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Testing for Factor Price Equality with Unobserved Differences in Factor Quality or Productivity†

By Andrew B. Bernard, Stephen J. Redding, and Peter K. Schott*

We develop a method for identifying departures from relative factor price equality that is robust to unobserved variation in factor productivity. We implement this method using data on the relative wage bills of nonproduction and production workers across 170 local labor markets comprising the continental United States for 1972, 1992, and 2007. We find evidence of statistically significant differences in relative wages in all three years. These differences increase in magnitude over time and are related to industry structure in a manner that is consistent with neoclassical models of production. (*JEL* J31, J61, R23)

A central challenge for empirical studies of price variation is controlling for unobserved differences in quality. This challenge is particularly relevant for tests of factor price equality, where workers and other factors of production can vary substantially in terms of productivity across regions and industries. This paper develops a general test for relative factor price equality in the presence of such variation. Our test exploits cost minimization, which implies that the observed quantities chosen by firms facing observed prices contain information about factors' unobserved attributes. We show that when these observables are multiplied, terms capturing unobserved factor productivity cancel. As a result, the equality of observed relative wage bills signifies the equality of unobserved, productivity-adjusted relative factor prices.

Our approach possesses a number of important advantages over traditional methods. First, it allows for variation in factor productivity, quality, or composition across factors, regions, and industries.[1] As such, it examines whether relative factor prices

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[1] "Factor productivity" and "factor quality" both refer to the flow of factor services generated by an observed factor of production in the production technology. To simplify the exposition, we use the term "factor productivity" from now onwards, where it is understood that this also captures "factor quality."

are equal after controlling for the type of factor-augmenting productivity differences emphasized in Trefler (1993) and subsequent research. Second, the only data our approach requires are wage bills by type of worker, which are readily available in censuses of production and similar datasets. Alternate methods that rely on wage data, and control for variation in productivity using observed worker characteristics, are limited by the fact that the econometrician typically observes only a subset of the employee attributes visible to firms, giving rise to often substantial residual wage inequality as emphasized in recent empirical research. Our test, by contrast, controls for both observable and unobservable worker characteristics using factor productivities that vary by factor, region, and industry. Third, our approach is derived from cost minimization and hence is valid under a range of assumptions about factors, markets, and production, including imperfect competition and increasing returns to scale. This generality, and the parsimony of its data requirements, renders our method applicable in a wide variety of contexts, where unobserved variation in productivity is a concern and only price and quantity data are available.

We implement our approach using data on nonproduction versus production workers across local labor markets comprising the continental United States in 1972, 1992, and 2007. This setting is attractive for testing relative factor price equality for a number of reasons. Both labor mobility and goods market integration are plausibly greater across regions within countries than across countries, suggesting that factor price equality is more likely to be observed within countries than internationally. In addition, our data from the US Census of Manufactures record establishments' activity within finely detailed regions and industries, allowing us to focus on regional wage variation after controlling for industry-level determinants of wages via industry fixed effects. Furthermore, the boundaries of the 170 local labor markets used in our empirical analysis are defined by the US Bureau of Economic Analysis according to workers' commuting patterns. As a result, they correspond to economically meaningful regions across which to test for relative factor price equality.

Surprisingly, despite the relatively high levels of goods and factor mobility within the United States, we strongly reject the hypothesis of relative factor price equality across US labor markets in all three years. We find that the relative wage of nonproduction workers varies widely across labor markets, and that the magnitude of departures from the national average increases with time. In 1972, relative wage bills vary from 130 percent of the US average in Boston, Massachusetts to 73 percent in Pueblo, Colorado. In 2007, the corresponding maximum and minimum are 133 percent and 69 percent, for Boston, Massachusetts and Grand Forks, North Dakota, respectively. More broadly, we find that the distributions of relative wage bills for 1992 and 2007 exhibit fatter tails and wider supports than the distribution in 1972. Moreover, while these baseline results include four-digit SIC or six-digit NAICS industry fixed effects to estimate a common within-industry difference in relative wage bills for all industries, we find similar results when performing separate tests for each two-digit SIC or three-digit NAICS sector.

Although our test for relative factor price equality holds under general assumptions about factors, markets, and production, we are able to decompose estimated variation in relative wage bills into estimates of productivity-adjusted relative wages

and relative factor employment under the special case of a constant-elasticity-of-substitution (CES) production technology. Using an elasticity of substitution based on existing empirical estimates, the range of implied productivity-adjusted relative wages is 77 percent (Boston) and 137 percent (Pueblo) of the national average in 1972, and 75 percent (Boston) and 145 percent (Grand Forks) of the national average in 2007. Intuitively, regions with low productivity-adjusted relative wages exhibit high productivity-adjusted relative employment. In 1972, relative nonproduction worker employment ranges from 220 percent (Boston) to 39 percent (Pueblo), while in 2007 it ranges 235 percent (Boston) to 33 percent (Grand Forks). Combining these estimates with observed relative *wages* allows us to back out the estimated relative productivity of nonproduction workers in each region and year. As with relative wage bills, we find that relative productivity becomes increasingly polarized over time.

As an additional check on the economic significance of our results, we examine the relationship between regions' relative wage bills and their industry structure. In neoclassical models of production, only regions with the same productivity-adjusted factor prices are able to satisfy the zero-profit conditions for positive production for the same set of goods. Consistent with a departure from relative factor price equality, we find that the number of industries that region pairs produce in common in each year declines with the distance between their estimated relative wage bills. Furthermore, we find that regions whose relative wage bills pull further apart over time exhibit a decline in commonly produced industries.

Our method and empirical analysis relate to a number of existing literatures. Tests of relative factor price equality across countries are common due to the importance of this condition in neoclassical models of trade.[2] In a standard version of these models, factor price equality implies price-wage arbitrage: countries with identical relative wages produce an identical mix of goods, so that price shocks affect relative wages in all countries.[3] In the absence of factor price equality, however, countries can specialize in different mixes of goods, with the result that their factors can be insulated from shocks to the prices of goods they do not produce (Leamer 1987; Schott 2003, 2008). Tests for factor price equality within countries include Davis et al. (1997) and Debaere (2004), who study prefectures in Japan; Debaere (2004) who examines administrative regions in the United Kingdom; and Hanson and Slaughter (2002) who analyze US states. Our contributions to this literature include the development of a test that is robust to variation in factor-augmenting productivity differences across factors, regions, and industries, and the application of this test to relatively disaggregate geographic regions within a country. To the extent that US labor markets specialize in different sets of industries, they are likely to be

[2] Empirical tests of factor price equality focus both directly on relative wage variation and indirectly on implications of factor price inequality, such as production specialization. See, for example, Trefler (1993), Repetto and Ventura (1998), Davis and Weinstein (2001), Cuñat (2000), Debaere and Demiroglu (2003), and Schott (2003). Theoretical conditions necessary for factor price equality are explored by Samuelson (1949), McKenzie (1955), Dixit and Norman (1980), Wu (1987), Courant and Deardorff (1992), and Deardorff (1994).

