Workplaces in the Primary Economy and Wage Pressure in the Secondary Labor Market

by

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This paper develops a two-sector general-equilibrium model in which firms in the primary economy have to create workplaces prior to production and product-market competition. For this, we introduce the endogenous sunk-cost approach with two-stage decisions of firms from IO in the macro labor literature. By hypothesizing that technological change has lowered marginal costs but has raised nonproduction requirements for providing workplaces, we are able to explain downsizing of low-skilled jobs in the primary economy despite wage flexibility *ex ante*. This leads to more accentuated labor-market segmentation, i.e., an increase in wage pressure in the secondary economy. (JEL: D 20, J 31)

1 *Introduction*

The goal of the present paper is to propose a general equilibrium model with dual labor markets that allows us to identify economic (rather than institutional) causes of downsizing of low-skilled jobs in the primary economy, implying a higher wage pressure in the secondary economy.

In the last years, an extensive literature on the relationship between wage inequality and technological change has been developed (e.g., GREGG AND MANNING [1997], GALOR AND TSIDDON [1997], ACEMOGLU [1998], CASELLI [1999], LLOYD-ELLIS [1999], GALOR AND MOAV [2000]). This literature largely focuses on shifts in relative labor productivity in favor of skilled workers, i.e., on the hypothesis of so-called skill-biased technological change. However, increasing wage inequality is not the only symptom of declining demand for low-skilled labor, and is largely confined to the U.S. and the U.K. (e.g., GOTTSCHALK AND SMEEDING [1997]). A more pervasive characteristic is that low-skilled jobs in manufacturing industries have

* We are grateful to Johannes Binswanger, Jim Malley, and two anonymous referees for valuable comments and to Armin Bänziger for excellent research assistence. Moreover, we are indebted for helpful discussions and comments to Dennis Snower and to seminar participants at the University of Zurich; the CESifo workshop on "Employment and Social Protection" in Munich, 2001; and the European Economic Association Annual Meeting (EEA) and the European Meeting of the Econometric Society (ESEM), both held in Lausanne, 2001.

been downsized substantially over the last two decades in both Anglo-American countries and continental Europe (e.g., BERMAN, BOUND, AND MACHIN [1998], MACHIN AND VAN REENEN [1998]). In the relatively rigid European labor markets, this has led to dramatic increases in unemployment rates for low-skilled labor. Thus, economists and policymakers more and more stress the need to create low-paid jobs in the service sector, for instance, by lowering minimum wages. In the U.S., real wages at the bottom have already declined sharply in the last decades (FORTIN AND LEMIEUX [1997], MURPHY AND TOPEL [1997]). In combination with a considerably larger service sector in the U.S. than in, say, Germany, this seems to have helped the U.S. economy to avoid the unemployment problems now faced by continental Europe.[1] This suggests that opening up the secondary labor market may be a successful strategy to reduce unemployment – but at two kinds of costs: first, a more substantial dualization of the labor market for low-skilled workers, with well-paid jobs in the primary economy and low-paid jobs in the secondary economy; and second, higher *overall* wage inequality, coming from job rationing in the primary sector rather than from rising wage differentials between skilled and unskilled workers in the primary sector.[2]

We hypothesize that the main difference between the primary and the secondary economy is technological (for instance, due to the different nature of goods produced in these sectors). The primary economy is characterized by firms with an organizational infrastructure in which workers can interact. Thus, a crucial feature of our model is that firms in the primary economy have to create *workplaces* prior to production and product-market competition. This is formalized by introducing the idea of *endogenous sunk costs* for capacity investments of firms from the IO literature in a macro labor context.[3] More precisely, firms in the primary economy choose their number of (high-skilled and low-skilled) workplaces at a first stage before entering monopolistic competition in a second stage. As known from the IO literature, such a two-stage framework is natural whenever capacity choices of firms are involved. In a macro labor context, it enables us to take the idea of a workplace seriously. By contrast, no *ex ante* creation of workplaces is needed in the secondary

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[1] According to OECD [2000], in 1998 the total share of service employment was 73.8 percent in the U.S. and 62.6 percent in Germany. The respective employment shares of personal services (which are characterized by particularly low-paid jobs, on average) are 12.1 compared to 7.1 percent.

[2] It should be noted that this view is rather different from the now famous *Krugman hypothesis* (KRUGMAN [1994]), which deals with an overall trade-off between wage inequality and unemployment due to wage differentials in a single-sector framework.

[3] See SUTTON [1991], [1998] for a general account of the theory of endogenous sunk costs, which is necessarily characterized by two-stage games among firms in IO contexts, with subgame-perfect equilibria. We adopt this approach to a general-equilibrium model by seeking perfect-foresight equilibria without strategic interactions. FALKINGER [2002] presents a systematic analysis of the macroeconomic consequences of internal organization of work in a two-stage monopolistic competition model. However, no dual economy is considered.

labor market. Those workers for whom no primary jobs are organized offer their labor to the secondary economy.

The endogenous sunk costs for the creation of workplaces in the primary economy are specified as wage costs for high-skilled nonproduction labor like that of managers, where managerial requirements and workplace creation are linked according to a linear homogeneous technology. A first analysis of this idea has been provided in FALKINGER AND GROSSMANN [2001]. However, only a one-sector framework has been considered, which does not allow us to address labor-market segmentation. Moreover, it has been assumed that only low-skilled jobs have to be organized.

In a comparative-static analysis we show how changes in this organization technology affect macroeconomic variables. Our hypothesis is that the cost of organizing work has increased, in the effort to achieve lower marginal production costs. This is motivated by the observation that the employment share of workers in managerial occupations has substantially increased in the last two decades (see BERMAN, BOUND, AND GRICHILIS [1994], among others). One reason is the increased requirements for human-resource management. Another reason may be more sophisticated marketing methods. In particular, new information and communication technologies (ITCs) have led to new demand for high-skilled nonproduction labor. A growing empirical literature on the complementarity between ITC and new forms of the organization of production (raising the demand for managerial skills) dismisses the earlier view of a direct complementarity of ITC and the human capital of computer users.[4] As stated by BRYNJOLFFSON AND HITT [2000, p. 24], "the business value of computers is limited less by computational capability and more by the ability of managers to invent new processes, procedures and organizational structures." Efficiency gains of computerization are twofold. On the one hand, repetitive tasks of low-wage white-collar workers in bureaucracies have been "regularised, routinised, and standardised" (BRESNAHAN [1999, p. F403]). On the other hand, large operational databases are available and await exploitation. "Managers and professionals do more research as a result, and turn their results into operations more systematically" (p. F409). For instance, customer databases allow firms to target marketing campaigns more effectively to consumers and to design products that better meet customers' needs (SHAPIRO AND VARIAN [1999]). Moreover, decreases in information and communication costs allow decentralization of decision-making and other forms of flexible work practices. But this requires organizational learning of workers and thus implies increased demand for human-resource managers (OECD [1999]). These developments justify our hypothesis that organizational setup costs have indeed increased, a possibility that has so far been neglected in the literature

[4] The standard notion of skill-biased technological change has been strongly criticized in that computer use has not been found to affect wages at the individual level (DINARDO AND PISCHKE [1997]). Rather, as pointed out by BRESNAHAN [1999, p. F402], the hypothesis of a skill complementarity of computer use "misses all the highly skilled managers who do not literally use a computer (perhaps getting a computer-based report from a subordinate) but whose skills are highly complemented by the computerisation of the organisation".

