

Trade Reforms and Wage Dispersion: Workforce Composition or Rent Sharing?

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Abstract

This paper develops an estimation framework to decompose the firm wage rate into the reservation wage, which proxies for workforce composition, and wage rent, which captures rent sharing between the firm and workers. This methodology is then applied to data from Colombian manufacturing censuses from 1981 to 1991. The analysis finds that wage rent is the main contributor to the total wage rate for skilled and unskilled labor. Using trade reforms during the 1980s in Colombia, the paper shows that trade reforms significantly and substantially affect within-industry variations in the reservation wage but have almost no effects on within-industry variations in wage rent. These results indicate that much of the trade effect on wage inequality comes from the changes in workforce composition.

Keyword: Wage inequality; Workforce composition; Rent sharing; Indissoluble bargaining model; Trade reforms; Colombia

JEL Classification:

1 Introduction

There are wide variations in wage rates paid by firms within industries and within occupations. For example, using the linked employee-employer data for Brazil from 1986 to 1998, Helpman, Itskhoki, Muendler, and Redding (forthcoming) calculate that within-sector-occupation wage inequality accounts for 68 percent of the overall wage inequality, and the majority of the growth in wage inequality comes from changes in within-sector-occupation wage inequality. Similar results are uncovered in the data on Swedish employee-employer data by Akerman, Helpman, Itskhoki, Muendler, and Redding (2013).

Two theories have been proposed to explain such within-industry and within-occupation wage inequality. One strand of research considers a competitive labor market, in which workers with similar characteristics are paid the same wage rate; hence, wage inequality comes from the differences in workforce composition across firms (e.g., Yeaple, 2005; Verhoogen, 2008). The other line of literature allows firms to pay different wages to workers with the same characteristics, given the existence of labor market frictions (e.g., Davidson and Matusz, 2009; Egger and Kreickemeier, 2009; Amiti and Davis, 2012). However, thus far, these two literatures have evolved independently, and no study, to the best of our knowledge, has yet systematically evaluated their relative importance in explaining within-industry wage inequality.

This work attempts to fill the void. We develop an estimation framework to decompose firm wages into two components, the reservation wage, which proxies the composition of the workforce, and the wage rent, which captures rent between firms and workers. Our framework is general to incorporate any market structures and can be applied to all firm data with accounting information such as output, employment, capital, intermediate inputs, and wages. The crucial part of our estimation framework is the estimation of output elasticities of inputs and firm markups, which have become standard in the literature (e.g., De Loecker, 2011; De Loecker, Goldberg, Khandelwal, and Pavcnik, forthcoming. For a review, see De Loecker and Goldberg, 2014), and the bargaining between firms and employees, for which we consider two widely used protocols.

We apply our methodology to data from Colombian manufacturing censuses from 1981 to 1991. We find that wage rent is the main contributor to the total wage rate for skilled and unskilled labor. Specifically, between 1981 and 1991, on average, 76.25 percent of the skilled wage rate came from the wage rent part for skilled labor and the corresponding number for unskilled labor was 84.12 percent. Given that the reservation wage captures workforce

composition and wage rent represents the bargaining premium, these findings suggest that, in general, a firm's wage rate is not determined by its workers' characteristics (e.g., education, experience), but by bargaining between the firm and workers.

Using our estimated reservation wage and wage rent, we then investigate how much trade reforms affect within-industry wage inequality through changes in workforce composition, and how much comes from the changes in rent sharing. To this end, we follow the identification framework in the literature (i.e., Attanasio, Goldberg, and Pavcnik, 2004; Goldberg and Pavcnik, 2005); specifically, two instruments are constructed for endogenous tariff changes and the first-difference approach is used to estimate the panel data.

We find that during the 1980s in Colombia, trade reforms caused within-industry wage inequality to decrease, which is consistent with findings by Attanasio, Goldberg, and Pavcnik (2004), although they used different data. Regarding our central interest, we find that trade reforms significantly and substantially affect within-industry variations in the reservation wage but have almost no effects on within-industry variations in wage rent. These results indicate that much of the trade effect on wage inequality comes from changes in workforce composition. In other words, trade reforms change the matching between employees and employers. These results are consistent with the theoretical framework by Helpman, Itskhoki, and Redding (2010), in which they argue that intensified competition after trade liberalization forces firms to put more effort into screening their employment, causing re-matching between firms and employees.

A paper closely related to ours is by Macis and Schivardi (forthcoming). They use merged employer-employee data from Italy to investigate how much the wage premium paid by exporters is due to the workforce composition difference between exporters and non-exporters, and how much is due to the rent sharing difference between the two groups. The major differences compared with our study lie in the estimation framework and the required data structure. Macis and Schivardi (forthcoming) use the framework in Abowd, Kramarz, and Margolis (1999) to decompose the total wage rate; specifically, it regresses individual wage on individual observed characteristics, individual fixed effects (which captures all unobserved characteristics, and hence the workforce heterogeneity), and firm fixed effects (which captures rent sharing). The implementation of this methodology requires merged employer-employee data. However, our decomposition framework is based on the production function estimation, which can be applied to all firm data with operational information such as output, labor, capital, materials, and total wages.

The remainder of this paper is organized as follows. The estimation framework to recover the reservation wage and wage rent is described in Section 2. Section 3 discusses the data and presents the descriptive results from the decomposition analysis. The estimation results

for trade reform and wage inequality are presented in Section 4. The paper concludes with section 5.

2 Estimation Framework to Recover the Reservation Wage and Wage Rent

In this section, we first elucidate a theoretical framework to decompose the firm wage rate into the reservation wage (which proxies differences in workforce composition across firms) and wage rent (which captures rent sharing across firms) at the firm level, and then elaborate how to use the firm-level operational information to estimate the framework.

2.1 Benchmark Model

Consider a one-principal-to-many-agents bargaining model, where the bargaining is indissoluble; that is, even if bargaining with one agent fails, the equilibrium agreements with other agents remain valid.¹ The model follows Montez’s (2014) framework, but we extend it to include bargaining power.

Suppose a firm f at time t has a set of workers \mathcal{L}_{ft} , and each worker j chooses L_{ftj} labor inputs to supply,² where L_{ftj} is assumed to be a continuous variable.³ Denote the total labor as $L_{ft} = \sum_{j \in \mathcal{L}_{ft}} L_{ftj}$.

We assume that each worker bargains with the firm independently. Let firm f ’s total surplus from cooperation with all workers be

$$R_{it} = P_{it}Q_{it} - r_t K_{ft} - p_t^m M_{ft} - p_t^e E_{ft}$$

where P_{ft} is the price; Q_{ft} is the quantity; r_t is the rental rate of capital; p_t^m is the price of intermediate goods; p_t^e is the price of energy; and K_{ft} , M_{ft} and E_{ft} are capital, intermediate materials, and energy, respectively.⁴ And let

$$R_{ft}(-j) = P_{ft}(-j)Q_{ft}(-j) - p_t^m M_{ft}(-j) - r_t K_{ft}(-j) - p_t^e E_{ft}(-j)$$

¹In Appendix A, we consider another widely used bargaining protocol, i.e., Stole and Zwiebel’s (1996) bargaining framework, and discuss its empirical implementation as well as the results.

²To make the setup comparable with the classical literature (e.g., McDonald and Solow, 1981; Brown and Ashenfelter, 1986), we follow the convention to assume that the labor supply is inelastic when supply is less than some limit. As a result, we do not explicitly model the labor supply side.

³In the data, L_{ftj} is either 0 or 1. We choose a continuous variable L_{ftj} here to simplify the derivations.

⁴Here, we consider three additional production inputs (capital, materials, and energy) in addition to labor, mainly because of the data structure. Our framework is general to any arbitrary number of production inputs.

be the surplus from cooperation with all workers except worker j . Accordingly, the profit levels with all workers and without worker j are, respectively,

$$\pi_{ft} = R_{ft} - \sum_{j \in \mathcal{L}_{ft}} w_{ftj} L_{ftj}$$

and

$$\pi_{ft}(-j) = R_{ft}(-j) - \sum_{k \in \mathcal{L}_{ft} \setminus j} w_{ftk} L_{ftk}$$

We decompose the firm's optimization problem into two stages. Specifically, firm f first chooses inputs M_{ft} , K_{ft} and E_{ft} , and then bargains about wage rate w_{ftj} and labor supply L_{ftj} with worker j .⁵ We use backward induction to derive the solution.

In the wage bargaining stage, the wage paid to worker j is

$$w_{ftj} L_{ftj} = \min \left\{ \frac{\beta_{ftj}}{1 - \beta_{ftj}} (R_{ft} - \sum_{j \in \mathcal{L}_{ft}} w_{ftj} L_{ftj}) + w_{a,ftj} L_{ftj}, \beta_{ftj} (R_{ft} - R_{ft}(-j)) + (1 - \beta_{ftj}) w_{a,ftj} L_{ftj} \right\},$$

where β_{ftj} is worker j 's bargaining power with firm f ; and $w_{a,ftj}$ is worker j 's outside reservation wage rate (see Appendix C for the derivation).⁶

Since the bargaining is done independently, it is reasonable to assume that no worker has such an important role to affect the whole production decision. Formally, we make the following assumption:

Assumption 1 *No worker is pivotal—that is, the absence of worker j does not cause the firm to shut down, i.e., $\pi_{ft}(-j) > 0$ for any j .*

With Assumption 1, we have (see Appendix C for the derivation)

$$\beta_{ftj} (R_{ft} - R_{ft}(-j)) + (1 - \beta_{ftj}) w_{a,ftj} L_{ftj} < \frac{\beta_{ftj}}{1 - \beta_{ftj}} (R_{ft} - \sum_{j \in \mathcal{L}_{ft}} w_{ftj} L_{ftj}) + w_{a,ftj} L_{ftj}.$$

Therefore, the wage paid to worker j becomes

$$w_{ftj} L_{ftj} = \beta_{ftj} (R_{ft} - R_{ft}(-j)) + (1 - \beta_{ftj}) w_{a,ftj} L_{ftj}. \quad (1)$$

⁵In the literature, materials and energy are often considered as flexible inputs (e.g., De Loecker, Goldberg, Khandelwal, and Pavcnik, forthcoming). In Appendix B, we consider an alternative scenario where labor is determined before the decision about materials and energy, but maintain the assumption that capital is determined first and not adjustable. We derive a similar estimation framework for the reservation wage and wage rent, and the estimation results are also similar.

⁶This bargaining solution coincides with the *Nucleolus* of a bankruptcy problem with some adjustments in bargaining power. Specifically, if all $\beta_{itj} = \frac{1}{2}$, this is the Nucleolus of a bankruptcy problem (see Montez, 2014 for more on this).

Next, we consider the firm's employment decision. Note that bargaining is indissoluble; that is, if other workers are paid by $\{w_{fjk}^* L_{fjk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}$ in equilibrium, whether the agreement with worker j is achieved or not does not affect $\{w_{fjk}^* L_{fjk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}$. In other words, other workers do not re-bargain over $\{w_{fjk}^* L_{fjk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}$ even if j leaves, and the equilibrium $R_{ft}^*(-j)$ does not depend on L_{ftj} . As a result, the firm's profit, given $\{w_{fjk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}$ and $\{L_{fjk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}$, can be written as

$$\begin{aligned} \pi_{ft}(w_{ftj} L_{ftj}, \{w_{fjk}^* L_{fjk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}) &= R_{ft} - w_{ftj} L_{ftj} \\ &= (1 - \beta_{ftj}) R_{ft} + \beta_{ftj} R_{ft}^*(-j) \\ &\quad - \sum_{k \in \mathcal{L}_{ft} \setminus j} w_{fjk}^* L_{fjk}^* - (1 - \beta_{ftj}) w_{a,ftj} L_{ftj}, \end{aligned}$$

where in the second step we plug in wage equation (1) given $R_{ft}^*(-j)$.

The first-order condition with respect to L_{ftj} is

$$\frac{\partial \pi_{ft}}{\partial L_{ftj}} = \frac{\partial P_{ft}}{\partial Q_{ft}} \frac{\partial Q_{ft}}{\partial L_{ftj}} Q_{ft} + P_{ft} \frac{\partial Q_{ft}}{\partial L_{ftj}} - w_{a,ftj} = 0,$$

which yields

$$w_{a,ftj} = \frac{P_{ft}}{\mu_{ft}} \frac{\partial Q_{ft}}{\partial L_{ftj}}, \quad (2)$$

where $\mu_{ft} = \left[\frac{\partial P_{ft}}{\partial Q_{ft}} \frac{Q_{ft}}{P_{ft}} + 1 \right]^{-1}$ is the firm's markup; and L_{fjk}^* is a function of K_{ft} , M_{ft} and E_{ft} .