[3] Such Stolper-Samuelson effects also appear in newer, "heterogeneous-firm" models of trade, such as Bernard, Redding, and Schott (2007).

asymmetrically affected by external shocks that have uneven effects across industries, such as China and India's growing exports of labor-intensive goods.[4]

Our method and results also contribute to the large literature on US income inequality. A number of papers have demonstrated a rise in the wage of nonproduction workers relative to production workers or the relative wage of college graduates to high school graduates (see, for example, Katz and Murphy 1992 and Berman, Bound, and Griliches 1994). One issue in this literature is the extent to which changes in observed wage inequality reflect changes in the return to given worker characteristics versus unobserved changes in worker characteristics or composition (e.g., Juhn, Murphy, and Pierce 1993 and Lemieux 2006). This issue is particularly salient because the occupation or education categories used to identify skilled and unskilled workers in this literature are typically broad. Our approach, by contrast, is robust to unobserved variation in factor quality, productivity, or composition across regions and industries within each worker category. Furthermore, much of the existing research on the US skill premium documents trends either for the United States as a whole, or for relatively aggregate Census Regions or states.[5] Our analysis of 170 local labor markets highlights the relevance of local variation in relative wages for understanding the evolution of overall US income inequality.

Finally, our findings relate to the macroeconomics literature on income convergence. Research in this literature typically finds sluggish equilibration of relative per worker income levels across US regions over time, which suggests that either relative factor endowments or relative factor prices are at best converging slowly.[6] Our results point to a role for relative factor prices, while our use of local labor market areas offers a much higher level of spatial resolution than is typical in this literature.

The remainder of the paper is organized as follows. Sections I and II discuss the relevant propositions on relative factor price equality and develop their testable implications. In Section III, we outline our empirical methodology. Section IV discusses the data and reports the results of our tests for relative factor price equality across US regions in 1972, 1992, and 2007. Section V discusses the economic interpretation of our results. Section VI concludes.

I. Relative Factor Price Equality

Factor price equality can be either absolute or relative. If absolute factor price equality holds (AFPE), regions have identical nominal factor rewards for identical productivity-adjusted factors. If relative factor price equality holds (RFPE), regions have identical relative factor rewards for identical productivity-adjusted factors, even though absolute factor prices can differ.

[4] See, for example, the discussion in Friedman (2005). Bernard, Jensen, and Schott (2006) demonstrate variation in manufacturing plants' exposure and reaction to imports from low-wage countries. Bernard, Jensen, and Schott (2004) and Autor, Dorn, and Hanson (forthcoming) find that this exposure varies across regions within the United States.

[5] Topel (1994), for example, documents a rise in US income inequality across nine US Census regions. An exception is Bound and Holzer (2000), which examines relative wage trends within US metropolitan statistical areas (MSAs).

[6] See, for example, Barro and Sala-i-Martin (1991) and Carlino and Mills (1993).

We devote our theoretical and empirical attention in this paper to a test of relative factor price equality for two reasons. First, a test of relative factor price equality is more stringent in the sense that relative factor prices can be equal even if absolute factor price equality fails. Second, there is a natural and rich link between variation in regions' relative factor prices and their industry structure, e.g., skill-intensive industries have an incentive to locate in skill-abundant regions. Nonetheless, in the Appendix, we provide a complementary test for absolute factor price equality.

Our method for identifying departures from factor price equality controls for unobserved variation in region-industry-factor productivity that can bias traditional wage comparisons. We demonstrate how total payments to each factor, i.e., wage bills, can be used to control for this unobserved variation.

A. *Production Structure*

We assume a constant returns to scale production technology for output (Y_{rj}) industry j and region r:

$$Y_{rj} = F_j(\mathbf{X}_{rj}), \tag{1}$$

where $\mathbf{X}_{rj}$ is a vector of productivity-adjusted factor inputs, which includes nonproduction and production workers.

We model technology differences across regions and industries as factor augmenting following Trefler (1993). Therefore, while the function that aggregates factor services $F_j(\cdot)$ is the same across regions r within industry j, we allow factor productivity to vary freely across factors, regions, and industries. Specifically, the productivity-adjusted employment (x^{ℓ}_{rj}) and wage (w^{ℓ}_{rj}) for an individual factor ℓ equals the observed value adjusted for productivity:

$$x^{\ell}_{rj} = \theta^{\ell}_{rj}\widetilde{x}^{\ell}_{rj}, \tag{2}$$

$$w^{\ell}_{r} = \widetilde{w}^{\ell}_{rj}/\theta^{\ell}_{rj},$$

where we use a tilde (˜) to signify observed values that have not been adjusted for productivity; θ^{ℓ}_{rj} denotes productivity for factor ℓ in region r and industry j, where we choose units in which to measure the productivity of factors of production in each industry such that productivity in a base region (b) is equal to one $(\theta^{\ell}_{bj} = 1)$.

We begin by assuming perfectly competitive factor markets, in which no arbitrage implies that productivity-adjusted factor prices are equalized across industries $(w^{\ell}_{rj} = w^{\ell}_{r}$ for all $j)$. Nonetheless, observed factor prices can vary across industries because of differences in factor productivity $(\widetilde{w}^{\ell}_{rj} \neq \widetilde{w}^{\ell}_{rk}$ and $\theta^{\ell}_{rj} \neq \theta^{\ell}_{rk}$ for $j \neq k)$, and we consider imperfectly competitive factor markets in which productivity-adjusted factor prices differ across industries below. While our formulation of technology differences follows Trefler (1993), it is more general because we do not require that factor productivity is common across industries within each region, but rather allow the productivity of each factor in each region to differ across industries.

Since technology differences are factor-augmenting in (1), our analysis explicitly allows for non-neutral technology differences that are uneven across factors, regions, and industries. For example, nonproduction workers in a particular region can have specialized knowledge relevant for a particular industry that generates higher productivity for that region and industry than in other regions and industries, whereas production workers in the same industry and region have productivity levels comparable to those in other industries and regions. One special case of our framework is Hicks-neutral technology differences, in which all factors in a region and industry are more productive than those in other regions and industries by the same proportion A_{rj}. In this special case, homogeneity of degree one of the production technology implies that (1) can be rewritten as $Y_{rj} = A_{rj} F_j(\widetilde{\mathbf{X}}_{rj})$. More generally, our analysis also encompasses the case of Hicks-neutral and non-neutral components of technology differences, since we allow productivity to vary freely across factors, regions, and industries.