Table 1
Employment Shares of White-Collar Workers by Tasks
in U.S. Manufacturing and Producer Services (in percent)

	Manufacturing			Producer services		
Year	Adminis-trators	Man-agers	Profes-sionals	Adminis-trators	Man-agers	Profes-sionals
1983	12.8	11.3	8.9	35.1	23.2	9.6
1989	10.4	11.9	9.0	30.2	26.4	11.0
1995	9.8	14.6	9.5	25.1	26.9	13.5
2000	9.1	15.8	10.7	19.5	29.3	15.6

Data Source: Current Population Survey (CPS). Refers to full-time workers aged 19–65.

on shifts in relative labor demand. In fact, Table 1 shows that the employment share of managers and professionals has substantially risen, whereas the share of administrative workers in U.S. manufacturing and the producer service sector has decreased in the last two decades. For instance, in manufacturing, the combined share of managers and professionals increased by 6.3 percentage points between 1983 and 2000, from 20.3 to 26.6 percent; in producer services, it increased by as much as 12.1 percentage points in this period.

We find that, despite flexible wages, increased organizational requirements lead to downsizing of low-skilled jobs in the primary economy in a perfect-foresight equilibrium. In the absence of the usually considered biased changes in the production technology, this leads to a more compressed wage structure between skill groups in the primary sector, but to increased wage pressure in the secondary sector. Under flexible wages (the U.S. case), this results in higher wage differentiation within the group of low-skilled workers across sectors. Consequently, overall wage inequality between skill groups may increase despite wage compression in the primary economy. With a minimum wage, unemployment of low-skilled labor increases, but wage inequality declines.

The paper is organized as follows. Section 2 briefly discusses the related literature. Section 3 presents the basic structure of the economy. Section 4 derives the equilibrium in the primary economy, and Section 5 closes the model by analyzing the equilibrium in the secondary labor market. The last section concludes.

2 *Related Literature*

Our analysis is related to the literature on segregation, labor-market dualization, and organizational change. Segregation of workers can mean that firms consist of relatively homogeneous groups with respect to skill levels (KREMER [1993], KREMER AND MASKIN [1996], SAINT-PAUL [2001]). Whereas in this *assortative matching* literature similar-skilled workers receive the same wages whether working in homogeneous or in heterogenous groups, in our model some (low-skilled) workers become increasingly marginalized in a segmented labor market.

For instance, firm-size wage differentials (controlling for all individually observable characteristics of workers) have been attributed to the complexity of the firm organization (ABOWD, KRAMARZ, AND MARGOLIS [1999]). Moreover, using Swiss data, RAMIREZ [2000] finds that the share of skilled, white-collar workers within a firm (which, in line with our model, is used as proxy for a firm's organizational complexity) positively affects wages. Thus, it is plausible to hypothesize that the primary and the secondary labor market differ in the organization of firms, with more complex firms paying higher wages. This is exactly what our model predicts. As in the story suggested by ABOWD, KRAMARZ, AND MARGOLIS [1999] to explain employer-size wage differentials, high-paying firms have market power. However, in contrast to their story, in our model equilibrium profits are zero and their is no rent sharing by employers with workers. In our model, market power is implied by the costs of installing workplaces *ex ante*, which are fixed costs *ex post* (i.e., at the production stage).[5]

Other dual-labor-market models that attempt to explain the decline of (relative) earning opportunities for low-skilled labor rely on the notion of so-called skill-biased technological change, i.e., a biased shift in the relative productivity towards high-skilled workers. AGENOR AND AIZENMAN [1997] study the impact of biased technology shocks on the structure of wages when sectorial differences in monitoring technologies (and thus in efficiency wages) lead to a segmentation into primary and secondary jobs. As in our model, this implies job rationing in the sense of involuntary nonemployment in the primary labor market. (See also SAINT-PAUL [1996a] for an extensive study of labor-market segmentation in the presence of efficiency wage payments.) By contrast, in our model the primary and secondary labor market differ in the need to organize workplaces. Thus, we provide a different source of job rationing in the primary economy, related to the necessity to create workplaces *ex ante*. SAINT-PAUL [1996b] analyzes a search model with only high-skilled labor in the primary labor market and only low-skilled labor in the secondary labor market.[6] Skill-biased technological change reduces the employment of low-skilled labor, as firms have a higher incentive to wait for more productive, high-skilled workers. This incentive is stronger when more high-skilled workers are available. In our model, low-skilled workers can also be employed in the primary labor market, and high-skilled and low-skilled labor are technological complements in production. Moreover, we analyze a general-equilibrium model that emphasizes the structure

[5] For an alternative theory on size–wage differentials, focusing on coordination failures with search in both the product and the labor market, see SHI [2002].

[6] Recently, GAUTIER [2002] has extended this framework of SAINT-PAUL [1996b] by allowing for free entry of vacancies and the possibility for high-skilled workers to occupy simple jobs.

of goods demand. In contrast, the analysis of SAINT-PAUL [1996a], [1996b] is partial-equilibrium.

Finally, there is a small theoretical literature on organizational change and the distribution of earnings. LINDBECK AND SNOWER [1996], [2000] argue that decreases in information and communication costs make flexible work practices like multitasking more attractive for firms, thereby increasing the demand for versatile workers with interactive abilities. However, they do not reflect the evidence that such organizational change also requires organizational learning of workers and support by human-resource management and other qualified services providing the infrastructure for the new work practices. A positive link between increases in qualified nonproduction services and wage inequality has been established in GROSSMANN [2000], THESMAR AND THOENIG [2001], and NAHUIS AND SMULDERS [2002]. These papers study the interactions between the innovation rate, wage inequality, and the allocation of skilled workers to production-related tasks and to productivity-enhancing nonproduction ones, respectively. However, there is no dual labor market in these models, and the focus is on the wage distribution rather than on downsizing of low-skilled labor and the provision of workplaces in the primary economy.

3 *The Structure of the Dual Economy*

There are two sectors in the economy: a so-called x-sector with (an exogenous number of) n firms, which produces a differentiated good, and a y-sector with a representative firm, which produces a homogeneous good. In both sectors, labor is the only input, and firms take wages as given in their employment decisions. Technologically, the sectors differ in two characteristics. First, whereas in the x-sector the production process and thus employment require organization in firms (e.g., WEITZMAN [1982]), in the y-sector no organization of work is required. Second, whereas the x-sector employs both high-skilled and low-skilled labor, low-skilled labor is the only input in the y-sector. These characteristics are supposed to represent crucial technological features of the *primary* economy (x-sector) and the *secondary* economy (y-sector). Examples of firms in the x-sector are General Motors and IBM. Such firms are characterized by complex organizational structures, high degree of interaction among employees, and a substantial share of high-skilled workers. An extreme example of the secondary labor market is self-employment of low-skilled workers. Realistically, one may also think of (low-paid) services like cleaning or newspaper selling as activities in the y-sector, in that they barely involve interaction among employees.