Given the employment decision $\{L_{fjk}^*(K_{ft}, M_{ft}, E_{ft})\}$ contingent on (K_{ft}, M_{ft}, E_{ft}) , we now go back to the firm's first-stage problem; that is, firm f 's decisions over M_{ft} , K_{ft} , or E_{ft} . We assume that once M_{ft} , K_{ft} , and E_{ft} are employed, they cannot be adjusted regardless of whether individual j is in or out of the production team, i.e. $K_{ft}(-j) = K_{ft}$, $M_{ft}(-j) = M_{ft}$, and $E_{ft}(-j) = E_{ft}$ for any j .⁷ The firm's problem can be written as

$$\begin{aligned} \max_{\{K_{ft}, M_{ft}, E_{ft}\}} \pi_{ft} &= R_{ft}(K_{ft}, M_{ft}, E_{ft}, \{L_{fjk}^*(K_{ft}, M_{ft}, E_{ft})\}_{j \in \mathcal{L}_{ft}}) \\ &\quad - \sum_{j \in \mathcal{L}_{ft}} w_{fjk}^*(K_{ft}, M_{ft}, E_{ft}) L_{fjk}^*(K_{ft}, M_{ft}, E_{ft}), \end{aligned}$$

where R_{ft} depends on (K_{ft}, M_{ft}, E_{ft}) and $L_{fjk}^*(K_{ft}, M_{ft}, E_{ft})$ for $j \in \mathcal{L}_{ft}$.

⁷This assumption is not crucial in our analysis. An alternative assumption could be that K_{ft} is not adjustable, but M_{ft} or E_{ft} can be adjusted, which may have a minor effect in the quantitative exercise.

By the envelope theorem, we have

$$\frac{\partial \pi_{ft}}{\partial K_{ft}} = \frac{\partial R_{ft}}{\partial K_{ft}} + \sum_{j \in \mathcal{L}_{ft}} \left(\frac{\partial}{\partial L_{ftj}} [R_{ft} - w_{ftj} L_{ftj}] \Big|_{L_{ftj} = L_{ftj}^*(K_{ft}, M_{ft}, E_{ft})} \right) \frac{\partial L_{ftj}^*}{\partial E_{ft}} = \frac{\partial R_{ft}}{\partial K_{ft}},$$

where $L_{ftj}^*(K_{ft}, M_{ft}, E_{ft})$ maximizing $R_{ft} - \sum_{k \in \mathcal{L}_{ft} \setminus j} w_{ftk}^* L_{ftk}^* - w_{ftj} L_{ftj}$ (note that $\sum_{k \in \mathcal{L}_{ft} \setminus j} w_{ftk}^* L_{ftk}^*$ does not depend on L_{ftj}) leads to

$$\frac{\partial}{\partial L_{ftj}} [R_{ft} - w_{ftj} L_{ftj}] \Big|_{L_{ftj} = L_{ftj}^*(K_{ft}, M_{ft}, E_{ft})} = 0.$$

Therefore, we have three first-order conditions:

$$\begin{cases} \frac{\partial R_{ft}}{\partial K_{ft}} = \frac{\partial P_{ft}}{\partial Q_{ft}} \frac{\partial Q_{ft}}{\partial K_{ft}} Q_{ft} + P_{ft} \frac{\partial Q_{ft}}{\partial K_{ft}} - r_t = 0 \\ \frac{\partial R_{ft}}{\partial M_{ft}} = \frac{\partial P_{ft}}{\partial Q_{ft}} \frac{\partial Q_{ft}}{\partial M_{ft}} Q_{ft} + P_{ft} \frac{\partial Q_{ft}}{\partial M_{ft}} - p_t^m = 0 \\ \frac{\partial R_{ft}}{\partial E_{ft}} = \frac{\partial P_{ft}}{\partial Q_{ft}} \frac{\partial Q_{ft}}{\partial E_{ft}} Q_{ft} + P_{ft} \frac{\partial Q_{ft}}{\partial E_{ft}} - p_t^e = 0 \end{cases}, \quad (3)$$

which jointly determine the optimal $(K_{ft}^*, M_{ft}^*, E_{ft}^*)$ and complete the model.

2.2 Reservation Wage and Wage Rent for Occupations

The key equation is equation (2), which backs out the reservation wage rate $w_{a,ftj}$. And once $w_{a,ftj}$ is estimated, the wage rent rate can be calculated as the difference between the wage rate and the reservation wage rate, i.e., $w_{r,ftj} = w_{ftj} - w_{a,ftj}$. Given that our data contain information for groups of labor, i.e., skilled and unskilled labor, we need to estimate equation (2) when data with different occupation information are available.

Assume that we now observe that workers are coarsely divided into several subgroups, $J_1, \dots, J_k, \dots, J_G$ —for example, production, mid-level management, top-rank management, and others. Within each subgroup, the workers are assumed to be identical. In other words, we observe

$$L_{ftJ_k} = \sum_{j \in \mathcal{J}_k} L_{ftj},$$

where \mathcal{J}_k denotes the set of workers in subgroup k .

In this case, we can estimate the output elasticity of subgroup J_k from the production function, i.e., $\theta_{ftJ_k}^l = \frac{\partial Q_{ft}}{\partial L_{ftJ_k}} \frac{L_{ftJ_k}}{Q_{ft}}$. Then, the reservation wage rate and wage rent rate for each each subgroup J_k can be calculated, respectively, as

$$reservation_{ftJ_k} = \frac{P_{ft} Q_{ft}}{\mu_{ft} L_{ftJ_k}} \theta_{ftJ_k}^l, \quad (4)$$

and

$$rent_{ftJ_k} = \sum_{j \in J_k} \frac{w_{ftj} L_{ftj}}{L_{ftJ_k}} - \frac{P_{ft} Q_{ft}}{\mu_{ft} L_{ftJ_k}} \theta_{ftJ_k}^l.$$

2.3 Estimation of the Production Function with Skilled and Unskilled Labor

According to equation (4), calculation of the reservation wage rates for skilled and unskilled labor requires information on total revenue, employment of the concerned labor, firm markup, and output elasticity of the concerned labor. As the first two variables can be directly taken from the data, we need to estimate output elasticities and firm markup. A crucial step for obtaining firm-level output elasticities and firm markup is estimation of the production function, which is presented in the following.

Consider the following translog production function in logs:

$$\begin{aligned} q_{ft} = & \theta_s l_{ft}^s + \theta_u l_{ft}^u + \theta_k k_{ft} + \theta_m m_{ft} + \theta_e e_{ft} + \theta_{ss} (l_{ft}^s)^2 + \theta_{uu} (l_{ft}^u)^2 + \theta_{kk} k_{ft}^2 + \theta_{mm} m_{ft}^2 + \theta_{ee} e_{ft}^2 \\ & + \theta_{su} l_{ft}^s l_{ft}^u + \theta_{sk} l_{ft}^s k_{ft} + \theta_{sm} l_{ft}^s m_{ft} + \theta_{se} l_{ft}^s e_{ft} + \theta_{uk} l_{ft}^u k_{ft} + \theta_{um} l_{ft}^u m_{ft} + \theta_{ue} l_{ft}^u e_{ft} \\ & + \theta_{km} k_{ft} m_{ft} + \theta_{ke} k_{ft} e_{ft} + \theta_{me} m_{ft} e_{ft} + \omega_{ft} + \varepsilon_{ft}, \end{aligned} \quad (5)$$

where lowercase letters represent the logarithm of the uppercase letters; s and u indicate skilled and unskilled labor, respectively; ω_{ft} is firm productivity; and ε_{ft} is measurement error and/or unanticipated shocks to output.

To obtain consistent production function estimates $\theta = \begin{pmatrix} \theta_s, \theta_u, \theta_k, \theta_m, \theta_e, \theta_{ss}, \theta_{uu}, \theta_{kk}, \theta_{mm}, \theta_{ee}, \\ \theta_{su}, \theta_{sk}, \theta_{sm}, \theta_{se}, \theta_{uk}, \theta_{um}, \theta_{ue}, \theta_{km}, \theta_{ke}, \theta_{me} \end{pmatrix}$, we need to control for unobserved productivity shocks potentially leading to simultaneity and selection biases.

There is a large literature on estimation of the production function, focusing on how to control for unobserved productivity ω_{ft} (for a review, see Akerberg, Benkard, Berry, and Pakes, 2007). The solution ranges from instrumental variable estimation, to generalized method of moments (GMM) estimation, to the control function approach pioneered by Olley and Pakes (1996). We adopt the control function approach developed by Akerberg, Caves, and Frazier (2015), which consists of a two-step estimation.

Specifically, we proxy for unobserved productivity using the following energy demand equation:

$$e_{ft} = e_t(l_{ft}^s, l_{ft}^u, k_{ft}, m_{ft}, \omega_{ft}). \quad (6)$$

Inverting (6) yields the following control function for productivity:

$$\omega_{ft} = h_t(l_{ft}^s, l_{ft}^u, k_{ft}, m_{ft}, e_{ft}).$$

In the first stage, we estimate the following equation:

$$q_{ft} = \phi_t(l_{ft}^s, l_{ft}^u, k_{ft}, m_{ft}, e_{ft}) + \varepsilon_{ft},$$

which yields an estimate of predicted output $\hat{\phi}_{ft}$. This implies the productivity for given values of $\boldsymbol{\theta}$:

$$\begin{aligned} \omega_{ft}(\boldsymbol{\theta}) = & \hat{\phi}_{ft} - \theta_s l_{ft}^s - \theta_u l_{ft}^u - \theta_k k_{ft} - \theta_m m_{ft} - \theta_e e_{ft} - \theta_{ss} (l_{ft}^s)^2 - \theta_{uu} (l_{ft}^u)^2 - \theta_{kk} k_{ft}^2 - \theta_{mm} m_{ft}^2 \\ & - \theta_{ee} e_{ft}^2 - \theta_{su} l_{ft}^s l_{ft}^u - \theta_{sk} l_{ft}^s k_{ft} - \theta_{sm} l_{ft}^s m_{ft} - \theta_{se} l_{ft}^s e_{ft} - \theta_{uk} l_{ft}^u k_{ft} - \theta_{um} l_{ft}^u m_{ft} \\ & - \theta_{ue} l_{ft}^u e_{ft} - \theta_{km} k_{ft} m_{ft} - \theta_{ke} k_{ft} e_{ft} - \theta_{me} m_{ft} e_{ft}. \end{aligned}$$

To recover all the production function coefficients $\boldsymbol{\theta}$ in the second stage, we model that firm productivity follows a first-order Markov movement, i.e., $\omega_{ft}(\boldsymbol{\theta}) = g_t(\omega_{ft-1}(\boldsymbol{\theta})) + \xi_{ft}(\boldsymbol{\theta})$, where ξ_{ft} is an idiosyncratic shock.

The innovation in productivity $\xi_{ft}(\boldsymbol{\theta})$ can be obtained by nonparametrically regressing $\omega_{ft}(\boldsymbol{\theta})$ on $\omega_{ft-1}(\boldsymbol{\theta})$. We construct moments and use GMM techniques to obtain estimates of the production function coefficients. Specifically, to comply with our model in Section 2.1, we model capital, materials, and energy as dynamic inputs and their moment conditions are constructed using their current values. Meanwhile, as skilled and unskilled labor can be freely adjusted, they are considered as flexible inputs and their lagged values are used to construct the moment conditions. Therefore, the moment conditions are:

$$E(\xi_{ft}(\boldsymbol{\theta}) \mathbf{Y}_{ft}) = 0,$$

where \mathbf{Y}_{ft} contains $l_{ft-1}^s, (l_{ft-1}^s)^2, l_{ft-1}^u, (l_{ft-1}^u)^2, k_{ft}, k_{ft}^2, m_{ft}, m_{ft}^2, e_{ft}, e_{ft}^2, l_{ft-1}^s k_{ft}, l_{ft-1}^s m_{ft}, l_{ft-1}^s e_{ft}, l_{ft-1}^u k_{ft}, l_{ft-1}^u m_{ft}, l_{ft-1}^u e_{ft}, k_{ft} m_{ft}, k_{ft} e_{ft}, m_{ft} e_{ft}$.