In our baseline formulation in (1) and (2), we assume that output depends solely on productivity-adjusted units of each factor of production (x_{rj}^{ℓ}) and not on their composition between physical units of the factor of production $(\tilde{x}_{rj}^{\ell})$ and productivity (θ_{rj}^{ℓ}). As a result, units of a given factor of production are perfect substitutes up to a vertical adjustment for differences in factor productivity. In a later section, we relax this assumption to allow each factor of production (e.g., nonproduction workers) to consist of many different types (e.g., managers and engineers), which are horizontally and vertically differentiated from one another. In that later extension, factor productivity corresponds to an index number that controls for differences in factor productivity and composition.

Firms in region r and industry j choose factor usage to minimize costs,

$$\begin{aligned} &\min\,(\mathbf{W}_r)'\,\mathbf{X}_{rj}, \\ \textit{subject to}\qquad &F_j(\mathbf{X}_{rj}) = Y_{rj}, \\ &\mathbf{X}_{rj} \geq 0, \end{aligned} \tag{3}$$

where $\mathbf{W}_r$ is the vector of productivity-adjusted factor prices with elements w_r^{ℓ}. The solution to this problem defines the total cost function,

$$C_{rj} = \Gamma_j(\mathbf{W}_r)\,Y_{rj}. \tag{4}$$

Since our approach is derived from cost minimization, firms can act either as price-takers in product markets (perfect competition; this section) or choose prices subject to a downward sloping demand curve (imperfect competition; next section). While we begin by assuming constant returns to scale, later we extend the analysis to allow for internal and external increasing returns to scale. Similarly, our analysis is compatible with imperfectly competitive factor markets in which productivity-adjusted factor prices differ across industries ($w_{rj}^{\ell} \neq w_{rk}^{\ell}$ for $j \neq k$), as long as employment is chosen to minimize costs given factor prices.[7] From the total

[7] Our analysis is therefore consistent with "right to manage" models of union behavior, where firms and unions bargain over wages within an industry but firms choose employment (see, for example, Farber 1986 and Layard,

cost function, the demand for productivity-adjusted factor ℓ can be obtained using Shephard's lemma:

$$x_{rj}^{\ell} = Y_{rj}\frac{\partial \Gamma_j(\cdot)}{\partial w_r^{\ell}}. \tag{5}$$

Taking the ratio of these demands for any two factors provides an expression for the relative demand for productivity-adjusted factors of production. Thus the demand for nonproduction workers (N) relative to production (P) workers is

$$\frac{N_{rj}}{P_{rj}} = \frac{\partial \Gamma_j(\cdot)/\partial w_r^N}{\partial \Gamma_j(\cdot)/\partial w_r^P}. \tag{6}$$

Using the relationship between productivity-adjusted and observed values in (2), this implies the following relative demand for observed factors of production,

$$\frac{\widetilde{N}_{rj}}{\widetilde{P}_{rj}} = \frac{\theta_{rj}^P}{\theta_{rj}^N}\frac{\partial \Gamma_j(\cdot)/\partial w_r^N}{\partial \Gamma_j(\cdot)/\partial w_r^P}. \tag{7}$$

B. *Null Hypothesis of Relative Factor Price Equality* (*RFPE*)

Under the null hypothesis that all relative factor prices are equalized (RFPE), *productivity-adjusted* relative wages and factor usage across regions r and b must be equal,

$$\frac{w_r^N}{w_r^P} = \frac{w_b^N}{w_b^P}, \qquad \frac{N_{rj}}{P_{rj}} = \frac{N_{bj}}{P_{bj}}, \tag{8}$$

where the second equation follows directly from equation (6).[8] Under this null hypothesis of RFPE, observed relative wages and factor usage across regions are given by

$$\frac{\widetilde{w}_{rj}^N}{\widetilde{w}_{rj}^P} = \frac{\theta_{rj}^N}{\theta_{rj}^P}\frac{\widetilde{w}_{bj}^N}{\widetilde{w}_{bj}^P}, \qquad \frac{\widetilde{N}_{rj}}{\widetilde{P}_{rj}} = \frac{\theta_{rj}^P}{\theta_{rj}^N}\frac{\widetilde{N}_{bj}}{\widetilde{P}_{bj}}. \tag{9}$$

Nickell, and Jackman 1991). With industry-specific bargaining, wages will generally vary across industries. As discussed further below, our empirical specification allows for inter-industry wage differentials through the inclusion of industry fixed effects.

[8] Homogeneity of degree one of the cost function implies that the derivatives $\partial \Gamma_j/\partial w_r^{\ell}$ are homogenous of degree zero in factor prices. It follows immediately from equation (6) that, with identical productivity-adjusted relative factor prices, regions will employ productivity-adjusted factors of production in the same proportions.

These relationships demonstrate the difficulty of using either observed relative wages, or observed factor usages, to test for factor price equality. Even under the null hypothesis of RFPE, observed relative wages and usages can vary across regions within industries because of unobserved differences in factor productivity (i.e., $\theta_{rj}^{N} \neq 1$ or $\theta_{rj}^{P} \neq 1$).[9]

We solve this problem by combining observed wages and employment into wage bills, where the wage bill for factor ℓ is equal to $\widetilde{w}_{rj}^{\ell} \widetilde{x}_{rj}^{\ell} = w_{rj}^{\ell} x_{rj}^{\ell}$. As is evident from equation (9), when observed wages and employment are multiplied, the terms in region-industry-factor productivity cancel. As a result, observed relative wage bills, which are generally available to empirical researchers, are equal under the null hypothesis of RFPE,

$$(10) \qquad (H_0 : RFPE) \quad \frac{\widetilde{wagebill}_{rj}^{N}}{\widetilde{wagebill}_{rj}^{P}} = \frac{\widetilde{wagebill}_{bj}^{N}}{\widetilde{wagebill}_{bj}^{P}}.$$

C. *Alternative Hypothesis of Non-Relative Factor Price Equality (non-RFPE)*

Under the alternative hypothesis of non-RFPE, the productivity-adjusted relative w_r^N / w_r^P wage differs across regions r and b by a multiplicative factor, γ_{rb}^{NP},

$$(11) \qquad \frac{w_r^N}{w_r^P} = \gamma_{rb}^{NP} \frac{w_b^N}{w_b^P},$$

where again we let region b be the benchmark region: $\gamma_{rb}^{NP} = \gamma_r^{NP} / \gamma_b^{NP}$ and $\gamma_b^{NP} = 1$. Across regions, observed relative wages now vary because of both differences in factor productivity and differences in productivity-adjusted factor prices:

$$(12) \qquad \frac{\widetilde{w}_{rj}^{N}}{\widetilde{w}_{rj}^{P}} = \gamma_{rb}^{NP} \frac{\theta_{rj}^{N}}{\theta_{rj}^{P}} \frac{\widetilde{w}_{bj}^{N}}{\widetilde{w}_{bj}^{P}}.$$