The requirement of an organization in the x-sector implies that firms have to decide the design of workplaces *ex ante* (i.e., before production starts). This design encompasses two dimensions: the number of workplaces and the wage structure. In our model, they are reflected by two assumptions.

First, firms have to choose the amount of *nonproduction* (i.e., managerial) labor that is necessary to create the desired capacity of workplaces. The nonproduction labor requirements in a firm increase with the amounts of both organized high-skilled and low-skilled production labor. It is assumed that only high-skilled labor can be employed for the creation of workplaces.[7] A natural setup for a model that reflects the idea that designing workplaces is necessarily an *ex ante* decision is a two-stage framework. This follows the IO literature, which hypothesizes endogenous sunk costs for capacity investments. In our model, at stage 1, firms in the x-sector set up workplaces under perfect foresight about the *ex post* situation (i.e., about both wages and the nature of product-market competition). At stage 2 (i.e., *ex post*) firms produce and supply their output on the goods market. Since the costs for nonproduction workers to set up workplaces are sunk when firms enter stage 2, imperfect competition in the goods market is implied. In our model, we assume monopolistic competition among firms in the x-sector (in stage 2). In contrast, there is perfect competition in the y-sector.

Second, firms have to choose the wage offers for the provided workplaces. It is assumed that the provision of workplaces is accompanied by hiring activities. That means firms announce vacancies, including wage offers. In standard models (as in the secondary labor market in our model), this assumption is consistent with the notion of a Walrasian auctioneer, in letting firms announce the equilibrium wage rates. In our sunk-cost approach to workplace creation in the primary economy, the assumption of the announcement of wage offers has to be spelled out explicitly. It implies that wages in the primary labor market are fixed at the equilibrium wage level anticipated by firms under perfect foresight of aggregate employment levels in the primary economy. This assumption precludes that, at production stage 2, firms in the x-sector replace workers employed at the offered wage with workers who underbid prevailing wage rates, i.e., no arbitrage possibilities exist *ex post*. *Ex ante* wages can be chosen freely. Rational firms choose the anticipated equilibrium wage structure.

Labor markets for high-skilled and low-skilled labor are segmented, where labor supply is inelastically given by N_H and N_L, respectively.

Remark 1: The two-stage decision process of firms can be easily incorporated in a (discrete-time) dynamic framework, along the lines of YOUNG [1998]. In this framework, firms which engage in monopolistic competition in period t have to incur setup cost in $t-1$. That is, in each period t, skilled labor is allocated to both the production process of firms that organized workplaces in $t-1$ and the organization of firms that are going to produce output in $t+1$. Whereas in YOUNG [1998] firms incur costs for product innovations, in our model firms incur setup costs for organizing workplaces. As these sunk costs have to be incurred each period, the decision horizon of firms is exactly one period long. This has two implications. First, our two-stage model can be viewed as a snapshot of a dynamic model in its steady-state equilibrium. (Young shows that there are no transitional dynamics

[7] See also DAS [2001] for a model in which high-skilled workers have a double role as production and nonproduction workers. In his model, the nonproduction activity is specified as supervising in the presence of shirking of production workers.

in this kind of framework, as no capital accumulation takes place.) Second, we implicitly assume both complete turnover of workers each period and the absence of recruitment costs.[8]

3.1 Technology

Output x_i of firm i in the x-sector is produced according to the constant-returns-to-scale production technology

$$x_i = aF(h_i, l_i) \equiv al_i f(\chi_i), \qquad \chi_i \equiv h_i/l_i, \tag{1}$$

where h_i and l_i denote the amounts of high-skilled and low-skilled production labor in firm i, respectively $a > 0$, and $f(\cdot)$ is a strictly monotonic increasing and strictly concave function that fulfills the Inada conditions and $f(0) = 0$. Before production starts, workplaces $\bar{h}_i$ and $\bar{l}_i$ for high-skilled and low-skilled labor, respectively, have to be created. Employment in production is limited by the provided workplaces, that is, $h_i \leq \bar{h}_i$ and $l_i \leq \bar{l}_i$. The organizational (nonproduction) high-skilled labor requirement m_i to create production workplaces for $\bar{h}_i$ and $\bar{l}_i$ production workers in firm i is given by

$$m_i = G(\bar{h}_i, \bar{l}_i; \gamma) \equiv \bar{l}_i g(\bar{\chi}_i; \gamma), \qquad \bar{\chi}_i \equiv \bar{h}_i/\bar{l}_i, \tag{2}$$

where G is linear homogeneous, $g(\cdot; \gamma)$ is monotonic increasing in $\bar{\chi}_i$, and γ is a shift parameter. We make the convention that the effect on g of an increase in γ is positive. Moreover, following the common hypothesis in the IO literature that fixed costs and marginal production costs are negatively related, we assume that γ and the productivity parameter a are positively related. Then an increase in γ can be interpreted as a kind of technological change that is associated with an increase in total factor productivity a but rising job creation costs in the primary sector. (As shown below, a change in a does not have an independent effect on the key variables in equilibrium.) Abstracting from endogenous technology choice by firms,[9] we hypothesize that fixed managerial labor requirements per unit of workplace capacity have indeed increased. As argued in the introduction, such a shift is plausible as new business computer systems have raised the demand for "managers and professionals ... [to] co-invent improvements in processes and products" (BRESNAHAN [1999, p. F409]). Moreover, an increase in γ is consistent with increased requirements for human resource development due to changes in skill requirements of workers (e.g., LLOYD-ELLIS [1999]). Note that an increase in γ is also consistent with the evidence on white-collar employment shares reported in Table 1.

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[8] Note that these assumptions ensure that there are no holdup problems, which might otherwise arise as an implication of investments in workplace capacity and human-resource development (e.g., firm-specific training). Regarding production workers, the problem does not arise, because at stage 1 firms in the primary economy post take-it-or-leave-it wage offers to workers employed at stage 2. Nonproduction workers only work for firms in the primary economy at stage 1, and thus cannot extract rents from firms either.

[9] See FALKINGER [2002] for an analysis of endogenous adoption of the organization technology g.

Production in the y-sector is unsophisticated. Low-skilled labor is the only input. The output y of the representative unit in the y-sector is given by

$$y = L_y, \tag{3}$$

where L_y is the employment level in the y-sector.