We estimate the translog production function (5) separately for each two-digit industry. To construct the quantity-based variables in the production function, we follow the approach in Roberts (1996). Specifically, from the nominal and real output values, we construct the industry-specific output price index, and use it to deflate the nominal output value to get the quantity of output. The quantity terms for labor and energy come directly from the data.

We obtain the raw material price index from the Colombian Central Bank, and use it to deflate the value of materials to get the quantity of materials. Construction of the quantity of capital takes a few steps, as we only observe investment values. Specifically, the data provide information on book values and investment for five types of capital: buildings and structures, machinery and equipment, land, transportation equipment, and office equipment. For each type of capital, we calculate the yearly stock using the perpetual inventory method

$$K_{fht} = (1 - \delta_h)K_{fht-1} + I_{fht},$$

where f , h , and t denote firm, type of capital, and year, respectively; K_{fht} is the stock of capital h in firm f in year t ; I_{fht} is investment in capital h made by firm f in year t ;⁸ and δ_h is the depreciation rate of capital h .⁹ The total amount of capital stock for firm f in year t is $K_{ft} = \sum_h K_{fht}$.

2.4 Implementation of the Indissoluble Bargaining Model

With the estimates from the production function, we are ready to calculate the firm-level reservation wage and wage rent.

Specifically, with $\hat{\theta}$, we can calculate the output elasticities for skilled and unskilled labor, respectively, as

$$\hat{\theta}_{ft}^s = \hat{\theta}_s + 2\hat{\theta}_{ss}l_{ft}^s + \hat{\theta}_{su}l_{ft}^u + \hat{\theta}_{sk}k_{ft} + \hat{\theta}_{sm}m_{ft} + \hat{\theta}_{se}e_{ft},$$

and

$$\hat{\theta}_{ft}^u = \hat{\theta}_u + 2\hat{\theta}_{uu}l_{ft}^u + \hat{\theta}_{su}l_{ft}^s + \hat{\theta}_{uk}k_{ft} + \hat{\theta}_{um}m_{ft} + \hat{\theta}_{ue}e_{ft}.$$

To recover the firm-level markup, we follow the recent work of De Loecker and Warzynski (2012). To maintain consistency with the exposition in the theoretical part, we present the estimation in terms of a profit maximization framework, which is equivalent to a cost minimization problem, as De Loecker and Warzynski (2012) point out.

The first-order condition for energy in equation (3) can be rewritten as

$$P_{ft} \left[1 + \frac{\partial P_{ft}}{\partial Q_{ft}} \frac{Q_{ft}}{P_{ft}} \right] \cdot \frac{\partial Q_{ft}}{\partial E_{ft}} \frac{E_{ft}}{Q_{ft}} = \frac{p_t^e E_{ft}}{Q_{ft}},$$

⁸Specifically, investment in Buildings and Structures is deflated by the construction price index from the Colombian Central Bank; investment in Machinery and Equipment is deflated by the average price index of Machinery (ISIC 382) and Electrical Machinery (383); investment in Land is deflated by the GDP deflator; investment in Transport Equipment is deflated by the price index of Transport Equipment (384); and investment in Office Equipment is deflated by the price index of Professional and Scientific Equipment (385).

⁹Specifically, the depreciation rate is 5 percent for buildings and structures; 10 percent for machinery and office equipment; 0 percent for land; and 20 percent for transportation equipment.

where $P_{ft} \left[1 + \frac{\partial P_{ft}}{\partial Q_{ft}} \frac{Q_{ft}}{P_{ft}} \right]$ is marginal revenue, which is equal to the marginal cost of production at the optimum. Therefore, we obtain our estimation expression for the firm-level markup¹⁰

$$\mu_{ft} = \theta_{ft}^e (\alpha_{ft}^e)^{-1}, \quad (7)$$

where $\theta_{ft}^e \equiv \frac{\partial Q_{ft}}{\partial E_{ft}} \frac{E_{ft}}{Q_{ft}}$ is the output elasticity of energy; and $\alpha_{ft}^e \equiv \frac{p_t^e E_{ft}}{P_{ft} Q_{ft}}$ is the share of expenditure on energy in total revenue.

α_{ft}^e can be readily calculated using the information in the data. And with the estimated $\hat{\theta}$, we can calculate the output elasticities of energy as

$$\hat{\theta}_{ft}^e = \hat{\theta}_e + 2\hat{\theta}_e e_{ft} + \hat{\theta}_{se} l_{ft}^s + \hat{\theta}_{ue} l_{ft}^u + \hat{\theta}_{ke} k_{ft} + \hat{\theta}_{me} m_{ft}.$$

Hence, the estimated firm markup $\hat{\mu}_{ft}$ can be recovered through equation (7).

With $\hat{\theta}_{ft}^s$, $\hat{\theta}_{ft}^u$ and $\hat{\mu}_{ft}$, we are able to recover the reservation wage rates for skilled and unskilled labor as

$$reservation_{ft}^o = \frac{P_{ft} Q_{ft} \hat{\theta}_{ft}^o}{\hat{\mu}_{ft} L_{ft}^o},$$

where $o = \{s, u\}$.

Meanwhile, the wage rent rates for skilled and unskilled labor are

$$rent_{ft}^o = w_{ft}^o - reservation_{ft}^o,$$

where w_{ft}^o is the wage rate paid to worker o by firm f in year t .

3 Data and Descriptives

3.1 Data

Our data come from the Colombian manufacturing censuses from 1981 to 1991, collected by the Departamento Administrativo Nacional de Estadística. The data cover all firms with 10 or more employees, and have an unbalanced panel of 76,093 firms across 19 two-digit ISIC industries.¹¹

¹⁰Note that this expression holds under any form of competition. In particular, De Locker and Warzynski (2012) discuss some alternative settings of market competition, including Cournot competition, Bertrand competition, and monopolistic competition, which lead to a similar estimation expression for firm-level markup.

¹¹The industry classification of the data is the International Standard Industrial Classification (ISIC). The industries in the data are Food Products (311, 312, 313), Tobacco (314), Textiles (321), Clothing and Apparel (322), Leather and Leather Products (323, 324), Wood and Wood Products (331), Paper (341), Printing and Publishing (342), Chemicals (351, 352), Petroleum and Coal Products (353, 354), Rubber and Plastic

The data contain detailed information on firm-level output, different types of labor and wage bills, investment, materials, and energy. The data record nominal and real values of output, the value of investment, and materials. The data also contain information for six types of workers, specifically, management staff, skilled workers, local technicians, foreign technicians, unskilled workers, and apprentices. To increase prediction power and reduce measurement errors, we classify the six types of labor into two groups: (i) skilled labor, which includes management staff, skilled workers, local technicians, and foreign technicians; and (ii) unskilled labor, which includes unskilled workers and apprentices. Moreover, the data report the value and quantity of energy consumption. For a detailed description of the data set, see Roberts (1996).

3.2 Total Wage, Reservation Wage, and Wage Rent

We apply the estimation framework in Section 2 to the data from the Colombian manufacturing censuses. We decompose the total wage rate into the reservation wage and wage rent for skilled labor and unskilled labor.¹² The results are reported in Table 1, with panels A and B for skilled labor and unskilled labor, respectively.

[Insert Table 1 Here]

As shown in column 1, there were steady increases in skilled and unskilled wage rates, with the former being modestly faster (i.e., 18.43 percent of growth for skilled labor versus 12.94 percent for unskilled labor between 1981 and 1991). Meanwhile, the average wage rate for skilled labor was about 65 percent greater than that for unskilled labor during this period, reflecting a substantial skill premium.

Columns 2 and 3, respectively, show the contributions to the total wage rate by the reservation wage and wage rent, which are estimated from the indissoluble bargaining model. Wage rent is the main contributor to the total wage rate for skilled labor: between 1981 and 1991, on average, 76.25 percent of the skilled wage rate came from the wage rent part. This number becomes even larger for unskilled labor—that is, between 1981 and 1991, on average, wage rent contributed to 84.12 percent of the unskilled wage rate.

As the reservation wage captures the quality of the labor force and wage rent represents the bargaining premium, these findings suggest that, in general, a firm’s wage rate is not

Products (355, 356), Other Non-metallic Mineral Products (361, 362, 369), Basic Metals (371, 372), Metal Products (381), Machinery (382), Electrical Machinery (383), Transport Equipment (384), Professional and Scientific Equipment (385), and Furniture and Miscellaneous Manufacturing Industries (332, 390).

¹²We use nominal wage rates and deflate them by the consumer price index to achieve comparability over time.

determined by its workers' characteristics (e.g., education, experience), but by bargaining between the firm and workers.

In Appendix Tables A1 and A2, we further report the decomposition of the total wage rate into the reservation wage and wage rent components for each of the 19 two-digit industries. There are variations in the average total wage rate across industries—for example, monopolized and capital-intensive industries (such as Tobacco, Petroleum and Coal Products, and Basic Metals) pay high wage rates, whereas competitive and labor-intensive industries (such as Clothing and Apparel, Furniture and Miscellaneous, and Leather and Leather products) have low wage rates. Across all industries, wage rent always contributes to the majority of the total wage rate for skilled and unskilled labor. For example, the contribution of wage rent for skilled labor ranges from 63.72 to 86.02 percent in the indissoluble bargaining model.

4 Trade Reforms and Wage Inequality

We now apply our estimated reservation wage and wage rent to trade reforms in Colombia during the 1980s, to investigate how much trade reforms affect within-industry wage inequality through changes in workforce composition across firms and through changes in rent sharing across firms.

4.1 Trade Reforms in Colombia

During the late 1970s and early 1990s, Colombia underwent significant changes in tariff rates. The trade reform process can be divided into three periods: (i) trade liberalization period (1977–1981); (ii) trade protection period (1982–1983); and (iii) trade re-liberalization period (1984–1991). During the late 1970s, the Colombia government gradually liberalized the trade environment by reducing import restrictions. The country's average tariff dropped from 39 percent in 1977 to 32 percent in 1982. From the late 1970s to the early 1980s, exchange rate appreciation due to soaring world coffee prices, foreign borrowing, and illegal drug trade contributed to a tightening of trade restrictions. Specifically, in 1984, Colombia's average tariff increased dramatically to reach 53 percent. During 1984–1991, the launch of an adjustment policy financed by international financial institutions led to another trade liberalization. The average tariff rate dropped to around 21 percent in 1991.

Figure 1 plots Colombia's average tariff rate during 1977–1991. Tariff rates dropped gradually during 1977–1981, followed by a sharp increase from 1982 to 1984, and another round of substantial reduction during the period 1984–1991. In this paper, we focus on

1984–1991, the period characterized by the most significant tariff reductions.

[Insert Figure 1 Here]

4.2 Estimation Framework

Our estimation model follows those used in the literature on trade reforms in Colombia (i.e., Attanasio, Goldberg, and Pavcnik, 2004; Goldberg and Pavcnik, 2005). Specifically, it takes the following form

$$\Delta y_{st} = \beta \Delta tariff_{st} + \Delta \mathbf{X}_{st} \cdot \boldsymbol{\gamma} + \lambda_t + \Delta \varepsilon_{st}, \quad (8)$$

where $\Delta y_{st} \equiv y_{st} - y_{st-1}$ measure the first difference of wage inequality in industry s between t and $t-1$; $\Delta tariff_{st}$ is our regressor of interest, capturing the change of import tariffs between t and $t-1$ in Colombia; λ_t is year fixed effects, controlling for all yearly shocks that are common to all industries; and $\Delta \varepsilon_{st}$ is the error term.

The concern in unbiased identification of β is the potential correlation between $\Delta tariff_{st}$ and $\Delta \varepsilon_{st}$. Goldberg and Pavcnik (2005) discuss in detail how the above equation can effectively control for this endogeneity issue. The first difference purges all the possible correlation between $\Delta tariff_{st}$ and $\Delta \varepsilon_{st}$ caused by time-invariant industry characteristics, such as industry inherent heterogeneity. Meanwhile, to capture any time-varying omitted variables, such as political considerations of tariff protection, several controls are included in $\Delta \mathbf{X}_{st}$, such as lagged exports, lagged imports, output, and capital. Finally, instrumental variable estimation is used to address the endogeneity issue. Two time-varying instruments are proposed by Goldberg and Pavcnik (2005): $tariff_{s1983} \times exchange\ rate_t$ and $tariff_{s1983} \times coffee\ price_t$, in which $tariff_{s1983}$ reflects the pre-sample protection degrees across industries, while $exchange\ rate_t$ and $coffee\ price_t$ reflect time variations.