Additionally, observed factor usage varies across regions because of both differences in factor productivity and differences in factor demand driven by the variation in productivity-adjusted relative factor prices:

$$(13) \qquad \frac{\widetilde{N}_{rj}}{\widetilde{P}_{rj}} = \frac{\theta_{rj}^{P}}{\theta_{rj}^{N}} \left[\left(\frac{\partial \Gamma_j(\cdot)/\partial w_r^N}{\partial \Gamma_j(\cdot)/\partial w_r^P} \right) \Big/ \left(\frac{\partial \Gamma_j(\cdot)/\partial w_b^N}{\partial \Gamma_j(\cdot)/\partial w_b^P} \right) \right] \frac{\widetilde{N}_{bj}}{\widetilde{P}_{bj}}.$$

Multiplying the expressions for observed relative factor prices and observed relative employments, equations (12) and (13), the terms in unobserved factor productivity again cancel. However, relative wage bills now generally vary across regions

[9] As the factor productivity of the base region has been normalized to equal one, $\theta_{bj}^{N} = 1$, $\theta_{rj}^{N} \neq 1$ indicates that factor productivity differs in industry j between the base region and region r.

because of differences in productivity-adjusted factor prices and variation in productivity-adjusted factor usage,

$$(14) \qquad (H_1 : Non - RFPE) \qquad \frac{\widetilde{wagebill}_{rj}^N}{\widetilde{wagebill}_{rj}^u} = \eta_{rbj}^{NP} \frac{\widetilde{wagebill}_{bj}^N}{\widetilde{wagebill}_{bj}^u},$$

where

$$(15) \qquad \eta_{rbj}^{NP} = \gamma_{rb}^{NP} \left[\left(\frac{\partial \Gamma_j(\cdot)/\partial w_r^N}{\partial \Gamma_j(\cdot)/\partial w_r^P} \right) \Big/ \left(\frac{\partial \Gamma_j(\cdot)/\partial w_b^N}{\partial \Gamma_j(\cdot)/\partial w_b^P} \right) \right].$$

D. *Testing for RFPE*

Together equations (10) and (14) provide the basis for a test of the null hypothesis of RFPE that is robust to unobserved variation in factor productivity across factors, regions, and industries. The intuition for this method is as follows. When firms minimize costs, the observed quantities chosen given observed factor prices contain information about the unobserved productivity of the factors. As a result, multiplying observed factor prices by observed factor quantities enables us to control for unobserved variation in factor productivity.

Our test for RFPE is derived under a number of assumptions of cost minimization, constant returns to scale, and vertical differentiation of factors of production. In addition, we test the null hypothesis that all relative factor prices are equalized.[10] To the extent that other factors of production have differing degrees of complementarity with nonproduction and production workers, and to the extent that the prices of these other factors vary across regions, this provides one potential explanation for regional differences in relative wage bills and productivity-adjusted relative wages. However, while our test is a joint test of our assumptions and the null hypothesis that all productivity-adjusted relative factor prices are equalized, its ability to allow for factor-augmenting productivity differences across factors, regions, and industries is an important advantage relative to other possible approaches. Furthermore, in subsequent sections below, we show how our assumptions can be relaxed to allow for example for increasing returns to scale and for both horizontal and vertical differentiation of factors of production.

A failure of RFPE has two effects on the relative wage bill for an industry across regions. The first direct effect is given in equation (15) by the difference in relative productivity-adjusted wages, γ_{rb}^{NP}. The second indirect effect is given by the term inside the square brackets in equation (15), which captures the changes in relative factor usage induced by the differences in relative productivity-adjusted factor prices, and is also a function of γ_{rb}^{NP}. Further intuition for these two sources of variation in relative wage bills can be garnered by considering the special case in

[10] With perfect capital mobility, the rate of return to capital will be equalized across regions. However, as long as there is imperfect mobility of at least one other factor of production, productivity-adjusted relative factor prices will in general vary.

which the production technology for a given industry exhibits a constant elasticity of substitution (CES) across all factors of production ($\sigma_j = 1/(1 - \rho_j)$, where ρ_j is the CES parameter for industry j). In this special case, the differences in relative wage bills in (10) become

$$\eta_{rbj}^{NP} = \gamma_{rb}^{NP}\left[(\gamma_{rb}^{NP})^{1/(\rho_j - 1)}\right] = (\gamma_{rb}^{NP})^{\rho_j/(\rho_j - 1)}, \tag{16}$$

where γ_{rb}^{NP} captures the direct effect of the difference in relative wages, while $(\gamma_{rb}^{NP})^{1/(\rho_j - 1)}$ inside the square brackets in the middle equation captures the indirect effect of the induced difference in relative factor usage.

One insight that emerges from considering the special case of a CES production technology is that a finding of $\eta_{rbj}^{NP} \neq 1$ in our relative wage bill test is sufficient but not necessary to reject RFPE. When the production technology is Cobb-Douglas ($\rho_j = 0$ in equation 16), relative wage bills are equalized ($\eta_{rbj}^{NP} = 1$) even if productivity-adjusted factor prices differ across regions ($\gamma_{rb}^{NP} \neq 1$). However, if relative wage bills are not equalized ($\eta_{rbj}^{NP} \neq 1$), productivity-adjusted relative factor prices must differ across regions ($\gamma_{rb}^{NP} \neq 1$).[11] Therefore a finding that relative wage bills differ is *sufficient* to reject RFPE. As we show below, relative wage bills in fact vary substantially across US local labor markets, and hence the Cobb-Douglas assumption does not appear to provide a close approximation to the data.

II. Generalizations

In this section we show that our method for testing for relative factor price equality is robust to a number of generalizations, including imperfect competition, external and internal economies of scale, and variation in factor composition.

A. *Imperfect Competition*

The robustness of our method to imperfect competition derives from its use of cost minimization. Suppose that firms maximize profits subject to a downward sloping inverse demand curve, $p_{rj}(Y_{rj})$, under conditions of imperfect competition, which implies the following first-order condition for profit-maximization,

$$\frac{dp_{rj}(Y_{rj})}{dY_{rj}} Y_{rj} + p_{rj}(Y_{rj}) - \Gamma_j(\cdot) = 0, \tag{17}$$

where we continue to assume that $C_{rj} = \Gamma_j(\cdot)Y_{rj}$ is constant returns to scale. Defining the elasticity of demand as $\varepsilon_{rj}(Y_{rj}) \equiv -(dY_{rj}/dp_{rj})p_{rj}/Y_{rj}$, where p_{rj} denotes price, we obtain the standard result that equilibrium price is a mark-up over marginal cost,

$$p_{rj}(Y_{rj}) = \left(\frac{\varepsilon_{rj}(Y_{rj})}{\varepsilon_{rj}(Y_{rj}) - 1}\right)\Gamma_j(\cdot). \tag{18}$$

[11] Indeed, the fact that $(\gamma_{rb}^{NP})^{\rho_j/(\rho_j - 1)}$ is close to 1 for ρ_j close to 0 actually makes it harder to reject the null hypothesis of RFPE and strengthens any finding of a rejection.