3.2 Preferences

There is a representative consumer, deriving utility from the consumption of the differentiated good produced by the x-sector and the homogeneous good produced by the y-sector. Preferences are represented by a utility function u, which is weakly separable in these two types of goods:

$$u(x_1, ..., x_n, y) = U(X, y) = X^{\alpha} y^{1-\alpha}, \tag{4}$$

$0 < \alpha < 1$, where X is a quantity index of the differentiated good given by the CES index $X = (\sum_i x_i^{\rho})^{1/\rho}$, $0 < \rho < 1$. Thus, the elasticity of demand for each variety i produced by firm i in the x-sector is constant and given by $\sigma \equiv 1/(1-\rho)$. Denoting the price of variety i in the x-sector by p_i and the price for the homogeneous good in the y-sector by q, we have for the optimal consumption structure

$$\mathrm{mrs}_i = \frac{p_i}{q}, \qquad i = 1, ..., n, \tag{5}$$

where $\mathrm{mrs}_i \equiv u_{x_i}/u_y$ is the marginal rate of substitution between x_i and y. (Subscripts denote partial derivatives.)

3.3 Prices and Wages

After each firm in the x-sector has chosen the number of production workplaces $\bar{h}_i$ and $\bar{l}_i$ (at stage 1; see Section 4), in stage 2 firms enter monopolistic competition. Thus, as in DIXIT AND STIGLITZ [1977], prices are set at a (constant) markup over marginal costs c, i.e.,

$$p_i = \mu c = p, \tag{6}$$

where $\mu \equiv \sigma/(\sigma - 1) > 1$ is the markup factor.[10] Denote nominal wage rates for high-skilled and low-skilled production workers in the primary labor market by w_H and $w_{L,x}$, respectively. Cost minimization implies that the relative wages $w_H/w_{L,x}$ of high-skilled labor and the skill intensity χ_i in production are related by the equation

$$\omega_x \equiv \frac{w_H}{w_{L,x}} = \frac{f'(\chi_i)}{f(\chi_i) - \chi_i f'(\chi_i)} \left(= \frac{F_1}{F_2}\right). \tag{7}$$

[10] The two-stage decision process of firms in the primary economy implies that sunk nonproduction costs are not passed on to output prices. As argued above, the organizational capacity has to be determined by firms before production starts, and thus organizational costs are fixed costs at the production stage. See BLANCHARD AND GIAVAZZI [2001] for a one-sector monopolistic competition model in which entry costs are proportional to output like the organizational costs in our model. They also are not reflected in output prices.

Note that this implies $\chi_i = \chi$. Marginal costs are given by

(8) $$c = \frac{w_{L,x}}{a\,[f(\chi) - \chi f'(\chi)]},$$

according to (1) and (7). Moreover, note that at stage 2 it is optimal to utilize capacity fully, i.e., to choose employment according to $h_i = \bar{h}_i$ and $l_i = \bar{l}_i$. Finally, symmetry implies $h_i = h$, $l_i = l$, and thus $x_i = x = l f(\chi)$ in equilibrium. Note that in a perfect-foresight equilibrium the installed skill intensity in production, $\bar{\chi} = \bar{h}/\bar{l}$, coincides with the skill intensity χ implied by the cost minimization condition (7). Moreover, firms will not install capacity for producing output that cannot be sold.

In the y-sector we have perfect competition. This implies

(9) $$q = w_{L,y},$$

where $w_{L,y}$ denotes the nominal wage rate (for low-skilled labor) in this sector.

4 *Equilibrium Number of Primary Jobs*

In our two-stage framework, the perfect-foresight equilibrium is derived by backwards induction.

In the preceding section the (profit-maximizing) behavior of firms in the x-sector at stage 2 (i.e., for a given workplace capacity) has been analyzed. At stage 1, firms in the x-sector choose their profit-maximizing number of workplaces $\bar{h}_i$ and $\bar{l}_i$, perfectly foreseeing the equilibrium at stage 2 (taking aggregate levels as given). Profits in firm i are earnings at stage 2 minus the nonproduction costs incurred at stage 1. The latter are given by $w_H m_i$. Thus, the profits of firm i are given by $\pi_i = (p - c)x_i - w_H m_i$, where p is the equilibrium price determined in Section 3.3, and x_i and m_i are given by the technology functions f and g, respectively.

Using (1), (2), (6), $\chi_i = \chi$, and the fact that all workplaces installed at stage 1 will indeed be occupied at stage 2 (i.e., $h_i = \bar{h}_i$, $l_i = \bar{l}_i$, $\chi = \bar{\chi}$), we can write this in the form

(10) $$\pi_i = \left[(\mu - 1)caf(\bar{\chi}) - w_H g(\bar{\chi};\gamma)\right]\bar{l}_i.$$

An equilibrium in the primary economy is reached when, under the anticipation of the price-setting behavior of firms and the expectations of aggregate variables at stage 2, firms have no incentive to change the structure or the amount of provided workplaces at stage 1.

Lemma 1 (zero-profit equilibrium in primary economy): There exists an equilibrium in the primary economy in which firms make zero profits and $\bar{\chi} = \chi^*(\gamma)$, where $\chi^*(\gamma)$ is implicitly defined by the equation

(11) $$\underbrace{(\mu - 1)f(\bar{\chi})}_{\equiv \mathrm{APL}(\bar{\chi})} = \underbrace{f'(\bar{\chi})g(\bar{\chi};\gamma)}_{\equiv \mathrm{ACL}(\bar{\chi};\gamma)}.$$

Proof: Appendix A.1.

For the intuitive understanding of the economic mechanisms behind Lemma 1, note that (7) and (8) imply that the real wage of skilled labor (in terms of unit cost) is given by $w_H/c = af'(\bar{\chi})$. Combining this expression with (10), it is easy to see that (11) implies both $\partial\pi_i/\partial\bar{l}_i = 0$ (i.e., firms have no incentive to provide further workplaces) and $\pi_i = 0$ for all i. The existence of a zero-profit equilibrium (for any given number n of firms) is an implication of the linear homogeneity of technologies $F(\cdot)$ and $G(\cdot)$.[11] Graphically, the equilibrium skill intensity $\chi^*(\gamma)$ can be determined in a familiar return–cost diagram. The left-hand side of (11) equals the "real" average profit margin per low-skilled worker (in terms of unit costs), whereas the right-hand side equals "real" average nonproduction labor costs per low-skilled worker. (In the following we use the abbreviations APL and ACL, respectively.) APL is an increasing function of $\bar{\chi}$ (starting at zero for $\bar{\chi} = 0$), since output per low-skilled worker is raised by a higher skill intensity in production. As far as the right-hand side of (11) is concerned, a marginal increase in $\bar{\chi}$ has two effects on ACL. First, the "real" wage rate for high-skilled workers, $w_H/c = af'(\bar{\chi})$, declines from infinity at $\bar{\chi} = 0$, lowering the average costs of organizing workplaces. Second, the average nonproduction labor requirement $g(\bar{\chi})$ per low-skilled job may increase. It is assumed that the latter effect does not outweigh the former. Thus, ACL is a nonincreasing function of $\bar{\chi}$. In sum, the intersection between the APL and ACL curves determines $\bar{\chi} = \chi^*(\gamma)$ as depicted in Figure 1.