Our outcome variable y_{st} concerns the degree of wage inequality in industry. Following the literature (e.g., Akerman, Helpman, Itskhoki, Muendler, and Redding, 2013; Helpman, Itskhoki, Muendler, and Redding, forthcoming), we use the standard deviation of wage (in log) within an industry to measure the degree of within-industry wage inequality, i.e.,

$$y_{st} \equiv \frac{1}{N_f} \sum_f (\ln w_{fst} - \overline{\ln w}_{st})^2,$$

where $\ln w_{fst}$ is the wage rate (in log) paid by firm f in industry s in year t ; and $\overline{\ln w}_{st}$ is the average wage rate in industry s in year t .

To investigate whether the effect of trade reforms on within-industry wage inequality comes from changes in workforce composition and/or changes in rent sharing, we further

decompose the within-industry wage inequality into the within-industry variations in reservation wage rates, the variation in wage rent rates, and their covariance. To simplify the decomposition, we redefine wage rent as $\ln rent_{fst} = \ln w_{fst} - \ln reservation_{fst}$. Hence, we have

$$\begin{aligned} y_{st} &= \frac{1}{N_f} \sum_f (\ln w_{fst} - \overline{\ln w}_{st})^2 \\ &= \frac{1}{N_f} \sum_f (\ln reservation_{fst} + \ln rent_{fst} - \overline{\ln reservation}_{st} - \overline{\ln rent}_{st})^2 \\ &= y_{st}^{reservation} + y_{st}^{rent} + y_{st}^{cov}, \end{aligned}$$

where

$$\begin{aligned} y_{st}^{reservation} &\equiv \frac{1}{N_f} \sum_f (\ln reservation_{fst} - \overline{\ln reservation}_{st})^2 \\ y_{st}^{rent} &\equiv \frac{1}{N_f} \sum_f (\ln rent_{fst} - \overline{\ln rent}_{st})^2 \\ y_{st}^{cov} &\equiv \frac{2}{N_f} \sum_f (\ln rent_{fst} - \overline{\ln rent}_{st}) (\ln reservation_{fst} - \overline{\ln reservation}_{st}). \end{aligned}$$

4.3 Empirical Findings

The instrumental variables estimation results are reported in Table 2, in which we do not add time-varying industry controls and two instruments are used in panels A and B, respectively.

Column 1 shows that higher import tariffs are associated with greater within-industry wage inequality for the total labor force. In columns 2 and 3, we report the effect of trade reforms on within-industry wage inequality for skilled labor and unskilled labor, respectively. We find similar positive effects of tariffs on within-industry wage inequality for skilled and unskilled labor, although the coefficient for the latter is small and statistically insignificant. These results are consistent with those by Attanasio, Goldberg, and Pavcnik (2004) for the same sample period, despite the fact that they collect wage information from national household surveys, whereas our data come from firm-level surveys. Meanwhile, Helpman, Itskhoki, Muendler, and Redding's (2015) theoretical model suggests that the abolishment of the autarky regime leads to a decrease in wage inequality, but further trade reforms cause an increase in wage inequality, further corroborating our findings.

[Insert Table 2 Here]

Regarding our central interest, the remaining columns in Table 2 illustrate whether the change in within-industry wage inequality in response to trade reforms comes through the

change in within-industry variations in the reservation wage rates and/or within-industry variations in the reservation wage rents. In columns 4 and 6, we find a significant and substantial effect of trade reforms on within-industry variations in reservation wage rates for skilled and unskilled labor, whereas almost no effects on within-industry variations in wage rents are revealed in columns 5 and 7.

Given that the reservation wage proxies for workforce composition heterogeneity, these results imply that much of the effect of trade reforms on within-industry wage inequality comes from changes in workforce composition instead of changes in rent sharing. These results resonate with the theoretical findings by Helpman, Itskhoki, and Redding (2010); specifically, intensified market competition caused by trade liberalization pushes firms to make greater efforts in screening in their recruiting and employment, which leads to better matching between workers and firms and hence more heterogeneity in workforce composition across firms within the industry.

Robustness.—We conduct a few robustness checks on the results. First, we add the time-varying industry controls and present the estimation results in Table 3. We find robust results that trade reforms have statistically significant effects on within-industry variations in reservation wage rates, but almost no effect on within-industry variations in wage rents.

[Insert Table 3 Here]

Second, as in Amiti and Davis (2012), a decline in input tariffs will increase the wages of firms using import inputs relative to those of firms that do not. Following this argument, we include input tariffs in the regressions as a further check on any omitted variables. Specifically, input tariffs in sector j are constructed as a weighted average of the tariffs on the goods that sector j procures:

$$input\ tariff_{jt} = \sum_s \omega_{js} \times tariff_{st}, \quad \omega_{js} = \frac{input_{sj}}{\sum_s input_{sj}},$$

where $input_{sj}$ is the value of intermediate inputs from sector s to produce the unit value of output in sector j , and ω_{js} is the input share from sector s in the total input in sector j .

The estimation results are reported in Table 4. Consistently, we find that our whole pattern of findings barely changes with the inclusion of these additional controls, alleviating the concern about bias from omitted variables.

[Insert Table 4 Here]

Third, we re-conduct the estimation of reservation wage and wage rents using Stole and Zwiebel's (1996) bargaining framework, as illustrated in Appendix A. We then re-do all the analyses using these newly constructed estimates. The estimation results are reported in Table 5, in which we find consistent results.

[Insert Table 5 Here]

5 Conclusion

This paper uses two bargaining protocols to estimate the wage rent, allowing heterogeneity of wage rent across firms and categories of labor. We find that on average wage rent counts for more than 70 percent of the total wage rate for skilled and unskilled labor. Since the wage rent reflects labor market competition and labor market friction (through bargaining power), our results show that the wage is largely determined by the labor market environment. We also find that trade liberalization does not have a significant impact on the wage rent, rather than the workforce composition itself, which provides new evidence to support the prediction of the Helpman-Itskhoki-Redding model. Although our empirical estimate is based on Colombian manufacturing census data, the modeling framework and estimation strategy apply to any firm-level data that contain accounting information such as input-output data. In particular, our main bargaining model, one-principal-to-many-agents indissoluble bargaining, does not require the parametric assumption about the demand system (in comparison with Stole and Zwiebel's 1996 bargaining model). Thus, our model may be useful for more general applications in conducting structural analysis in labor market misallocation.

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Figure 1 Colombia's average tariff rate (1977–1991)

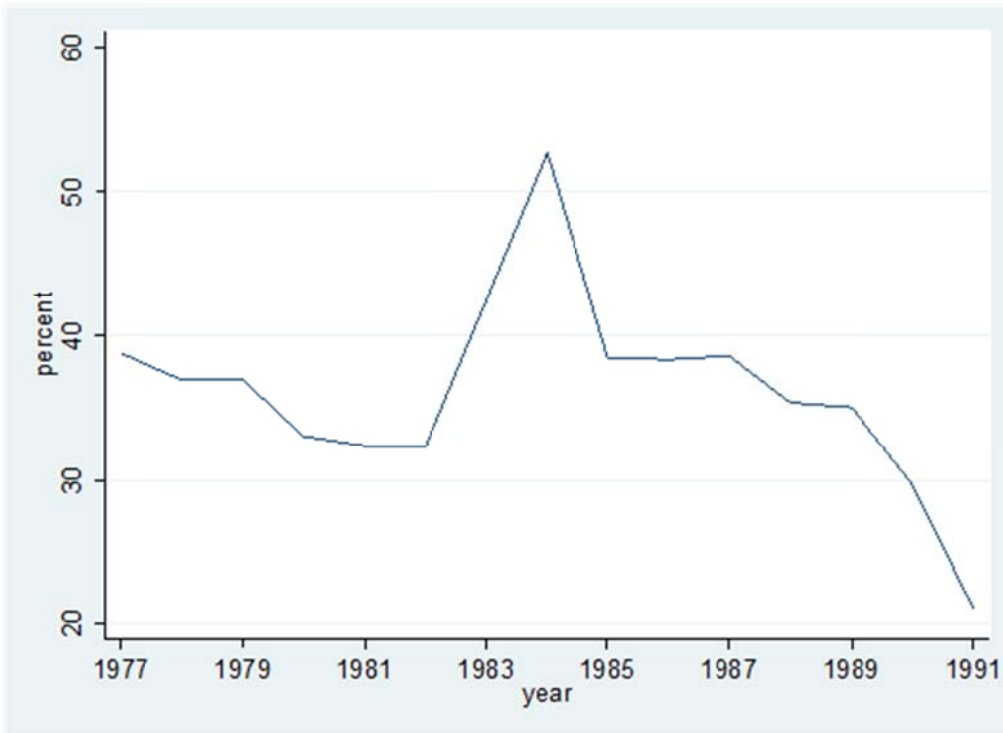


Table 1 Wage decomposition

Year	Total wage rate	Reservation wage rate	Wage rents
	(1)	(2)	(3)
Panel A. Skilled labor			
1981	229.82	56.18	173.64
1982	238.29	56.30	181.99
1983	254.42	59.31	195.11
1984	270.47	63.32	207.15
1985	257.46	62.42	195.04
1986	262.58	63.43	199.16
1987	267.05	62.64	204.41
1988	267.70	63.14	204.55
1989	272.08	63.04	209.04
1990	273.29	64.98	208.31
1991	272.18	65.82	206.36
Average 1981-91	260.90	61.95	198.94
Change 1981-91 (%)	18.43	4.19	14.24
Panel B. Unskilled labor			
1981	138.64	23.05	115.59
1982	147.82	23.30	124.52
1983	155.55	23.36	132.19
1984	164.23	26.00	138.23
1985	159.70	25.71	133.99
1986	163.22	26.00	137.22
1987	162.97	25.27	137.70
1988	161.17	25.34	135.83
1989	164.32	25.77	138.55
1990	160.73	26.33	134.40
1991	156.58	25.35	131.23
Average 1981-91	157.76	25.05	132.71
Change 1981-91 (%)	12.94	1.66	11.28

Note: The unit of value: thousands of pesos. Nominal value is deflated by CPI.

Table 2 Trade reform and wage inequality

Δ wage inequality	Total wage rate			Reservation wage rate		Wage rents	
	Total labor	Skilled labor	Unskilled labor	Skilled labor	Unskilled labor	Skilled labor	Unskilled labor
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
<i>Panel A</i>							
Δ tariff	0.022*	0.032**	0.011	0.477***	0.410***	0.044	-0.055
	(0.012)	(0.013)	(0.019)	(0.183)	(0.136)	(0.096)	(0.169)
<i>Panel B</i>							
Δ tariff	0.021	0.023*	0.013	0.384***	0.306***	0.029	-0.033
	(0.013)	(0.012)	(0.018)	(0.140)	(0.105)	(0.075)	(0.140)

Note: The regression is weighted by the number of firms. The number of observations is 203. In Panel A, the instrument for Δ tariff is exchange rate \times tariff 1983. In Panel B, the instrument for Δ tariff is coffee price \times tariff 1983. Year dummies are included in all specifications. Standard errors are clustered at 3-digit industry level in parentheses. ***, ** and * denote significance at the 1, 5 and 10% level respectively.

Table 3 Time-varying industry-level controls

Δ wage inequality	Total wage rate			Reservation wage rate		Wage rents	
	Total labor	Skilled labor	Unskilled labor	Skilled labor	Unskilled labor	Skilled labor	Unskilled labor
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
<i>Panel A</i>							
Δ tariff	0.028**	0.026	0.014	0.401*	0.488**	0.051	-0.088
	(0.012)	(0.019)	(0.017)	(0.230)	(0.234)	(0.152)	(0.166)
<i>Panel B</i>							
Δ tariff	0.025**	0.017	0.015	0.321*	0.382*	0.030	-0.062
	(0.012)	(0.019)	(0.017)	(0.177)	(0.203)	(0.126)	(0.140)

Note: The regression is weighted by the number of firms. The number of observations is 203. In Panel A, the instrument for Δ tariff is exchange rate \times tariff 1983. In Panel B, the instrument for Δ tariff is coffee price \times tariff 1983. Year dummies are included in all specifications. Time-varying controls include first difference of lagged exports, lagged imports, output, and capital-labor ratio. Standard errors are clustered at 3-digit industry level in parentheses. ***, ** and * denote significance at the 1, 5 and 10% level respectively.