Applying Shephard's lemma, equilibrium demand for each productivity-adjusted factor of production continues to be given by the derivative of the total cost function with respect to the productivity-adjusted factor price, as specified in equation (5). Therefore, the introduction of imperfect competition leaves the derivation of our test for relative factor price equality unchanged.

B. *External Economies of Scale*

Our framework can also be extended to incorporate external economies of scale under either perfectly or imperfectly competitive market structures. Under external economies of scale, each firm's production technology remains a constant returns to scale function of its own factor inputs and each firm takes factor productivity as given when minimizing costs. But factor productivity depends on overall production scale for the region and industry because of the external economies of scale. In the most general case, we have,

$$\theta_{rj}^{x} = \theta_{rj}^{x}(Y_{rj}, Y_{r,-j}, Y_{-r,j}, Y_{-r,-j}), \tag{19}$$

where $Y_{r,-j}$ is the vector of outputs in all other industries in a region, $Y_{-r,j}$ is the vector of all other regions' outputs in the industry, and $Y_{-r,-j}$ is the vector of all other regions' outputs in all other industries. Since our method allows factor productivity to vary freely across factors, regions, and industries, and does not make assumptions about its determinants, and since the cost-minimization behavior of the firm remains the same (see equation 3), the derivation of our test for relative factor price equality again remains unchanged.

C. *Internal Economies of Scale*

Our analysis can also incorporate internal economies of scale, which must be combined with imperfect competition. We assume that the cost function (4) remains homothetic, but is no longer homogenous of degree one in the firm's own factor inputs. Under imperfect competition, equilibrium price continues to be a mark-up over marginal cost,

$$p_{rj}(Y_{rj}) = \frac{\varepsilon_{rj}(Y_{rj})}{\varepsilon_{rj}(Y_{rj}) - 1} \frac{\partial C_{rj}(\mathbf{W}_r, Y_{rj})}{\partial Y_{rj}}. \tag{20}$$

where marginal cost, $\partial C_{rj}(\cdot)/\partial Y_{rj}$, now depends on output. Equilibrium demand for quality-adjusted factors of production can be obtained from Shephard's lemma, and the relative demand for observed skilled and unskilled workers is given by

$$\frac{\widetilde{N}_{rj}}{\widetilde{P}_{rj}} = \frac{\theta_{rj}^{P}}{\theta_{rj}^{N}} \frac{\partial C_{rj}(\mathbf{W}_r, Y_{rj})/\partial w_r^N}{\partial C_{rj}(\mathbf{W}_r, Y_{rj})/\partial w_r^P}. \tag{21}$$

Multiplying the expressions for observed relative factor prices and observed relative employments, the terms in unobserved factor productivity again cancel. The expression for relative wage bills becomes

$$(22) \qquad \frac{\widetilde{wagebill}_{rj}^{N}}{\widetilde{wagebill}_{rj}^{P}} = \gamma_{rb}^{NP}\left[\left(\frac{\partial C_{rj}(\cdot)/\partial w_r^N}{\partial C_{rj}(\cdot)/\partial w_r^P}\right)\Bigg/\left(\frac{\partial C_{rj}(\cdot)/\partial w_b^N}{\partial C_{rj}(\cdot)/\partial w_b^P}\right)\right]\frac{\widetilde{wagebill}_{bj}^{N}}{\widetilde{wagebill}_{bj}^{P}},$$

where the terms in brackets that capture relative unit factor input requirements are now a function of output, Y.

In the standard case of trade under internal economies of scale in the theoretical literature (Helpman and Krugman 1985), firms within an industry face the same constant elasticity of substitution ε_j, cost functions are homothetic and identical within industries, and there is free entry so that price equals average cost. Combining free entry with the pricing relationship in (20), the equilibrium ratio of average to marginal cost is equal to a constant $\varepsilon_j/(\varepsilon_j - 1)$, which with a homothetic cost function defines a unique equilibrium value of output for each firm in the industry. Under the null hypothesis of RFPE, $\gamma_{rb}^{NP} = 1$, and with all firms in the industry facing the same factor prices and producing the same output, the terms in parentheses in (22) cancel. Therefore we again obtain the prediction that relative wage bills are equalized under the null hypothesis of RFPE.[12] More generally, in the presence of internal economies of scale, variation in firm size across regions and industries can influence relative factor demands and provides a potential explanation for rejections of RFPE.

D. *Factor Productivity and Composition*

While our analysis has so far assumed vertical differentiation of factors of production, in this section we show that the analysis can be extended to allow each factor of production (e.g., nonproduction workers) to consist of many different types (e.g., managers and engineers), which are horizontally and vertically differentiated from one another. We assume a constant returns to scale production technology that is weakly separable in nonproduction and production workers, so that firms first choose optimal quantities of nonproduction and production workers as a whole before choosing optimal amounts of each worker type within these two categories. We demonstrate the point formally for nonproduction workers, but, without loss of generality, the argument applies for any factor of production. Though, for simplicity, we consider two types of nonproduction workers, the analysis goes through for any number of types. To avoid notational clutter, we suppress region and industry subscripts throughout this section.

[12] See Helpman and Krugman (1985) for further analysis of theoretical models of monopolistic competition and increasing returns to scale with factor price equalization.

We assume that the productivity-adjusted flow of nonproduction worker services is a constant returns to scale function of the productivity-adjusted flow of managerial and engineering services:

$$
\begin{aligned}
N &= \phi(N_1, N_2), \\
&= \phi\left(\frac{N_1}{\widetilde{N_1} + \widetilde{N_2}}, \frac{N_2}{\widetilde{N_1} + \widetilde{N_2}}\right)(\widetilde{N_1} + \widetilde{N_2}), \\
&= \phi(\theta^{N_1}\tilde{n}_1, \theta^{N_2}\tilde{n}_2)\widetilde{N},
\end{aligned} \tag{23}
$$

where N is productivity-adjusted nonproduction worker services, N_1 is productivity-adjusted managerial services, N_2 is productivity-adjusted engineering services, $\phi(\cdot)$ is linearly homogenous of degree one, $\widetilde{N} = \widetilde{N_1} + \widetilde{N_2}$ is the observed number of nonproduction workers, $\theta^{N_1} = N_1/\widetilde{N}_1$ is the productivity of managers, $\theta^{N_2} = N_2/\widetilde{N}_2$ is the productivity of engineers, and $\widetilde{n_1} = \widetilde{N}_1/(\widetilde{N}_1 + \widetilde{N}_2)$ and $\widetilde{n_2} = \widetilde{N}_2/(\widetilde{N}_1 + \widetilde{N}_2)$ are the observed shares of engineers and managers in nonproduction employment. Equation (23) may be rewritten more compactly as

$$
N = \theta^N \widetilde{N}, \qquad \theta_N \equiv \phi(\theta^{N_1}\tilde{n}_1, \theta^{N_2}\tilde{n}_2), \tag{24}
$$

where the productivity of nonproduction workers is now an index number, $\theta^N = \phi(\theta^{N_1}\tilde{n}_1, \theta^{N_2}\tilde{n}_2)$, which captures the productivity of managers, the productivity of engineers, and the composition of nonproduction workers between these two categories.