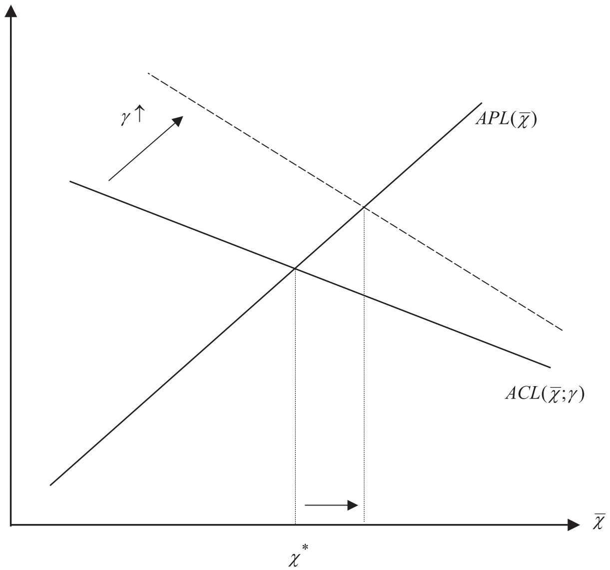
As shown in full detail in Appendix A.1, there are multiple (perfect-foresight) equilibria in the model. First, if firms expect high wages of low-skilled production workers, they wish to provide a high proportion of workplaces for skilled workers so that the expansion of employment may be constrained by skilled labor supply *before* the zero-profit condition is reached. Second, if firms have pessimistic expectations, zero-profit equilibria with unemployment of both low-skilled and high-skilled workers result.

In order to point out that job rationing (i.e., involuntary nonemployment of low-skilled labor in the primary labor market) is not the result of unfavorable expectations, we focus on the zero-profit equilibrium with full employment of high-skilled labor. This is the equilibrium at which employment in the primary labor market reaches the highest possible level.[12] This may be compared with WEITZMAN [1982], who also analyzes a monopolistic competition model where multiple (rational expectations) equilibria exist. As in the primary labor market in our model, in his model employment requires an organization in firms. (Unlike our model, his model allows neither for another sector where no organization of work is necessary nor for heterogeneity among workers.) However, in his model involuntary unemployment

[11] Thus, our equilibrium concept allows for zero profits of monopolistically competitive firms in the x-sector, despite an exogenous number of firms n. In contrast to the free-entry equilibrium of, e.g., DIXIT AND STIGLITZ [1977], employment levels rather than the number of firms adjust so that profits are driven to zero.

[12] Of course, it is also assumed that firms in the x-sector are not constrained by the supply of low-skilled labor. Otherwise the notion of a dual economy would not make sense.

Figure 1
The Skill Intensity of Production in the Primary Economy in Zero-Profit Equilibrium and the Impact of an Increase in γ



is due to pessimistic expectations. In contrast, in our model, due to its two-stage nature, involuntary nonemployment (in the primary labor market) may occur even with the most optimistic expectations.

The next result implies that, generally, there is indeed job rationing of low-skilled labor $\bar{L}_x$ $(= n\bar{l})$ in the primary economy in any zero-profit equilibrium.

Proposition 1 (job rationing): In any zero-profit equilibrium, the maximal equilibrium employment level of low-skilled labor in the primary economy, L_x^*, is given by

$$L_x^*(N_H, \gamma) = \frac{N_H}{\chi^*(\gamma) + g(\chi^*(\gamma); \gamma)}. \tag{12}$$

Proof: Full employment of high-skilled labor implies $\bar{H} + M = N_H$, where $\bar{H}$ $(= n\bar{h})$ and M $(= nm)$ are the aggregate employment levels of high-skilled labor in production-related and management activities, respectively. Note that $\bar{H} = \chi^*(\gamma)\bar{L}_x$ in equilibrium; moreover, $M = \bar{L}_x g(\chi^*(\gamma); \gamma)$, according to (2) and $\bar{\chi} = \chi^*(\gamma)$. Thus, we have $\chi^*(\gamma)\bar{L}_x + \bar{L}_x g(\chi^*(\gamma); \gamma) = N_H$, which implies (12). In zero-profit equilibria with less than full employment of N_H, the employable level of low-skilled labor $\bar{L}_x$ is clearly lower. *Q.E.D.*

The maximal zero-profit equilibrium employment level of low-skilled labor in the primary labor market, L_x^*, corresponds to optimistic expectations and thus to full employment of high-skilled labor. [In a zero-profit equilibrium with pessimistic expectations we would have H^e instead of N_H in (12), where $H^e < N_H$ is the aggregate level of employment of high-skilled labor that is expected by pessimistic firms.] As shown below, Proposition 1 implies that there is generally a wage gap between the primary and secondary labor markets (i.e., $w_{L,x} > w_{L,y}$) in equilibrium. (In a zero-profit equilibrium $w_{L,x} = w_{L,y}$ may only occur as a knife-edge case.) Workers in the secondary labor market would like to work in the primary one. However, firms provide no workplaces for them. Hence, they must supply their labor to the less attractive secondary economy. As can immediately be seen from (12), L_x^* increases with N_H. This reduces wage pressure in the secondary labor market, as is discussed in Section 5.

The further analysis concentrates on the role of technological change. The notion of skill-biased technological change played a major role in the economic literature of the 1990s.[13] However, focusing on mere changes in the production technology has been strongly criticized (e.g., DINARDO AND PISCHKE [1997]). Changes in the way firms organize work seem more relevant in practice. In our model, this means that γ increases, shifting both the g-curve and thus the ACL curve upwards. This increases the average costs of providing workplaces for low-skilled workers relative to their profit yield, implying the following.

Proposition 2 (comparative statics in the primary economy): In any zero-profit equilibrium, if γ increases, then both the equilibrium employment level of low-skilled labor in the primary labor market (L_x^*) and the relative equilibrium wage ω_x^* decline.

Proof: Apply the implicit-function theorem to condition (11) to show that χ^* increases with γ. Then use (12) and (7), respectively. *Q.E.D.*

Note that neither χ^* nor L_x^* depends on the number of firms n or the productivity parameter a in the x-sector, respectively. Therefore, our comparative-static results regarding γ apply also if a varies simultaneously with γ, i.e., if the technical and organizational changes that make workplace provision more costly lower marginal production costs. An increase in γ means that, for any skill intensity in production χ, the ACL curve shifts upwards, as depicted in Figure 1. As nonproduction

[13] The impact of skill-biased technological change on L_x^* and ω_x^* can be derived as follows. Note that, according to (7), an increase in the relative marginal productivity F_1/F_2 (for any given skill intensity in production, χ) is equivalent to an increase in $f'(\chi)/f(\chi)$. Include a parameter ζ in the production function, i.e., write $f(\cdot) = \tilde{f}(\chi;\zeta)$, representing skill-biased technological change. Then define a function $v(\chi,\zeta) = \tilde{f}_\chi(\chi;\zeta)/\tilde{f}(\chi;\zeta)$ with $v_\zeta(\chi,\zeta) > 0$. For the impact of ζ, rewrite (11) as $\mu - 1 = v(\chi^*,\zeta)g(\chi^*;\gamma)$ to confirm $\partial\chi^*/\partial\zeta > 0$ [note that the quantity $v(\chi^*,\zeta)g(\chi^*;\gamma)$ is decreasing in χ^*]. Thus, L_x^* is decreasing in ζ, according to (12). Moreover, it is straightforward but tedious to show that $\partial\omega_x^*/\partial\zeta > 0$ if and only if $v(\chi^*,\zeta) > g_\chi(\chi^*;\gamma)/g(\chi^*;\gamma)$.

requirements for low-skilled labor rise, firms in the primary economy have a disincentive to create jobs for the low-skilled. Note that, in contrast to the skill-bias literature, wage inequality decreases rather than increases in the primary economy. Also note that Proposition 2 holds in any zero-profit equilibrium, not just in one with full employment of high-skilled labor. We focus on optimistic expectations in order to discuss changes in the *maximal* (possible) equilibrium employment level in the primary labor market.