Table 4 Input tariff control

Δ wage inequality	Total wage rate			Reservation wage rate		Wage rents	
	Total labor	Skilled labor	Unskilled labor	Skilled labor	Unskilled labor	Skilled labor	Unskilled labor
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
<i>Panel A</i>							
Δ tariff	0.031**	0.026	0.018	0.425*	0.520**	0.053	-0.094
	(0.014)	(0.019)	(0.014)	(0.249)	(0.247)	(0.148)	(0.166)
<i>Panel B</i>							
Δ tariff	0.026**	0.018	0.016	0.330	0.394*	0.031	-0.064
	(0.013)	(0.020)	(0.012)	(0.207)	(0.229)	(0.122)	(0.142)

Note: The regression is weighted by the number of firms. The number of observations is 203. In Panel A, the instrument for Δ tariff is exchange rate \times tariff 1983. In Panel B, the instrument for Δ tariff is coffee price \times tariff 1983. Year dummies are included in all specifications. Time-varying controls include first difference of input tariffs, lagged exports, lagged imports, output, and capital-labor ratio. Standard errors are clustered at 3-digit industry level in parentheses. ***, ** and * denote significance at the 1, 5 and 10% level respectively.

Table 5 Stole and Zwiebel's model

Δ wage inequality	Reservation wage rate		Wage rents	
	Skilled labor	Unskilled labor	Skilled labor	Unskilled labor
	(1)	(2)	(3)	(4)
<i>Panel A</i>				
Δ tariff	0.574**	0.022**	0.265**	-0.002
	(0.235)	(0.010)	(0.119)	(0.001)
<i>Panel B</i>				
Δ tariff	0.382*	0.016*	0.178	-0.002
	(0.231)	(0.010)	(0.114)	(0.001)

Note: The regression is weighted by the number of firms. The number of observations is 203. In Panel A, the instrument for Δ tariff is exchange rate \times tariff 1983. In Panel B, the instrument for Δ tariff is coffee price \times tariff 1983. Year dummies are included in all specifications. Time-varying controls include first difference of input tariffs, lagged exports, lagged imports, output, and capital. Standard errors are clustered at 3-digit industry level in parentheses. ***, ** and * denote significance at the 1, 5 and 10% level respectively.

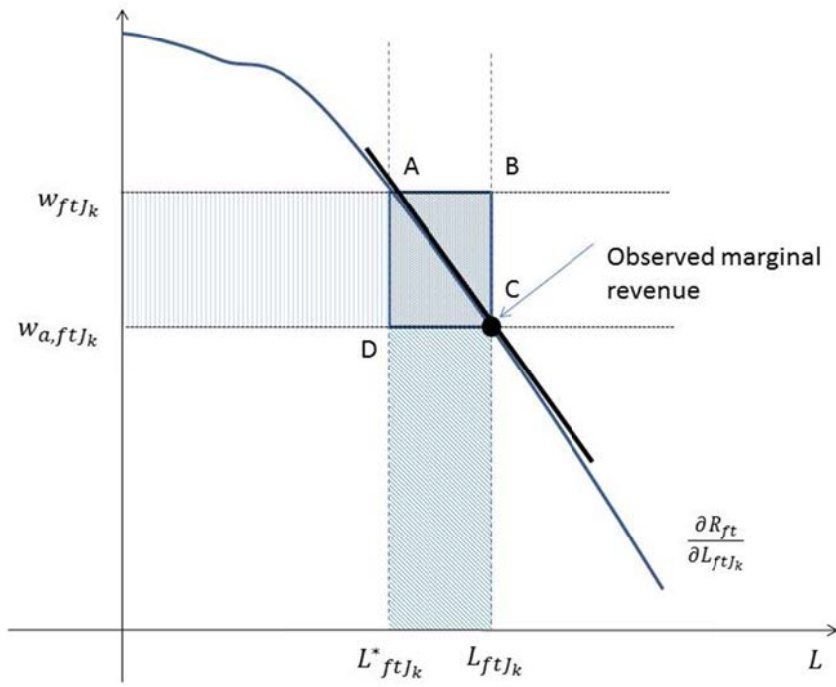
Table A1 Wage decomposition by industry: skilled labor

Industry	Total wage rate		Wage rents		Reservation wage rate	
	Average 1981-91	Change 1981-91 (%)	Average 1981-91	Change 1981-91 (%)	Average 1981-91	Change 1981-91 (%)
	(1)	(2)	(3)	(4)	(5)	(6)
Food Products	278.91	14.27	219.31	9.90	59.60	4.38
Tobacco	407.31	53.67	336.80	27.56	70.52	26.10
Textiles	265.29	14.10	199.15	8.75	66.14	5.36
Clothing and Apparel	195.16	11.80	167.88	8.69	27.28	3.11
Leather and Leather Products	212.07	-0.52	156.63	1.22	55.44	-1.74
Wood and Wood Products	217.83	19.51	159.07	18.38	58.76	1.13
Paper	342.73	12.61	251.26	13.71	91.47	-1.10
Printing and Publishing	228.10	32.10	180.18	33.06	47.91	-0.96
Chemicals	349.05	-20.23	236.72	-13.16	112.34	-7.07
Petroleum and Coal Products	365.50	18.31	282.45	18.77	83.04	-0.46
Rubber and Plastic Products	292.91	23.94	186.63	10.48	106.28	13.46
Other Non-metallic Mineral Products	303.17	28.08	201.36	20.92	101.81	7.16
Basic Metals	370.77	6.76	212.39	10.40	158.38	-3.63
Metal Products	235.00	28.58	152.17	17.97	82.83	10.61
Machinery	254.17	22.92	211.67	21.72	42.50	1.20
Electrical Machinery	360.19	19.34	258.31	14.95	101.88	4.39
Transport Equipment	221.39	16.77	163.49	5.87	57.90	10.90
Professional and Scientific Equipment	271.54	16.70	231.31	16.67	40.24	0.02
Furniture and Miscellaneous	214.36	13.06	182.45	10.54	31.91	2.52

Table A2 Wage decomposition by industry: unskilled labor

Industry	Total wage rate		Wage rents		Reservation wage rate	
	Average 1981-91	Change 1981-91 (%)	Average 1981-91	Change 1981-91 (%)	Average 1981-91	Change 1981-91 (%)
	(1)	(2)	(3)	(4)	(5)	(6)
Food Products	176.73	8.47	148.36	7.86	28.37	0.61
Tobacco	236.40	82.65	215.52	68.79	20.88	13.86
Textiles	158.08	15.60	137.77	13.28	20.31	2.32
Clothing and Apparel	121.61	18.81	104.38	16.72	17.23	2.09
Leather and Leather Products	136.59	1.22	104.05	-1.62	32.54	2.84
Wood and Wood Products	140.09	16.81	120.57	17.33	19.52	-0.51
Paper	182.52	5.83	155.84	7.76	26.68	-1.93
Printing and Publishing	162.19	16.30	134.86	14.49	27.33	1.81
Chemicals	265.52	5.87	222.93	8.05	42.59	-2.17
Petroleum and Coal Products	181.09	11.03	163.51	14.32	17.58	-3.29
Rubber and Plastic Products	167.51	20.80	122.52	8.32	44.98	12.48
Other Non-metallic Mineral Products	182.60	19.24	144.69	17.58	37.91	1.66
Basic Metals	172.55	3.85	138.89	10.61	33.66	-6.76
Metal Products	150.33	14.37	122.86	13.66	27.47	0.72
Machinery	147.91	12.15	138.76	13.35	9.15	-1.20
Electrical Machinery	186.89	18.09	141.99	18.91	44.90	-0.83
Transport Equipment	144.11	5.16	120.29	7.43	23.82	-2.27
Professional and Scientific Equipment	161.50	4.48	150.08	5.10	11.42	-0.62
Furniture and Miscellaneous	132.36	11.10	128.51	11.17	3.85	-0.07

Figure A1 Rent difference between individual bargaining model and SZ model



Appendix

A Estimation Using Stole and Zwiebel's (1996) Bargaining Protocol

A.1 Benchmark Model

Following Stole and Zwiebel's (1996, henceforce SZ) setting, there are G categories of workers. Within each category, the workers are identical. Let w_{a,ftJ_k} be the outside reservation wage for the k -th category. Then, a neoclassical firm's profit function is

$$\pi_{ft}^o(\mathbf{L}_{ft}, K_{ft}, M_{ft}, E_{ft}) = P_{ft}Q_{ft} - r_t K_{ft} - p_t^m M_{ft} - p_t^e E_{ft} - \sum_{k \in \mathcal{G}} L_{ftJ_k} w_{a,ftJ_k}, \quad (\text{A.1})$$

where $\mathbf{L}_{ft} = (L_{ft1}, \dots, L_{ftJ_k}, \dots, L_{ftG})$ is the vector of employment of firm f at time t . The above profit function prescribes a relationship between input $(\mathbf{L}_{ft}, K_{ft}, M_{ft}, E_{ft})$ and profit π_{ft}^o . It is important to note that π_{ft}^o is not the observed profit. In fact, the firm's profit level under the SZ bargaining protocol should be given by:

$$\tilde{\pi}_{ft}(\mathbf{L}_{ft}, K_{ft}, M_{ft}, E_{ft}) = \frac{1}{L_{ft}} \int_0^{L_{ft}} \pi_{ft}^o(s\boldsymbol{\alpha}_{ft}, K_{ft}, M_{ft}, E_{ft}) ds$$

where $\boldsymbol{\alpha}_{ft} = \frac{1}{L_{ft}}(L_{ft1}, \dots, L_{ftJ_k}, \dots, L_{ftG})$ is the vector of ratio of the different categories of workers and L_{ft} is total labor. Therefore, a profit-maximizing firm should choose $(\mathbf{L}_{ft}, K_{ft}, M_{ft}, E_{ft})$ to maximize $\tilde{\pi}_{ft}(\mathbf{L}_{ft}, K_{ft}, M_{ft}, E_{ft})$. So the firm will pay wage w_{ftJ_k} , the same as w_{a,ftJ_k} , but may hire more labor than what a neoclassical firm would do. As a result, the workers' rent does not come from the wage difference as in the previous individual bargaining model, but from over-employment. More precisely, the rent of each group of workers in the SZ model is given by

$$rent^{SZ} = \sum_{k \in \mathcal{G}} w_{ftJ_k} (L_{ftJ_k} - L_{ftJ_k}^*), \quad (\text{A.2})$$

where $\{L_{ftJ_k}^*\}_{k \in \mathcal{G}}$ is the counterfactual optimal employment that maximizes the profit function $\pi_{ft}^o(\mathbf{L}_{ft}, K_{ft}, M_{ft}, E_{ft})$. Therefore, $L_{ftJ_k}^*$ should satisfy the first-order condition

$$\frac{\partial P_{ft}}{\partial Q_{ft}} \frac{\partial Q_{ft}}{\partial L_{ftJ_k}} Q_{ft} + P_{ft} \frac{\partial Q_{ft}}{\partial L_{ftJ_k}} - w_{ftJ_k} = 0. \quad (\text{A.3})$$

A.2 Comparison with the Indissoluble Bargaining Model

We use Figure A1 to show the difference between SZ rent and the rent in the individual bargaining model. The downward-sloping curve is the marginal revenue of labor $\frac{\partial R_{ft}}{\partial L_{ftJ_k}}$. In the indissoluble bargaining model, the optimal employment is determined by $\frac{\partial R_{ft}}{\partial L_{ftJ_k}} = w_{a,ftJ_k}$, which suggests that w_{a,ftJ_k} can be backed out by observed employment L_{ftJ_k} . Thus, area $BCw_{a,ftJ_k}w_{ftJ_k}$ is the corresponding rent. In the SZ model, the counterfactual optimal employment $L_{ftJ_k}^*$ is determined by $\frac{\partial R_{ft}}{\partial L_{ftJ_k}} = w_{ftJ_k}$. Thus, the area $ABL_{ftJ_k}L_{ftJ_k}^*$ is SZ rent. The rectangle ABCD is the common area of the rent in these two approaches.