The productivity-adjusted wage of nonproduction workers is now a price index, defined as the dual to equation (23):

$$
w^N = \psi(\omega_1, \omega_2), \tag{25}
$$

where ω_1 is the productivity-adjusted wage of managers and ω_2 is the productivity-adjusted wage of engineers. Expenditure on productivity-adjusted nonproduction worker services is equal to observed expenditure on nonproduction workers,

$$
w^N N = \widetilde{w}^N \widetilde{N}, \tag{26}
$$

where w^N is the price index defined above and $\widetilde{w}^N$ is the observed wage per nonproduction worker. It follows that the productivity-adjusted nonproduction worker price index and the observed nonproduction worker wage are related according to

$$
w^N = \widetilde{w}^N / \theta^N. \tag{27}
$$

It is evident from equations (24) and (27) that the derivation of the test for relative factor price equality remains exactly the same as above and is unchanged by this extension.

III. Econometric Specification

In Section I, we showed that under the null hypothesis of RFPE, the relative wage bills of nonproduction and production workers (10) are equalized across regions within industries. To test this prediction empirically, we estimate the following OLS regression using region-industry data on the relative wage bill of nonproduction and production workers:

$$\ln\left(\frac{\widetilde{wagebill}_{rj}^{N}}{\widetilde{wagebill}_{rj}^{P}}\right) = \alpha_r + \mu_j + u_{rj}, \tag{28}$$

where α_r is a region fixed effect; μ_j is an industry fixed effect; and u_{rj} is a stochastic error. We report heteroscedasticity robust standard errors adjusted for clustering by region, which allows the error term to be correlated across industries within regions without imposing prior structure on the pattern of this correlation.

The industry fixed effects control for differences in the relative wage bills of nonproduction and production workers across industries that are common to all regions. For example, some industries may use nonproduction workers more intensively than others, and hence have higher values for the relative wage bill for nonproduction workers. More generally, other industry characteristics controlled for by the industry fixed effects include inter-industry wage differentials, or differences across industries in the classification of nonproduction and production workers. Additionally, since the left-hand side of the regression is the log relative wage bill, any region-industry characteristic that has the same proportionate effect on the wages or employment of nonproduction and production workers cancels from the numerator and denominator of the relative wage bill.

The region fixed effects capture average within-industry differences in relative wage bills across regions. We normalize the region and industry fixed effects so that they each sum to zero, which implies that we can estimate a separate fixed effect for each region and industry as well as the regression constant (see, for example, Greene 2002). Under this normalization, the regression constant captures the mean relative wage bill across regions and industries, and the region and industry fixed effects are estimated as deviations from this overall mean, which provides an implicit base region. Since relative wage bills are equalized under the null hypothesis of RFPE, a test for the joint statistical significance of the region fixed effects corresponds to a test of the null hypothesis of RFPE. In our baseline specification, the region fixed effects capture average within-industry differences in relative wage bills between regions that are assumed to be same for all industries. As a robustness test, we also consider an augmented specification in which we estimate (28) separately across four-digit SIC or six-digit NAICS industries within each two-digit SIC or three-digit NAICS sector. These estimations allow the size of the average difference in relative wage bills within more disaggregate industries to vary across more aggregate sectors.

Our empirical specification (28) is estimated using region-industry observations with positive relative wage bills for nonproduction and production workers. Since

each industry is not necessarily active in each region in the data, these data form an unbalanced panel of industries across regions. Under the null hypothesis that productivity-adjusted relative factor prices are equalized, the zero-profit conditions for positive production are satisfied for each sector in each region. As a result, positive production is feasible for each industry in each region and there is no reason for a systematic selection of industries across regions. It follows that the region fixed effects are statistically insignificant under RFPE, both because relative wage bills are equalized within industries across regions and because there is no systematic industry selection.

In contrast, under the alternative hypothesis of non-RFPE, the zero-profit conditions for positive production are not satisfied for each industry in each region, and industries that use a factor intensively should systematically select into regions where that factor has a low productivity-adjusted relative price. It follows that the region fixed effects are in general statistically significantly different from zero under non-RFPE, both because relative wage bills differ across regions within industries and because industry selection is nonrandom. Whatever the respective contributions of the two sources of the statistical significance of the region fixed effects under the alternative hypothesis of non-RFPE, their statistical significance is sufficient to reject relative factor price equality. As a check on our empirical estimates of relative wage bill differences, we provide direct evidence below on the extent to which they are correlated with differences in industry structure, as expected from the zero-profit conditions for production in a neoclassical economy.

IV. Empirical Implementation

In this section, we use our method to test for relative factor price equality across local US labor markets in 1972, 1992, and 2007.

A. *Data*

We implement our method using data from the US Census of Manufactures (CM). These data have a number of advantages with respect to testing for relative factor price equality. First, the CM records the employment and wages of all US manufacturing establishments every five years, and hence can be used to construct representative data on aggregate wages and employment for each region-industry over a long time period, even when using finely-detailed definitions of regions and industries.[13] Second, establishments can be linked to one of the 170 Economic Areas (EAs) that make up the continental United States. These regions are defined by the US Bureau of Economic Analysis based on commuting patterns and other measures of local economic activity, and therefore correspond closely to the concept of regional labor markets where wages are determined.[14] EAs also provide greater

[13] As is usual in empirical work using the CM, we exclude very small establishments, known as "administrative records," which are not required to report information on their inputs.

[14] See http://www.bea.gov/regional/docs/econlist.cfm and http://www.bea.gov/newsreleases/regional/rea/rea1104.htm for more detail. As noted in the latter, these Economic Areas "define the relevant regional markets surrounding

resolution of relative factor price variation than more aggregate geographic units that have been studied in much of the literature on US wage inequality, such as Census Regions or states.[15]

Third, the CM records the major industry of each establishment according to detailed industry categories. For the 1972 and 1992 CMs, each establishment is linked to one of 455 four-digit Standard Industrial Classification (SIC) categories. For the 2007 CM, there are 473 six-digit North American Industry Classification System (NAICS) categories.[16] We compare relative wage bills across regions within these detailed industry categories to control for any industry-level determinants of relative wages. To further ensure that the economic activities undertaken by regions within industries are as comparable as possible, we drop industries that explicitly include miscellaneous products, i.e., four-digit SIC or six-digit NAICS codes ending in "9."[17] While non-manufacturing industries are not included in our analysis, the null hypothesis of relative factor price equality implies that relative wage bills are equalized within each industry, and hence can be tested using industries within manufacturing.