Also interestingly, wage inequality between skill groups in the primary labor market (ω_x^*) is not affected by an increase in high-skilled labor supply N_H, according to (7) and (11). This is due to the following opposing effects. First, as in conventional models with a segmented labor market for different skill groups, an increased availability of high-skilled labor reduces wage inequality, given that the skill intensity in production increases. Second, however, if N_H increases, firms have an incentive to install more workplaces which raises the demand for (high-skilled) organizational labor. (This reduces the skill intensity in production and raises relative wages.) In our model, the two effects exactly cancel.[14] As will be seen in the next section, the sign of the overall change in wage inequality depends on institutional barriers for a secondary labor market.

5 *Equilibrium in the Secondary Labor Market*

In this section, we derive the number of secondary jobs and the equilibrium wage differentiation for low-skilled labor between sectors.

The *labor supply* L_y^S in the secondary labor market equals the amount of low-skilled labor that is not employed in the primary labor market, i.e.,

$$L_y^S = N_L - L_x^*(N_H, \gamma). \tag{13}$$

The *labor demand* in the y-sector, L_y^D, is given by goods demand in this sector, implied by (5). In view of the fact that relative prices p_i/q are related [by (6), (8), and (9)] to marginal production costs in the primary and secondary economies, we obtain the following characterization of L_y^D.

Lemma 2 (labor demand in secondary economy): The following relationship between labor demand L_y^D in the y-sector and the wage differential of low-skilled labor holds:

$$\frac{w_{L,y}}{w_{L,x}} = B(L_y^D, N_H, \gamma) \equiv \frac{1-\alpha}{\alpha} \cdot \frac{L_x^*(N_H, \gamma)}{L_y^D} \cdot \frac{\mu}{1-\eta(\chi^*(\gamma))}, \tag{14}$$

where $\eta(\chi) \equiv \chi f'(\chi)/f(\chi) < 1$.

Proof: Appendix A.2.

[14] Formally, this is due to the linear homogeneity of both $F(\cdot)$ and $G(\cdot)$, which implies that the (zero-profit) equilibrium skill intensity χ^* does not depend on N_H. See EGGER AND GROSSMANN [2003] for a similar result in a different context.

B is negatively sloped in L_y^D, since mrs, the marginal rate of substitution between x and y, increases in $y = L_y^D$. By contrast, the supply curve L_y^S in (13) is vertical. For all $w_{L,y}/w_{L,x} > 1$ everybody would prefer to work in the secondary labor market.[15] For $w_{L,y}/w_{L,x} \leq 1$ the amount of low-skilled labor that is left over from the primary economy does not depend on the secondary labor market. Since the number of workplaces provided in the primary economy is limited and wages are fixed at the level offered in the announcement of vacancies, in general we have $w_{L,x} > w_{L,y}$ in equilibrium.

For the comparative-static analysis it is important to note that a cancels in (14) because of two opposing effects. On the one hand, mrs decreases with increasing a; on the other hand, the "real" equilibrium wage rate $(w_{L,x}/c)^* = a[f(\chi^*) - \chi^* f'(\chi^*)]$ of low-skilled labor in the primary economy [as implied by (8)] increases with a. In sum, variations in a do not affect the relationship between labor demand and relative wages in the secondary economy.

With flexible wages, both the equilibrium number of secondary jobs (L_y^*) and the equilibrium wage for low-skilled workers in the secondary economy relative to those in the primary economy $[(w_{L,y}/w_{L,x})^*]$ are given by the intersection of the curves defined by (13) and (14), as depicted in Figure 2. This gives us the following result.

Lemma 3 (equilibrium in the secondary economy): Under flexible wages, the equilibrium wage for low-skilled workers relative to those in the primary economy, $(w_{L,y}/w_{L,x})^*$, and equilibrium employment in the secondary economy, L_y^*, are given by

$$(15) \qquad \left(\frac{w_{L,y}}{w_{L,x}}\right)^* = B(N_L - L_x^*(N_H, \gamma), N_H, \gamma) \equiv b(N_H, N_L, \gamma)$$

and $L_y^* = N_L - L_x^*(N_H, \gamma)$, respectively, where $(w_{L,y}/w_{L,x})^* \leq 1$ must hold in such an equilibrium.

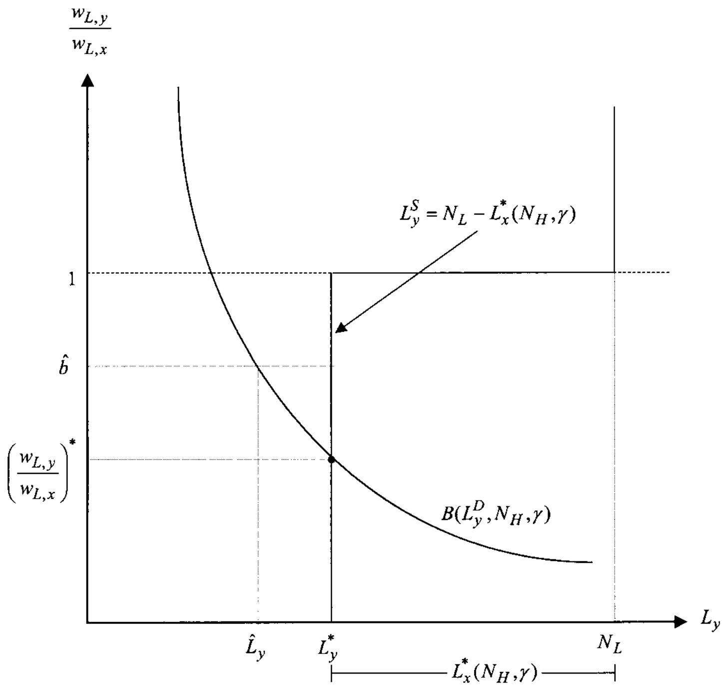
Proof: Directly follows from (13) and (14). *Q.E.D.*

Thus, under wage flexibility, $(w_{L,y}/w_{L,x})^*$ is a function of the labor supplies of both skill groups (N_H and N_L) and the shift parameter γ.[16] However, there may be limits to wage differentiation across sectors due to union power, fairness considerations among low-skilled workers across sectors, minimum wages, and the like. As Figure 2 reveals, if for some reason the sectorial wage gap $w_{L,y}/w_{L,x}$ cannot fall below a bound $\hat{b} > b(N_H, N_L, \gamma)$ (with $\hat{b} \leq 1$), there is unemployment of low-skilled labor. Note that

[15] Of course, this can never be an equilibrium situation. Again, we refer to Appendix A.1 for a detailed discussion of possible equilibria.