[Insert Figure A1 Here]

A.3 Empirical Implementation

Structural estimation of the SZ model is very involved. The main challenging is to back out the counterfactual optimal input decision of a neoclassical firm. There are two main issues that we have to deal with.

First, to back out the optimal input decision, we have to know the entire marginal revenue $\frac{\partial R_{ft}}{\partial L_{ftJ_k}}$ as a function of L_{ftJ_k} (not just the marginal value at some given point). Because the nonparametric estimation of the functional form of R_{ft} in terms of L_{ftJ_k} is too involved, we follow De Loecker (2011) and assume a log linear demand system:

$$P_{ft} = P_{it} \left(\frac{Q_{ft}}{Q_{it}} \right)^{-b_i}, \quad (\text{A.4})$$

where P_{ft} is the firm's own price, P_{it} is the average price of industry i , Q_{it} is aggregate demand for industry i , and $-\frac{1}{\gamma_i}$ is the elasticity of demand for industry i . Using equation (A.4), we obtain the firm's revenue:

$$R_{ft} = P_{ft}Q_{ft} = Q_{ft}^{1-b_i}Q_{it}^{b_i}P_{it}. \quad (\text{A.5})$$

Here, we introduce a translog production function and consider the cases where labor is total raw labor, and divided into skilled and unskilled categories.

The second difficulty is that the data do not contain complete information on the market price of inputs. For example, the prices of capital and energy are not directly observed. We have to use a dynamic structural approach to back out the counterfactual inputs even if a log linear demand system is assumed. The details are provided as follows.

From Equation (A.5), we get

$$\frac{\partial R_{ft}}{\partial Q_{ft}} \frac{Q_{ft}}{R_{ft}} = \frac{\partial \ln R_{ft}}{\partial \ln Q_{ft}} = 1 - \widehat{b}_i,$$

or equivalently,

$$\frac{\partial R_{ft}}{\partial Q_{ft}} = (1 - \widehat{b}_i) \frac{R_{ft}}{Q_{ft}}, \quad (\text{A.6})$$

where the hat denotes estimates. It follows that a neoclassical firm's skilled labor input decision is given by $\widehat{\theta}_{mu}m_{ft} + \widehat{\theta}_{uk}k_{ft} + \widehat{\theta}_{eu}e_{ft}$. Denote by $q_{ft} \equiv \ln(Q_{ft})$, $l_{ft}^s \equiv \ln(L_{ft}^s)$, $l_{ft}^u \equiv \ln(L_{ft}^u)$, $k_{ft} \equiv \ln(K_{ft})$, $m_{ft} \equiv \ln(M_{ft})$, and $e_{ft} \equiv \ln(E_{ft})$.

$$\frac{\partial Q_{ft}}{\partial L_{ft}^s} \frac{L_{ft}^s}{Q_{ft}} = \frac{\partial q_{ft}}{\partial l_{ft}^s} = \widehat{\theta}_s + 2\widehat{\theta}_{ss}l_{ft}^s + \widehat{\theta}_{su}l_{ft}^u + \widehat{\theta}_{sm}m_{ft} + \widehat{\theta}_{sk}k_{ft} + \widehat{\theta}_{se}e_{ft},$$

which leads to the marginal product of labor

$$\frac{\partial Q_{ft}}{\partial L_{ft}^s} = \left(\widehat{\theta}_s + 2\widehat{\theta}_{ss}l_{ft}^s + \widehat{\theta}_{su}l_{ft}^u + \widehat{\theta}_{sm}m_{ft} + \widehat{\theta}_{sk}k_{ft} + \widehat{\theta}_{se}e_{ft} \right) \frac{Q_{ft}}{L_{ft}^s}, \quad (\text{A.7})$$

where all $\widehat{\theta}$ come from estimation of the production function. From Equations (A.6) and (A.7), we derive the marginal benefit of labor:

$$\begin{aligned} \frac{\partial R_{ft}}{\partial L_{ft}^s} &= \frac{\partial R_{ft}}{\partial Q_{ft}} \frac{\partial Q_{ft}}{\partial L_{ft}^s} \\ &= (1 - \widehat{b}_i) \frac{R_{ft}}{Q_{ft}} \left(\widehat{\theta}_s + 2\widehat{\theta}_{ss}l_{ft}^s + \widehat{\theta}_{su}l_{ft}^u + \widehat{\theta}_{sm}m_{ft} + \widehat{\theta}_{sk}k_{ft} + \widehat{\theta}_{se}e_{ft} \right) \frac{Q_{ft}}{L_{ft}^s} \\ &= (1 - \widehat{b}_i) \frac{R_{ft}}{L_{ft}^s} \left(\widehat{\theta}_s + 2\widehat{\theta}_{ss}l_{ft}^s + \widehat{\theta}_{su}l_{ft}^u + \widehat{\theta}_{sm}m_{ft} + \widehat{\theta}_{sk}k_{ft} + \widehat{\theta}_{se}e_{ft} \right). \end{aligned}$$

Similarly, we have

$$\begin{aligned} \frac{\partial R_{ft}}{\partial L_{ft}^u} &= \frac{\partial R_{ft}}{\partial Q_{ft}} \frac{\partial Q_{ft}}{\partial L_{ft}^u} = (1 - \widehat{b}_i) \frac{R_{ft}}{L_{ft}^u} \left(\widehat{\theta}_u + 2\widehat{\theta}_{uu}l_{ft}^u + \widehat{\theta}_{su}l_{ft}^s + \widehat{\theta}_{um}m_{ft} + \widehat{\theta}_{uk}k_{ft} + \widehat{\theta}_{ue}e_{ft} \right). \\ \frac{\partial R_{ft}}{\partial K_{ft}} &= \frac{\partial R_{ft}}{\partial Q_{ft}} \frac{\partial Q_{ft}}{\partial K_{ft}} = (1 - \widehat{b}_i) \frac{R_{ft}}{K_{ft}} \left(\widehat{\theta}_k + 2\widehat{\theta}_{kk}k_{ft} + \widehat{\theta}_{sk}l_{ft}^s + \widehat{\theta}_{uk}l_{ft}^u + \widehat{\theta}_{km}m_{ft} + \widehat{\theta}_{ke}e_{ft} \right). \\ \frac{\partial R_{ft}}{\partial M_{ft}} &= \frac{\partial R_{ft}}{\partial Q_{ft}} \frac{\partial Q_{ft}}{\partial M_{ft}} = (1 - \widehat{b}_i) \frac{R_{ft}}{M_{ft}} \left(\widehat{\theta}_m + 2\widehat{\theta}_{mm}m_{ft} + \widehat{\theta}_{sm}l_{ft}^s + \widehat{\theta}_{um}l_{ft}^u + \widehat{\theta}_{km}k_{ft} + \widehat{\theta}_{me}e_{ft} \right). \end{aligned}$$

$$\frac{\partial R_{ft}}{\partial E_{ft}} = \frac{\partial R_{ft}}{\partial Q_{ft}} \frac{\partial Q_{ft}}{\partial E_{ft}} = (1 - \widehat{b}_i) \frac{R_{ft}}{E_{ft}} \left(\widehat{\theta}_e + 2\widehat{\theta}_{ee}e_{ft} + \widehat{\theta}_{se}l_{ft}^s + \widehat{\theta}_{ue}l_{ft}^u + \widehat{\theta}_{ke}k_{ft} + \widehat{\theta}_{me}m_{ft} \right).$$

At the optimum, the neoclassical firm will choose inputs according to the first-order conditions $\frac{\partial R_{ft}}{\partial L_{ft}^s} = w_{ft}^s$, $\frac{\partial R_{ft}}{\partial L_{ft}^u} = w_{ft}^u$, $\frac{\partial R_{ft}}{\partial K_{ft}} = r_t$, $\frac{\partial R_{ft}}{\partial M_{ft}} = p_t^m$, and $\frac{\partial R_{ft}}{\partial E_{ft}} = p_t^e$, given market prices $(w_{ft}^s, w_{ft}^u, r_t, p_t^m, p_t^e)$. It remains to back out the counterfactual revenue R_{ft} .

A counterfactual neoclassical firm in the SZ model should also generate the same profit level as the one under the SZ bargaining protocol, i.e.,

$$\tilde{\pi}_{ft}(\boldsymbol{\alpha}_{ft}L_{ft}, K_{ft}, M_{ft}, E_{ft}) = \pi_{ft}^o(\boldsymbol{\alpha}_{ft}L_{ft}, K_{ft}, M_{ft}, E_{ft}),$$

therefore, the counterfactual revenue R_{ft}^* can be written as

$$R_{ft}^* = \pi_{ft} + L_{ft}^{s*}w_{ft}^s + L_{ft}^{u*}w_{ft}^u + r_tK_{ft}^* + p_t^mM_{ft}^* + p_t^eE_{ft}^* \quad (\text{A.8})$$

where π_{ft} is estimated/observed from the data. Associated with Equation (A.8), the counterfactual optimal inputs $(L_{ft}^*, K_{ft}^*, M_{ft}^*, E_{ft}^*)$ are jointly solved according to the following equations:

$$(1 - \widehat{b}_i) \frac{R_{ft}}{L_{ft}^s} \left(\widehat{\theta}_s + 2\widehat{\theta}_{ss}l_{ft}^s + \widehat{\theta}_{su}l_{ft}^u + \widehat{\theta}_{sm}m_{ft} + \widehat{\theta}_{sk}k_{ft} + \widehat{\theta}_{se}e_{ft} \right) = w_{ft}^s \quad (\text{A.9})$$

$$(1 - \widehat{b}_i) \frac{R_{ft}}{L_{ft}^u} \left(\widehat{\theta}_u + 2\widehat{\theta}_{uu}l_{ft}^u + \widehat{\theta}_{su}l_{ft}^s + \widehat{\theta}_{um}m_{ft} + \widehat{\theta}_{uk}k_{ft} + \widehat{\theta}_{ue}e_{ft} \right) = w_{ft}^u \quad (\text{A.10})$$

$$(1 - \widehat{b}_i) \frac{R_{ft}}{K_{ft}} \left(\widehat{\theta}_k + 2\widehat{\theta}_{kk}k_{ft} + \widehat{\theta}_{sk}l_{ft}^s + \widehat{\theta}_{uk}l_{ft}^u + \widehat{\theta}_{km}m_{ft} + \widehat{\theta}_{ke}e_{ft} \right) = r_t \quad (\text{A.11})$$

$$(1 - \widehat{b}_i) \frac{R_{ft}}{M_{ft}} \left(\widehat{\theta}_m + 2\widehat{\theta}_{mm}m_{ft} + \widehat{\theta}_{sm}l_{ft}^s + \widehat{\theta}_{um}l_{ft}^u + \widehat{\theta}_{km}k_{ft} + \widehat{\theta}_{me}e_{ft} \right) = p_t^m \quad (\text{A.12})$$

$$(1 - \widehat{b}_i) \frac{R_{ft}}{E_{ft}} \left(\widehat{\theta}_e + 2\widehat{\theta}_{ee}e_{ft} + \widehat{\theta}_{se}l_{ft}^s + \widehat{\theta}_{ue}l_{ft}^u + \widehat{\theta}_{ke}k_{ft} + \widehat{\theta}_{me}m_{ft} \right) = p_t^e \quad (\text{A.13})$$

where $(1 - \widehat{b}_i) = \frac{\partial \ln R_{ft}}{\partial \ln Q_{ft}}$.

