}{\partial l_j \partial \mu} = -\frac{\sigma r_j}{c_j}\frac{\partial c_j}{\partial Z_j} + \lambda(1-\gamma^{\sigma}) = \frac{1}{1-\mu}\frac{\sigma r_j}{c_j}\frac{\partial c_j}{\partial l_j} < 0 \ \text{ for } l_j = l_{-j}. \qquad (61)
$$

Differentiating the first-order condition $\partial\mathcal{B}_j/\partial l_j = 0$ and noting (61) and the second-order condition $\partial^2\mathcal{B}_j/\partial l_j^2 < 0$, we obtain

$$
l_j = \min[l_j^f(l_{-j},\mu), \hat{l}_j(l_{-j},\mu)], \quad \frac{\partial \hat{l}_j}{\partial \mu} = -\frac{\partial^2 \mathcal{B}_j}{\partial l_j \partial \mu}\bigg/\frac{\partial^2 \mathcal{B}_j}{\partial l_j^2} < 0 \ \text{ for } l_j = l_{-j}. \qquad (62)
$$

If $\hat{l}_j(l_{-j},\mu) > l_j^f(l_{-j},\mu)$, there is unemployment.

We examine now the equilibrium of the world. Because of symmetry across j, we obtain constant $l_j^f(l_{-j}) = l^f$ for all j. Given the functions (62), we can define a system of equations

$$
\mathcal{A}_j = l_j - \min[l^f, \hat{l}_j(l_{-j},\mu)] = 0 \ \text{ for all } j, \qquad (63)
$$

with endogenous variables l_j for all j. Differentiating this system, we obtain the coefficient matrix $\left(\partial\mathcal{A}_j/\partial l_k\right)$. The reaction function of country j is given by (63). The sufficient conditions for the stability of the equilibrium require that the coefficient matrix $\left(\partial\mathcal{A}_j/\partial l_k\right)$ is subject to diagonal dominance.[13] Noting (9), (62) and (63), we obtain the diagonal dominance in the form

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

This implies $\partial\hat{l}_j/\partial l_{-j} < 1$. Because of symmetry $l_j = l_{-j} = l$ obtains, we can transform relations (62) into $l = \min[l^f, \hat{l}_j(l,\mu)]$. Differentiating this totally and noting (62), we obtain

$$l_j = \min[l(\mu), l^f], \quad dl/d\mu = (\partial\hat{l}_j/\partial\mu)/[1 - \partial\hat{l}_j/\partial l_{-j}] < 0.$$

If $l(\mu) > l^f(\mu)$, there is unemployment.

Finally, we examine optimal worldwide regulation. Because in this case the governments behaves as if there were only one government in the world, we let $\mu \to 0$. Given the symmetry across countries j, equations (9) and (22) yield $C_j = C$, $l_j = l_{-j} = Z_j = Z$ and $r_j = r = \rho + (1-\gamma^\sigma)\lambda Z$ for all j. Noting $\gamma^\sigma > 1$, (22), (24), (28) and (60), we obtain the elasticity of consumption C with respect to the interest rate r as follows:

$$\begin{aligned}\eta &\doteq \frac{r}{C}\frac{dC}{dr} = \frac{r}{c}\frac{dc}{dr} = \frac{r}{c}\frac{dc}{dZ}\frac{dZ}{dr} = \frac{r}{c}\frac{1}{(1-\gamma^\sigma)\lambda}\frac{dc}{dZ} \\ &= \frac{r}{c}\frac{1}{(1-\gamma^\sigma)\lambda}\left[\frac{\partial c_j}{\partial l_j} + \frac{\partial c_j}{\partial Z_j}\frac{\partial Z_j}{\partial l_j}\right] > 0.\end{aligned}$$

Given this, (9) and $\mu \to 0$, the partial derivative (59) becomes

$$\frac{1}{\Upsilon_j(t)}\frac{\partial\mathcal{B}_j}{\partial l_j} = \frac{\sigma r}{c}\left[\frac{\partial c_j}{\partial l_j} + \frac{\partial c_j}{\partial Z_j}\frac{\partial Z_j}{\partial l_j}\right] + \lambda(\gamma^\sigma - 1)(1-\mu) = (1-\gamma^\sigma)\lambda[\sigma\eta - 1].$$

Noting this and $\gamma^\sigma > 1$, we obtain $\partial\mathcal{B}_j/\partial l_j > 0$ (< 0) for $\eta < 1/\sigma$ $\left(\eta > 1/\sigma\right)$. According to proposition 1(ii), this means that the labour market should be regulated (deregulated) to increase (decrease) $l_j = l$ for $\eta < 1/\sigma$ $\left(\eta > 1/\sigma\right)$.

[13] See footnote 12.

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