[16] Substituting (12) into (13) reveals that relative employment of low-skilled labor in the secondary labor market, L_y^*/N_L, is a function of relative skill supply N_H/N_L and γ. The same is true for L_x^*/L_y^*.

Figure 2
Equilibrium in the Secondary Labor Market



such a lower bound is equivalent to a real minimum wage for low-skilled labor.[17] Clearly, if $\hat{b} > b(N_H, N_L, \gamma)$, the equilibrium unemployment rate

$$\hat{u}_L = 1 - \frac{\hat{L}_y}{N_L} \tag{16}$$

is a function of $\hat{b}$, N_H, N_L, and γ, where $\hat{L}_y$ denotes equilibrium employment level in the y-sector in this case.

Note that the B-curve shifts upwards if N_H increases, according to (12) and (14). (Remember that χ^* does not depend on N_H.) Moreover, the L_y^S-curve shifts leftwards if N_H increases (or N_L decreases). Thus, an increase in N_H (or a decrease in N_L) softens wage pressure in the secondary labor market.

[17] Formally, this can be seen as follows. Denote by Γ the aggregate price index, which should be an increasing and linear homogeneous function of the output prices. We can write $\Gamma = \tilde{\Gamma}(p, q) \equiv q\beta(p/q)$ with $\beta'(\cdot) > 0$. Thus, using $p = \mu(w_{L,x}/a)/[f(\chi^*) - \chi^* f'(\chi^*)]$ and $q = w_{L,y}$, the real wage in the secondary labor market is given by $w_{L,y}/\Gamma = 1/\beta\{(w_{L,x}/w_{L,y})(\mu/a)/[f(\chi^*) - \chi^* f'(\chi^*)]\}$. Thus, imposing $w_{L,y}/w_{L,x} > \hat{b}$ puts a lower bound on the real wage in the y-sector.

How is the B-curve affected by an increase in γ? Remember that an increase in γ leads to downsizing of low-skilled labor L_x^* in the primary economy, according to Proposition 2. Such downsizing goes hand in hand with a rise in the skill intensity χ^* [see (12)]. Thus, according to (14), the condition that $\eta(\chi)$ is a non-increasing function of χ is sufficient for the B-curve not to shift upwards when γ increases. For instance, this is fulfilled if $f(\cdot)$ is isoelastic, which implies that $\eta(\cdot)$ is a constant. Moreover, it should be noted that our Cobb–Douglas utility specification (4), although simplifying the analysis, implies a rather strong substitutability between output y of the secondary economy (say, cleaning services) and the differentiated good (say, cars). If, for instance, instead of (4) we had assumed quasilinear preferences, then mrs would not depend on the total output $Q = nx$ in the primary economy. It is easy to show that the B-curve would unambiguously shift downwards in this case if γ increases.

Proposition 3 (comparative statics in secondary economy): Suppose the B-curve, defined in (14), does not shift up if γ increases. In any zero-profit equilibrium we have the following: (i) If wages are flexible, then L_y^* increases and $(w_{L,y}/w_{L,x})^*$ decreases with increasing γ. (ii) If there is a bound $\hat{b} > b(N_H, N_L, \gamma)$ on $w_{L,y}/w_{L,x}$, the equilibrium unemployment rate $\hat{u}_L$ increases with γ.

Proof: Use (12)–(16) and Proposition 2. *Q.E.D.*

Thus, an increase in γ is able to account for increasing labor-market segmentation, which is revealed by both downsizing of low-skilled labor in the primary labor market and rising wage pressure for already low-paid work in the secondary labor market. Productivity changes in a that may accompany the variations in γ do not affect this result.

As pointed out above, an increase in the skill supply N_H shifts the B-function up, and thus is a possible means to counteract the effect of γ towards segmentation and rising inequality. These opposing effects of N_H and γ remind one of the old debate on the race between education and technological change (see TINBERGEN [1975]). Also, recent discussions to promote immigration of high-skilled ("green card") labor can be interpreted as an attempt to accommodate technological changes. However, the implied reduction of N_H in the source countries has of course corresponding adverse effects.

6 Conclusion

Firm-level evidence suggests that skill upgrading, computerization, and workplace decentralization are strongly related. (For an excellent survey of this evidence, see BRYNJOLFSSON AND HITT [2000].) Moreover, the evidence suggests that skill upgrading in manufacturing firms is the result of downsizing of low-skilled labor, rather than increases in high-skilled employment (e.g., BERMAN, BOUND, AND GRICHILIS [1994]). That is, declining earning opportunities for low-skilled workers seem to be due to changes in methods of organizing work, rather than mere (biased) changes in the production technology. In our model, changes in the organization of work have a very natural place, since organization of production by nonproduction workers is the keystone of the model.

By using the endogenous-sunk-cost approach from the IO literature, our model has formalized the idea that firms (in the primary economy) have to create workplaces. We have shown that the incentive for firms to create workplaces depends on the organizational technology. On the one hand, technical progress like computerization and operational databases creates new possiblitites for managers and professionals to organize production more efficiently, thereby raising demand for skilled, white-collar workers. On the other hand, new methods of organization like customer orientation or decentralized information processing and decision making require relatively high abilities of production workers. In other words, the cost of organizing jobs for low-skilled workers rises under new, productivity-enhancing organization methods. This has been shown to induce firms in the primary economy to an upgrading of the skill structure by downsizing their low-skilled work force. The workers who are set free from the primary economy constitute an additional supply of low-skilled workers in the secondary labor market. Typically, with flexible wages the secondary economy expands and wages for low-skilled labor go down. This is not only consistent with the evidence of rising overall wage inequality in Anglo-American countries, but also with the expansion of a low-paid service sector. In contrast, with rigid wages unemployment is raised and wage inequality may even decrease, which may be viewed as the European case.

Thus, in contrast to the one-sector models in the skill-bias literature, we can deal with the phenomena of rising segregation, even in combination with decreases in wage inequality. Regarding the effects of deregulation of the labor market, the policy implications are rather negative. Although higher wage differentiation may reduce unemployment of low-skilled workers, it does not help to create jobs in the primary economy. The only remedy in our framework is to increase the supply of skilled relative to low-skilled workers.