The above reasoning provides the theoretical method to back out the optimal input when π_{ft} and $(w_{ft}^s, w_{ft}^u, r_t, p_t^m, p_t^e)$ are observed. Unfortunately, even if $(w_{ft}^s, w_{ft}^u, r_t, p_t^e)$ can be estimated, R_{ft} or π_{ft} is not observed and only the index of p_t^m , i.e., $\frac{p_t^m}{p_{t-1}^m}$, is observed. To overcome this difficulty, we take advantage of the dynamic structure of the problem. Consider the optimal inputs at times $t-1$ and t , where there are 10 unknowns $(L_{ft-1}^{s*}, L_{ft-1}^{u*}, K_{ft-1}^*, M_{ft-1}^*, E_{ft-1}^*)$ and $(L_{ft}^{s*}, L_{ft}^{u*}, K_{ft}^*, M_{ft}^*, E_{ft}^*)$. We collect the following 10 equations:

The first six equations come from the marginal rate of technical substitution (MRTS) in each period. For example, in period t , we have three equations:

$$\frac{K_{ft} \left(\widehat{\theta}_s + 2\widehat{\theta}_{ss}l_{ft}^s + \widehat{\theta}_{su}l_{ft}^u + \widehat{\theta}_{sm}m_{ft} + \widehat{\theta}_{sk}k_{ft} + \widehat{\theta}_{se}e_{ft} \right)}{L_{ft}^s \left(\widehat{\theta}_k + 2\widehat{\theta}_{kk}k_{ft} + \widehat{\theta}_{sk}l_{ft}^s + \widehat{\theta}_{uk}l_{ft}^u + \widehat{\theta}_{km}m_{ft} + \widehat{\theta}_{ke}e_{ft} \right)} = \frac{w_{ft}^s}{r_t} \quad (\text{A.14})$$

$$\frac{K_{ft} \left(\widehat{\theta}_u + 2\widehat{\theta}_{uu}l_{ft}^u + \widehat{\theta}_{su}l_{ft}^s + \widehat{\theta}_{um}m_{ft} + \widehat{\theta}_{uk}k_{ft} + \widehat{\theta}_{ue}e_{ft} \right)}{L_{ft}^u \left(\widehat{\theta}_k + 2\widehat{\theta}_{kk}k_{ft} + \widehat{\theta}_{sk}l_{ft}^s + \widehat{\theta}_{uk}l_{ft}^u + \widehat{\theta}_{km}m_{ft} + \widehat{\theta}_{ke}e_{ft} \right)} = \frac{w_{ft}^u}{r_t} \quad (\text{A.15})$$

$$\frac{E_{ft} \left(\widehat{\theta}_k + 2\widehat{\theta}_{kk}k_{ft} + \widehat{\theta}_{sk}l_{ft}^s + \widehat{\theta}_{uk}l_{ft}^u + \widehat{\theta}_{km}m_{ft} + \widehat{\theta}_{ke}e_{ft} \right)}{K_{ft} \left(\widehat{\theta}_e + 2\widehat{\theta}_{ee}e_{ft} + \widehat{\theta}_{se}l_{ft}^s + \widehat{\theta}_{ue}l_{ft}^u + \widehat{\theta}_{ke}k_{ft} + \widehat{\theta}_{me}m_{ft} \right)} = \frac{r_t}{p_t^e}. \quad (\text{A.16})$$

And there are similar equations for period $t - 1$. The other four equations come from the dynamic comparison of MRTS. Note that

$$\frac{\partial Q_{ft}/\partial K_{ft}}{\partial Q_{ft}/\partial M_{ft}} = \frac{r_t}{p_t^m} \quad \text{and} \quad \frac{\partial Q_{ft-1}/\partial K_{ft-1}}{\partial Q_{ft-1}/\partial M_{ft-1}} = \frac{r_{t-1}}{p_{t-1}^m},$$

which can be rewritten as

$$\frac{\partial q_{ft}/\partial k_{ft}}{\partial q_{ft}/\partial m_{ft}} = \frac{r_t K_{ft}}{p_t^m M_{ft}} \quad \text{and} \quad \frac{\partial q_{ft-1}/\partial k_{ft-1}}{\partial q_{ft-1}/\partial m_{ft-1}} = \frac{r_{t-1} K_{ft-1}}{p_{t-1}^m M_{ft-1}}.$$

Therefore, we obtain an equation

$$\frac{\partial q_{ft}/\partial k_{ft}}{\partial q_{ft}/\partial m_{ft}} = \left(\frac{r_t K_{ft}}{r_{t-1} K_{ft-1}} \cdot \frac{p_{t-1}^m M_{ft-1}}{p_t^m M_{ft}} \right) \frac{\partial q_{ft-1}/\partial k_{ft-1}}{\partial q_{ft-1}/\partial m_{ft-1}}. \quad (\text{A.17})$$

where $\frac{p_{t-1}^m}{p_t^m}$ is the price index for the capital. Similarly, we can generate three more equations

$$\frac{\partial q_{ft}/\partial k_{ft}}{\partial q_{ft}/\partial e_{ft}} = \left(\frac{r_t K_{ft}}{r_{t-1} K_{ft-1}} \cdot \frac{p_{t-1}^e E_{ft-1}}{p_t^e E_{ft}} \right) \frac{\partial q_{ft-1}/\partial k_{ft-1}}{\partial q_{ft-1}/\partial e_{ft-1}}, \quad (\text{A.18})$$

$$\frac{\partial q_{ft}/\partial l_{ft}^s}{\partial q_{ft}/\partial m_{ft}} = \left(\frac{w_{ft}^s L_{ft}^s}{w_{ft-1}^s L_{ft-1}^s} \cdot \frac{p_{t-1}^m M_{ft-1}}{p_t^m M_{ft}} \right) \frac{\partial q_{ft-1}/\partial l_{ft-1}^s}{\partial q_{ft-1}/\partial m_{ft-1}}, \quad (\text{A.19})$$

and

$$\frac{\partial q_{ft}/\partial l_{ft}^u}{\partial q_{ft}/\partial m_{ft}} = \left(\frac{w_{ft}^u L_{ft}^u}{w_{ft-1}^u L_{ft-1}^u} \cdot \frac{p_{t-1}^m M_{ft-1}}{p_t^m M_{ft}} \right) \frac{\partial q_{ft-1}/\partial l_{ft-1}^u}{\partial q_{ft-1}/\partial m_{ft-1}}. \quad (\text{A.20})$$

Equations (A.14), (A.15) and (A.16) and their period $t - 1$ analogs, plus equations (A.17) to (A.20) give the desired estimators. And for period $t + 1$, we use a new set of equations

generated by period $t + 1$, that is, the analogs of equations (A.14), (A.15), and (A.16) in period $t + 1$, plus the analogs of equations (A.17) and (A.18) concerning MRTS in periods $t + 1$ and t .¹³

In particular, if we do not distinguish between skilled and unskilled labor; we treat L_{ft}^s and L_{ft}^u the same. Thus, we have eight equations solving eight unknowns.

B Alternative Timing of Inputs Determination in the Indissoluble Bargaining Model

Our benchmark model in Section 2.1 assumes that materials, capital, and energy are chosen before labor. In this appendix, we show that our results do not change if we allow labor to be determined first, and the decision about M and E will be contingent on the decision about labor, but we maintain the assumption that K goes first and is not adjustable.

We apply backward induction. Without individual j , the profit maximization problem is

$$\max_{\{M_{ft}, E_{ft}\}} \pi_{ft}(-j) = R_{it}(K_{ft}, M_{ft}, E_{ft}, \{L_{ftk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}) - \sum_{k \in \mathcal{L}_{ft} \setminus j} w_{ftk}^* L_{ftk}^*,$$

where R_{ft} depends on (M_{ft}, E_{ft}) and $\{L_{ftk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}$, which are already given. Denote $M_{ft}^*(K_{ft}, \{L_{ftk}^*\}_{k \in \mathcal{L}_{ft} \setminus j})$ and $E_{ft}^*(K_{ft}, \{L_{ftk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}, \{w_{ftk}^*\}_{k \in \mathcal{L}_{ft} \setminus j})$ as the solution to the above problem.

With individual j , the profit maximization problem is

$$\max_{\{M_{ft}, E_{ft}\}} \pi_{ft} = R_{it}(K_{ft}, M_{ft}, E_{ft}, \{L_{ftj}^*\}_{j \in \mathcal{L}_{ft}}) - \sum_{j \in \mathcal{L}_{ft}} w_{ftj}^* L_{ftj}^*,$$

and we denote $M_{ft}^*(K_{ft}, \{L_{ftj}^*\}_{j \in \mathcal{L}_{ft}}, \{w_{ftj}^*\}_{j \in \mathcal{L}_{ft}})$ and $E_{ft}^*(K_{ft}, \{L_{ftj}^*\}_{j \in \mathcal{L}_{ft}}, \{w_{ftj}^*\}_{j \in \mathcal{L}_{ft}})$ as the solution.

Taking the consequence of j 's effect on the (M_{ft}, E_{ft}) decision into account, we have

$$\pi_{ft}(w_{ftj} L_{ftj}, \{w_{ftk}^* L_{ftk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}) = (1 - \beta_{ftj}) R_{ft} + \beta_{ftj} R_{ft}^*(-j) - \sum_{k \in \mathcal{L}_{ft} \setminus j} w_{ftk}^* L_{ftk}^* - (1 - \beta_{ftj}) w_{a,ftj} L_{ftj},$$

where $\{M_{ft}, E_{ft}\}$ affects R_{ft} through the channel $M_{ft}^*(K_{ft}, \{L_{ftk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}, L_{ftj}, \{w_{ftk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}, w_{ftj})$ and $E_{ft}^*(K_{ft}, \{L_{ftk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}, L_{ftj}, \{w_{ftk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}, w_{ftj})$ and $\{M_{ft}, E_{ft}\}$ affects $R_{ft}^*(-j)$ through $M_{ft}^*(K_{ft}, \{L_{ftk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}, \{w_{ftk}^*\}_{k \in \mathcal{L}_{ft} \setminus j})$ and $E_{ft}^*(K_{ft}, \{L_{ftk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}, \{w_{ftk}^*\}_{k \in \mathcal{L}_{ft} \setminus j})$. The first-order condition with respect to L_{ftj} is

¹³In principle, we can generate 12 equations to solve 10 unknowns. This may change the choice of equations a bit, but the conclusion does not change.

$$\begin{aligned}
& \frac{\partial}{\partial L_{ftj}} \pi_{ft} (w_{ftj} L_{ftj}, \{w_{ftk}^* L_{ftk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}) \\
&= (1 - \beta_{ftj}) \left[\frac{\partial R_{ft}}{\partial M_{ft}} \frac{\partial M_{ft}^*}{\partial L_{ftj}} + \frac{\partial R_{ft}}{\partial E_{ft}} \frac{\partial E_{ft}^*}{\partial L_{ftj}} + \frac{\partial R_{ft}}{\partial L_{ftj}} \right] - (1 - \beta_{ftj}) w_{a,ftj} \\
&= 0,
\end{aligned}$$

where $\beta_{ftj} R_{ft}^*(-j) - \sum_{k \in \mathcal{L}_{ft} \setminus j} w_{ftk}^* L_{ftk}^*$ does not depend on L_{ftj} in equilibrium.

By the envelope theorem, $\frac{\partial R_{ft}}{\partial M_{ft}} \Big|_{M_{ft}=M_{ft}^*(K_{ft}, \{L_{ftk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}, L_{ftj}, \{w_{ftk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}, w_{ftj})} = 0$ and

$\frac{\partial R_{ft}}{\partial E_{ft}} \Big|_{E_{ft}=E_{ft}^*(K_{ft}, \{L_{ftk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}, L_{ftj}, \{w_{ftk}^*\}_{k \in \mathcal{L}_{ft} \setminus j}, w_{ftj})} = 0$ at the optimum, therefore, we obtain

$$\frac{\partial R_{ft}}{\partial L_{ftj}} = \frac{\partial P_{ft}}{\partial Q_{ft}} \frac{\partial Q_{ft}}{\partial L_{ftj}} Q_{ft} + P_{ft} \frac{\partial Q_{ft}}{\partial L_{ftj}} = w_{a,ftj},$$

which yields

$$w_{a,ftj} = \frac{P_{ft}}{\mu_{ft}} \frac{\partial Q_{ft}}{\partial L_{ftj}}, \tag{B.1}$$

where $\mu_{ft} = \left[\frac{\partial P_{ft}}{\partial Q_{ft}} \frac{Q_{ft}}{P_{ft}} + 1 \right]^{-1}$ is firm markup. The above formula is the same as we have derived in the paper.