Fourth, the CM reports wage and employment data by two worker categories—nonproduction and production—that have been used widely in the literature concerned with US wage inequality.[18] While the productivity, quality, and composition of nonproduction and production workers (or any other worker category) can vary across regions and industries, a key advantage of our test for relative factor price equality is that it is designed explicitly to control for such variation. Finally, the combination of wage and employment data for different categories of workers and detailed region and industry disaggregation enables us to examine the relationship between relative factor prices and industry structure.

Though we implement our test using the US Census of Manufactures, it can in principle be applied to any dataset containing information on wages and employment by region and industry for different categories of workers, such as the US Current Population Survey (CPS). An important consideration in the use of such datasets, however, is their representativeness. While use of the CPS may be appropriate for large regions (e.g., Topel 1994 uses the CPS to examine wages across the nine US Census Regions that comprise the United States), it provides a less attractive setting for analysis of relative wages across more disaggregate labor markets: when one simultaneously conditions on worker type, detailed industry, and detailed region, as required by our analysis, the number of observations for many cells is too small to be statistically representative. Furthermore, although the CPS data do have the advantage of containing more information on worker characteristics,

metropolitan or micropolitan statistical areas" and are used throughout the federal government and the private sector to describe local economic activity.

[15] A number of studies (e.g., Topel 1986, Lee 1999, Bound and Holzer 2000, Hanson and Slaughter 2002, and Bernard and Jensen 2000) document variation in income inequality or wages across either the nine US Census regions or across US states. Related work using wage regressions by Heckman, Layne-Farrar, and Todd (1996) finds that worker characteristics are priced differently across US Census regions.

[16] For results comparing 1972 and 2007, we map SIC industries to NAICS industries using a concordance developed by Pierce and Schott (forthcoming).

[17] This pruning leaves us with 396 SIC industries and 433 NAICS industries.

[18] See, for example, Berman, Bound, and Griliches (1994) and Lawrence and Slaughter (1993).

a growing empirical literature using employee data emphasizes the importance of residual wage inequality that is unexplained by worker characteristics observable to the econometrician.[19] Our method can be employed in settings in which information on worker characteristics is incomplete or missing because the factor productivity terms (e.g., θ_{rj}^{N}) account for variation in factor productivity, quality, and composition across factors, regions, and industries.

B. *Testing RFPE*

Using our baseline specification (28), we find strong evidence of a rejection of relative factor price equality. The null hypothesis that the region fixed effects are jointly equal to zero is rejected at the one percent level in all three years.[20] Table 1 reports the region fixed effects (α_r) for 1972 and 2007. The region fixed effects for 1992, as well as the standard errors clustered by region for all estimates, are reported in the online Appendix. Since the region fixed effects are normalized to sum to zero, they capture average proportional differences in relative wage bills within industries. As indicated in the tables, relative wage bills in 1972 vary from a low of 73 percent $(e^{-0.31})$ of the US average in Pueblo, Colorado to 130 percent $(e^{0.26})$ in Boston, Massachusetts. In 2007, the maximum and minimum estimates are 69 percent and 133 percent for Grand Forks, North Dakota and Boston, Massachusetts, respectively.

Overall, we find that the number of EAs with statistically significant differences in relative wage bills at the 5 percent level are 151, 156, and 157 in 1972, 1992, and 2007, respectively.[21] Further confirmation of a rejection of relative factor price equality is manifest in tests of the null hypothesis that unique region-pairs' relative wage bills are equal, i.e., $\hat{\alpha}_r = \hat{\alpha}_s$ for all regions $s > r$. We find that the average region rejects relative factor price equality with more than 90 percent of the remaining regions in all three years, and that every region rejects relative factor price equality with at least 77 percent of the remaining regions in all three years.

Examination of the distributions of estimated relative wage bills reveals an increase in the magnitude of departures from relative factor price equality over time. This trend is illustrated in Figure 1, which displays kernel density estimates of the region fixed effects by year, where these region fixed effects sum to zero in each year. The densities for both 1992 and 2007 exhibit fatter tails and wider support than the density for 1972, indicating a polarization of relative wage bills over time. As reported in Figure 1, the 25th and 75th percentiles of the 1992 and 2007 distributions are both further from the implicit national average of 0. Across all bilateral pairs in each year, we find the median absolute difference in unique region-pairs' relative wage bills, $|\hat{\alpha}_r - \hat{\alpha}_s|$, rises from 0.108 in 1972 to 0.117 and 0.116 in 1992 and 2007, respectively.

[19] See, for example, Juhn, Murphy, and Pierce (1993); Lemieux (2006); and Autor, Katz, and Kearney (2008).

[20] The F-statistics for this test are: 103,538.95 (1972); 10,407,973.00 (1992); and 38,402.69 (2007).

[21] In principle, these tests for the number of EAs in each year with statistically significant differences in relative wage bills could be affected by changes in the overall precision of the estimates over time. In practice, we find that the overall precision of the estimates, as reflected in the regression standard error, does not change substantially over time.