Appendix

A.1 Proof of Lemma 1 and Perfect-Foresight Equilibria

In this appendix, we prove Lemma 1 and show which kind of (perfect-foresight) equilibria can exist in our model. Expected variables of firms in the x-sector (from the perspective of stage 1) are denoted by superscript e. $\bar{\chi}^e = \bar{H}^e/\bar{L}_x^e$ and $M^e = \bar{L}_x^e g(\bar{\chi}^e;\gamma)$ imply $H^e = \bar{H}^e + M^e = [\bar{\chi}^e + g(\bar{\chi}^e;\gamma)]\bar{L}_x^e$, where H^e denotes aggregate expected employment of high-skilled labor. If $H^e = N_H$ ($H^e < N_H$), we speak of optimistic (pessimistic) expectations.

Given expectations $\bar{\chi}^e$ for the aggregate skill intensity in production in the primary economy, each firm expects a wage differential $\omega_x^e = \Lambda(\bar{\chi}^e)$, where $\Lambda(\bar{\chi}^e) \equiv f'(\bar{\chi}^e)/\left[f(\bar{\chi}^e) - \bar{\chi}^e f'(\bar{\chi}^e)\right]$ [use (7)]. Thus, from the perspective of stage 1, the optimal (i.e., cost-minimizing) skill intensity is given by $\bar{\chi}_i = \Lambda^{-1}(\omega_x^e) = \bar{\chi}^e$. Hence, according to (10), real profits (in terms of unit costs) of firm i in the x-sector from the perspective of stage 1 can be written as

$$\hat{\pi}_i \equiv \frac{\pi_i}{c} = \left[(\mu - 1)af(\bar{\chi}^e) - \left(\frac{w_H}{c}\right)^e g(\bar{\chi}^e;\gamma)\right]\bar{l}_i$$
$$= \left[(\mu - 1)f(\bar{\chi}^e) - f'(\bar{\chi}^e)g(\bar{\chi}^e;\gamma)\right]a\bar{l}_i. \tag{A1}$$

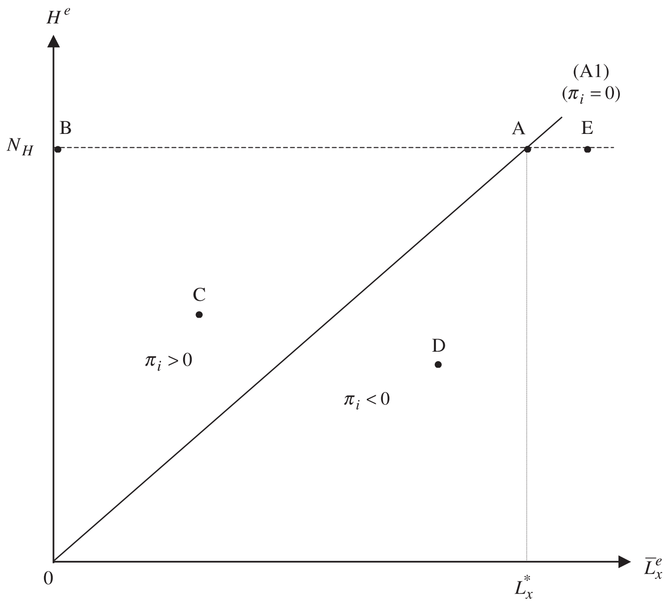
[Note that $(w_H/c)^e = af'(\bar{\chi}^e)$, according to (7) and (8).] If the factor in square brackets in (A1) is positive (negative), firms want to raise (reduce) $\bar{l}_i$ and at the same time $\bar{h}_i$ according to $\bar{h}_i/\bar{l}_i = \bar{\chi}^e$. If $\hat{\pi}_i = 0$ [i.e., $\bar{\chi}^e = \chi^*(\gamma)$ defined by (11) in Lemma 1], firms have no incentive to deviate.

If $\bar{\chi}^e = \chi^*(\gamma)$, we have

$$H^e = \left[\chi^*(\gamma) + g(\chi^*(\gamma);\gamma)\right]\bar{L}_x^e, \tag{A2}$$

which relates (expected) aggregate employment levels of high-skilled and low-skilled labor in the x-sector when profits are zero. This *zero-profit line* is depicted in Figure A1.

Figure A1
Zero-Profit Equilibrium (L_χ^*, N_H) in the Primary Economy



It is easy to see that the area above the zero-profit line in Figure A1 corresponds to positive profits, whereas the area below this line means negative profits. Since no firm has an incentive to deviate if $\hat{\pi}_i = 0$, any point on the line between points 0 and A in Figure A1 can be an equilibrium. It is easy to show that there always exist some points on the line between 0 and A where $w_{L,y} \leq w_{L,x}$ holds, i.e., there always exists a zero-profit equilibrium. This proves Lemma 1. *Q.E.D.*

Point A is the zero profit equilibrium with full employment of high-skilled labor (i.e., optimistic expectations) on which we have focused in this paper. Note that points like C, D, and E in Figure A1 cannot be equilibrium situations. At point C, the factor in square brackets in (A1) is positive, so that firms would like to raise the number of workplaces for both high-skilled and low-skilled labor. At points D and E, firms want to reduce capacity. Finally, note that any situation with full employment of high-skilled labor and nonnegative profits (not just point A, but any point on the line between B and A in Figure A1) can be a perfect-foresight equilibrium. Although at such a point (except at A) it would be profitable to raise employment levels $\bar{h}_i$ and $\bar{l}_i$ along $\bar{\chi}^e$, firms have no incentive to do so if high-skilled labor is already fully employed. They obviously cannot expect to be able to fill additional workplaces for high-skilled workers. And deviating from $\bar{\chi}^e$ by extending $\bar{l}_i$ alone would imply losses, since $\bar{\chi}^e$ is the cost-minimal choice.

A.2 Proof of Lemma 2

Substituting (6), (8), and (9), we obtain for (5)

$$\text{(A3)} \qquad \text{mrs}_i = \frac{w_{L,x}}{w_{L,y}} \frac{\mu}{a\,[f(\chi) - \chi f'(\chi)]} \left(= \frac{p}{q}\right).$$

According to (4), for $x_i = x$, we have $u_{x_i} = \alpha\,(x/y)^{\alpha-1}\,n^{(\alpha/\rho)-1}$ and $u_y = (1-\alpha)\,(x/y)^{\alpha}\,n^{\alpha/\rho}$. Thus, in a symmetric equilibrium in the primary economy, for all i we have

$$\text{(A4)} \qquad \text{mrs}_i = \frac{\alpha}{1-\alpha} \frac{y}{Q},$$

where $Q \equiv nx$ denotes total output in the primary economy. Moreover, in a symmetric equilibrium, $l_i = L_x/n$ for all i, and thus, according to (1), $Q = aL_x f(\chi)$. Substituting this and (3) into (A4), we get

$$\text{(A5)} \qquad \text{mrs} = \frac{\alpha}{1-\alpha} \frac{L_y}{aL_x f(\chi)}.$$

Evaluation of (A3) and (A5) at the equilibrium values $L_x = L_x^*(N_H, \gamma)$ and $\chi = \chi^*(\gamma)$ leads to (14). *Q.E.D.*

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