Next, the two first-order conditions for (M_{ft}, E_{ft}) are

$$\begin{aligned}
\frac{\partial R_{ft}}{\partial M_{ft}} &= \frac{\partial P_{ft}}{\partial Q_{ft}} \frac{\partial Q_{ft}}{\partial M_{ft}} Q_{ft} + P_{ft} \frac{\partial Q_{ft}}{\partial M_{ft}} - p_t^m = 0 \\
\frac{\partial R_{ft}}{\partial E_{ft}} &= \frac{\partial P_{ft}}{\partial Q_{ft}} \frac{\partial Q_{ft}}{\partial E_{ft}} Q_{ft} + P_{ft} \frac{\partial Q_{ft}}{\partial E_{ft}} - p_t^e = 0.
\end{aligned}$$

Finally, we deal with the capital decision K_{ft} . Solving L_{ftj}^* , M_{ft}^* and E_{ft}^* , they all are contingent on capital K_{ft} . The firm's problem is

$$\max_{\{K_{ft}\}} \pi_{ft} = R_{it}(K_{ft}, M_{ft}^*, E_{ft}^*, \{L_{ftj}^*(K_{ft}, M_{ft}^*, E_{ft}^*)\}_{j \in \mathcal{L}_{ft}}) - \sum_{j \in \mathcal{L}_{ft}} w_{ftj}^*(K_{ft}, M_{ft}^*, E_{ft}^*) L_{ftj}^*(K_{ft}, M_{ft}^*, E_{ft}^*).$$

By the envelope theorem $\frac{\partial \pi_{ft}}{\partial M_{ft}} \Big|_{M_{ft}=M_{ft}^*(K_{ft}, \{L_{ftj}^*\}_{j \in \mathcal{L}_{ft}}, \{w_{ftj}^*\}_{j \in \mathcal{L}_{ft}})} = 0$

and $\frac{\partial \pi_{ft}}{\partial E_{ft}} \Big|_{E_{ft}=E_{ft}^*(K_{ft}, \{L_{ftj}^*\}_{j \in \mathcal{L}_{ft}}, \{w_{ftj}^*\}_{j \in \mathcal{L}_{ft}})} = 0$, and $\frac{\partial \pi_{ft}}{\partial L_{ftj}} \Big|_{L_{ftj}=L_{ftj}^*} = 0$ at optimum, we

have

$$\begin{aligned} \frac{\partial \pi_{ft}}{\partial K_{ft}} &= \frac{\partial}{\partial K_{ft}} R_{it}(K_{ft}, M_{ft}^*, E_{ft}^*, \{L_{ftj}^*(K_{ft})\}_{j \in \mathcal{L}_{ft}}) + \sum_{j \in \mathcal{L}_{ft}} \frac{\partial \pi_{ft}}{\partial L_{ftj}} \frac{\partial L_{ftj}^*}{\partial K_{ft}} + \frac{\partial \pi_{ft}}{\partial M_{ft}} \frac{\partial M_{ft}^*}{\partial K_{ft}} + \frac{\partial \pi_{ft}}{\partial E_{ft}} \frac{\partial E_{ft}^*}{\partial K_{ft}} \\ &= \frac{\partial}{\partial K_{ft}} R_{it}(K_{ft}, M_{ft}^*, E_{ft}^*, \{L_{ftj}^*(K_{ft})\}_{j \in \mathcal{L}_{ft}}) = 0, \end{aligned}$$

which gives the first-order condition

$$\frac{\partial R_{ft}}{\partial K_{ft}} = \frac{\partial P_{ft}}{\partial Q_{ft}} \frac{\partial Q_{ft}}{\partial K_{ft}} Q_{ft} + P_{ft} \frac{\partial Q_{ft}}{\partial K_{ft}} - r_t = 0.$$

So we obtain first-order conditions for K , M , and E that are the same as equation (B.1). Even if capital goes after of labor, by similar reasoning, the first-order conditions will be similar.

C Derivation of the Wage Function in the Indissoluble Bargaining Model

In this appendix, we derive the wage function in the main context. Consider a one-to-many bargaining between a firm (denoted 0) and a set of workers N , where each worker is denoted $j \in N$. The total coalitional value of all workers is denoted v , and the counterpart without worker j is denoted $v(-j)$. For each bilateral bargaining with individual j , if it succeeds, the firm and worker j earn ϕ_0 and ϕ_j , respectively; otherwise, the firm can operate with the other workers $N \setminus j$ and earns d_0^j , and the worker j obtains 0 (which is a normalization). Suppose individual j has bargaining power β_j in the bilateral bargaining. Then the Nash bargaining gives

$$\phi_j = \beta_j(\phi_j + \phi_0 - d_0^j) \text{ and } \phi_0 - d_0^j = (1 - \beta_j)(\phi_j + \phi_0 - d_0^j), \quad (\text{C.1})$$

which can be written as

$$\phi_0 - d_0^j = \frac{1 - \beta_j}{\beta_j} \phi_j.$$

In equilibrium, the firm's disagreement payoff when bargaining with j (if it fails) is

$$d_0^j = \left[v(-j) - \sum_{N \setminus j} \phi_i \right]_+ \geq \underline{\phi}_0 = 0, \quad (\text{C.2})$$

where $x_+ \equiv \max\{0, x\}$ and $\underline{\phi}_0 = 0$ is the firm's outside reservation value.

Following Montez (2014), we define the stable outcome as:

Definition 1 *A stable bargaining outcome with indissoluble agreements is a payoff vector $\{\phi_j\}_{0 \cup N}$ that is (i) individually rational, $\phi_j \geq 0$ for all $j \in N \cup 0$; (ii) efficient, $\sum_{N \cup 0} \phi_i = R$; and (iii) consistent with bilateral Nash bargaining, i.e., $\{\phi_0, \phi_j\}$ satisfies (C.1) for each pair $\{0, j\}$ with $j \in N$ when the disagreement payoff d_0^i is given by (C.2).*

Therefore, we can show the following result.

Proposition 2 *There exists a unique stable bargaining outcome with indissoluble agreement such that*

$$\phi_j^B = \min \left\{ \frac{\beta_j}{1 - \beta_j} \phi_0^B, \beta_j (v - v(-j)) \right\} \text{ for all } j \in N \text{ and } \phi_0^B = v - \sum_N \phi_i^B.$$

Proof. The idea follows Montez (2014). Note that in the bilateral bargaining problem with j , under efficient and individually rational allocation, we have

$$\phi_0^B = v - \sum_N \phi_i^B \text{ and } d_0^i = \left[v(-j) - \sum_{N \setminus j} \phi_i \right]_+.$$

So the gain from a bilateral agreement between 0 and j does not exceed j 's marginal contribution

$$\phi_0^B + \phi_j^B - d_0^i \leq v - v(-j)$$

by the following facts:

$$\phi_0^B + \phi_j^B = v - \sum_{N \setminus j} \phi_i^B = v - v(-j) + v(-j) - \sum_{N \setminus j} \phi_i^B \leq v - v(-j) + d_0^i.$$

If $d_0^i = 0$, the bilateral Nash bargaining gives

$$\phi_j^B = \frac{\beta_j}{1 - \beta_j} \phi_0^B = \frac{\beta_j}{1 - \beta_j} (v - \sum_N \phi_i^B) = \beta_j (v - \sum_{N \setminus j} \phi_i) \text{ and } \phi_0^B = (1 - \beta_j) (v - \sum_{N \setminus j} \phi_i).$$

If $d_0^i > 0$, then we have that

$$\phi_j^B = \beta_j (v - v(-j)) < \frac{\beta_j}{(1 - \beta_j)} \phi_0^B,$$

because

$$\phi_0^B = v - \sum_N \phi_i^B = v - v(-j) + v(-j) - \sum_{N \setminus j} \phi_i^B - \beta_j(v - v(-j)) > (1 - \beta_j)(v - v(-j)).$$

Therefore

$$\phi_j^B = \min \left\{ \frac{\beta_j}{1 - \beta_j} \phi_0^B, \beta_j(v - v(-j)) \right\} \text{ for all } j \in N. \quad (\text{C.3})$$

We now show that this stable allocation is unique. Suppose there are two distinct $\{\phi_j^B\}_{0 \cup N}$ and $\{\phi_j^{B'}\}_{0 \cup N}$. We have $\sum_{N \cup 0} \phi_i^B = \sum_{N \cup 0} \phi_i^{B'} = v$ and there should exist at least one agent j such that

$$\phi_0^B \geq \phi_0^{B'} \text{ and } \phi_j^B < \phi_j^{B'},$$

which contradicts (C.3). The existence of ϕ_j^B and ϕ_0^B is by construction. ■

We now apply our theory to the employment problem. The total value of cooperation is the total social surplus, given employment L_{ftj} , that is

$$v = R_{ft} - \sum_{j \in \mathcal{L}_{ft}} w_{a,ftj} L_{ftj}, \quad (\text{C.4})$$

where $R_{ft} = P_{ft}Q_{it} - r_t K_{ft} - p_t^m M_{ft} - p_t^e E_{ft}$.

Without j , the value is

$$v(-j) = R_{ft}(-j) - \sum_{k \in \mathcal{L}_{ft} \setminus j} w_{a,ftk} L_{ftk}, \quad (\text{C.5})$$

where $R_{ft}(-j) = P_{ft}(-j)Q_{ft}(-j) - r_t K_{ft} - p_t^m M_{ft} - p_t^e E_{ft}$. And worker j 's value is

$$\phi_j^B = (w_{ftj} - w_{a,ftj}) L_{ftj}. \quad (\text{C.6})$$

Proposition 3 *Under Assumption 1, we have $\beta_{ftj}(R_{ft} - R_{ft}(-j)) + (1 - \beta_{ftj})w_{a,ftj}L_{ftj} < \frac{\beta_{ftj}}{1 - \beta_{ftj}}(R_{ft} - \sum_{j \in \mathcal{L}_{ft}} w_{ftj}L_{ftj}) + w_{a,ftj}L_{ftj}$.*

Proof. We show the result by contradiction. Suppose not, i.e., $\beta_{ftj}(R_{ft} - R_{ft}(-j)) + (1 - \beta_{ftj})w_{a,ftj}L_{ftj} \geq \frac{\beta_{ftj}}{1 - \beta_{ftj}}(R_{ft} - \sum_{j \in \mathcal{L}_{ft}} w_{ftj}L_{ftj}) + w_{a,ftj}L_{ftj}$. By canceling $w_{a,ftj}L_{ftj}$ on both sides, it follows

$$R_{ft} - R_{ft}(-j) - w_{a,ftj}L_{ftj} \geq \frac{1}{1 - \beta_{ftj}}(R_{ft} - \sum_{j \in \mathcal{L}_{ft}} w_{ftj}L_{ftj}).$$

Since $\pi_{ft}(-j) > 0$, we have

$$R_{ft}(-j) > \sum_{k \in \mathcal{L}_{ft} \setminus j} w_{ftk} L_{ftk} = \sum_{j \in \mathcal{L}_{ft}} w_{ftj} L_{ftj} - w_{ftj} L_{ftj}.$$

Therefore,

$$R_{ft} - \sum_{j \in \mathcal{L}_{ft}} w_{ftj} L_{ftj} + w_{ftj} L_{ftj} - w_{a,ftj} L_{ftj} > \frac{1}{1 - \beta_{ftj}} (R_{ft} - \sum_{j \in \mathcal{L}_{ft}} w_{ftj} L_{ftj}). \quad (\text{C.7})$$

Plugging equalities (C.4) to (C.6) into (C.3), and using the hypothesis $\beta_{ftj}(R_{ft} - R_{ft}(-j)) + (1 - \beta_{ftj})w_{a,ftj}L_{ftj} \geq \frac{\beta_{ftj}}{1 - \beta_{ftj}}(R_{ft} - \sum_{j \in \mathcal{L}_{ft}} w_{ftj}L_{ftj}) + w_{a,ftj}L_{ftj}$, we obtain

$$w_{ftj}L_{ftj} - w_{a,ftj}L_{ftj} = \frac{\beta_{ftj}}{1 - \beta_{ftj}}(R_{ft} - \sum_{j \in \mathcal{L}_{ft}} w_{ftj}L_{ftj}).$$

Therefore, plugging the above equality into the right-hand side of inequality (C.7), we obtain a contradiction

$$\begin{aligned} R_{ft} - \sum_{j \in \mathcal{L}_{ft}} w_{ftj} L_{ftj} + \frac{\beta_{ftj}}{1 - \beta_{ftj}} (R_{ft} - \sum_{j \in \mathcal{L}_{ft}} w_{ftj} L_{ftj}) &= \frac{1}{1 - \beta_{ftj}} (R_{ft} - \sum_{j \in \mathcal{L}_{ft}} w_{ftj} L_{ftj}) \\ &> \frac{1}{1 - \beta_{ftj}} (R_{ft} - \sum_{j \in \mathcal{L}_{ft}} w_{ftj} L_{ftj}). \end{aligned}$$

■

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