Table 1—Estimated 1972 and 2007 Relative Wage Bill Coefficients

Name	1972	2007	Name	1972	2007	Name	1972	2007
Bangor, ME	−0.215	0.027	Northern Michigan, MI	0.003	−0.067	Rapid City, SD	0.070	0.033
Portland, ME	0.053	0.159	Green Bay, WI	−0.095	0.120	Sioux Falls, SD	0.175	−0.111
Boston, MA	0.263	0.285	Appleton, WI	0.018	−0.040	Sioux City, IA	−0.002	−0.114
Burlington, VT	−0.047	0.153	Traverse City, MI	0.022	0.152	Omaha, NE	−0.003	−0.041
Albany, NY	0.151	0.114	Grand Rapids, MI	0.156	0.181	Lincoln, NE	0.046	−0.040
Syracuse, NY	0.011	0.168	Milwaukee, WI	0.153	0.229	Grand Island, NE	−0.084	−0.156
Rochester, NY	0.127	0.055	Chicago, IL	0.242	0.127	North Platte, NE	−0.076	−0.059
Buffalo, NY	0.071	0.109	Elkhart, IN	0.063	0.049	Wichita, KS	0.025	−0.026
State College, PA	−0.162	−0.056	Fort Wayne, IN	0.032	−0.095	Topeka, KS	−0.109	−0.134
New York, NY	0.243	0.220	Indianapolis, IN	0.046	0.007	Tulsa, OK	0.081	0.021
Harrisburg, PA	−0.046	0.063	Champaign, IL	0.049	−0.146	Oklahoma City, OK	0.056	−0.050
Philadelphia, PA	0.126	0.185	Evansville, IN	−0.115	−0.093	West Oklahoma, OK	−0.191	−0.214
Washington, DC	0.088	0.044	Louisville, KY	0.049	−0.024	Dallas, TX	0.093	0.096
Salisbury, MD	−0.076	0.050	Nashville, TN	0.034	−0.048	Abilene, TX	−0.046	−0.205
Richmond, VA	0.020	−0.016	Paducah, KY	−0.187	−0.093	San Angelo, TX	−0.244	0.172
Staunton, VA	0.005	−0.059	Memphis, TN	0.046	−0.061	Austin, TX	0.143	0.157
Roanoke, VA	0.022	0.028	Huntsville, AL	−0.117	−0.124	Houston, TX	0.105	0.047
Greensboro, NC	0.117	−0.012	Tupelo, MS	−0.211	−0.139	Corpus Christi, TX	0.050	−0.057
Raleigh, NC	0.054	0.061	Greenville, MS	−0.186	−0.144	McAllen, TX	−0.146	−0.049
Norfolk, VA	0.027	0.150	Jackson, MS	−0.031	−0.097	San Antonio, TX	0.013	0.079
Greenville, NC	0.000	−0.030	Birmingham, AL	0.031	0.015	Odessa, TX	−0.004	−0.083
Fayetteville, NC	−0.001	−0.050	Montgomery, AL	−0.115	0.043	Hobbs, NM	0.115	−0.160
Charlotte, NC	0.178	0.025	Mobile, AL	0.113	−0.097	Lubbock, TX	0.010	0.004
Columbia, SC	0.073	−0.031	Pensacola, FL	−0.050	0.031	Amarillo, TX	0.013	−0.044
Wilmington, NC	−0.104	−0.017	Biloxi, MS	−0.144	−0.038	Santa Fe, NM	0.058	−0.003
Charleston, SC	0.065	0.187	New Orleans, LA	0.108	0.040	Pueblo, CO	−0.314	0.006
Augusta, GA	0.101	−0.145	Baton Rouge, LA	0.024	−0.043	Denver, CO	0.230	0.156
Savannah, GA	0.064	−0.052	Lafayette, LA	0.051	−0.082	Scottsbluff, NE	−0.225	−0.198
Jacksonville, FL	−0.047	0.142	Lake Charles, LA	−0.034	−0.290	Casper, WY	−0.109	−0.005
Orlando, FL	0.149	0.201	Beaumont, TX	0.004	−0.103	Billings, MT	−0.016	−0.054
Miami, FL	0.156	0.157	Shreveport, LA	−0.083	−0.087	Great Falls, MT	−0.165	−0.094
Fort Myers, FL	0.063	0.153	Monroe, LA	−0.073	0.005	Missoula, MT	−0.118	−0.100
Sarasota, FL	0.089	0.162	Little Rock, AR	−0.139	−0.010	Spokane, WA	−0.027	0.120
Tampa, FL	0.121	0.149	Fort Smith, AR	−0.146	−0.123	Idaho Falls, ID	0.004	−0.031
Tallahassee, FL	−0.040	0.047	Fayetteville, AR	−0.195	−0.005	Twin Falls, ID	−0.081	−0.118
Dothan, AL	−0.153	−0.032	Joplin, MO	−0.047	−0.064	Boise City, ID	−0.065	0.003
Albany, GA	0.008	−0.101	Springfield, MO	−0.175	0.010	Reno, NV	−0.099	0.051
Macon, GA	−0.064	−0.148	Jonesboro, AR	−0.205	−0.175	Salt Lake City, UT	0.036	0.057
Columbus, GA	−0.117	−0.022	St. Louis, MO	0.101	0.012	Las Vegas, NV	−0.084	−0.086
Atlanta, GA	0.066	0.034	Springfield, IL	−0.045	−0.069	Flagstaff, AZ	−0.049	0.153
Greenville, SC	0.057	−0.029	Columbia, MO	−0.123	−0.062	Farmington, NM	0.055	0.170
Asheville, NC	0.039	0.109	Kansas City, MO	0.083	0.077	Albuquerque, NM	0.115	0.076
Chattanooga, TN	0.032	−0.102	Des Moines, IA	0.107	0.030	El Paso, TX	−0.010	−0.039
Knoxville, TN	0.062	0.099	Peoria, IL	−0.092	−0.039	Phoenix, AZ	0.128	0.151
Johnson City, TN	−0.057	−0.157	Davenport, IA	0.064	−0.013	Tucson, AZ	0.008	0.081
Hickory, NC	−0.023	0.020	Cedar Rapids, IA	0.022	0.079	Los Angeles, CA	0.236	0.175
Lexington, KY	−0.084	−0.148	Madison, WI	−0.015	−0.009	San Diego, CA	0.164	0.268
Charleston, WV	−0.072	−0.083	La Crosse, WI	−0.061	−0.152	Fresno, CA	0.020	0.057
Cincinnati, OH	0.179	0.120	Rochester, MN	0.034	0.007	San Francisco, CA	0.128	0.160
Dayton, OH	0.124	0.068	Minneapolis, MN	0.142	0.215	Sacramento, CA	−0.025	0.058
Columbus, OH	−0.001	0.037	Wausau, WI	−0.105	−0.204	Redding, CA	0.049	−0.152
Wheeling, WV	−0.280	−0.132	Duluth, MN	−0.079	0.072	Eugene, OR	0.027	0.094
Pittsburgh, PA	0.013	0.144	Grand Forks, ND	0.048	−0.370	Portland, OR	0.083	0.129
Erie, PA	0.076	−0.015	Minot, ND	−0.112	−0.298	Pendleton, OR	−0.181	−0.206
Cleveland, OH	0.166	0.070	Bismarck, ND	−0.245	−0.155	Richland, WA	−0.187	−0.192
Toledo, OH	0.006	−0.005	Fargo, ND	−0.149	0.073	Seattle, WA	0.021	0.111
Detroit, MI	0.165	0.183	Aberdeen, SD	−0.009	−0.312			

Notes: Table lists estimated relative wage bill by BEA Economic Area and year. Economic Areas have been abbreviated to indicate first city and state they encompass. Complete results are reported in the online Appendix.

Polarization of relative wage bills is also evident geographically. Figure 2 sorts regions' relative wage bills into quartiles, by year. To render these quartiles comparable over time, they are defined using the 25th, 50th, and 75th percentiles *of the 1972 distribution*, which are −0.079, 0.013, and 0.070, respectively. As indicated

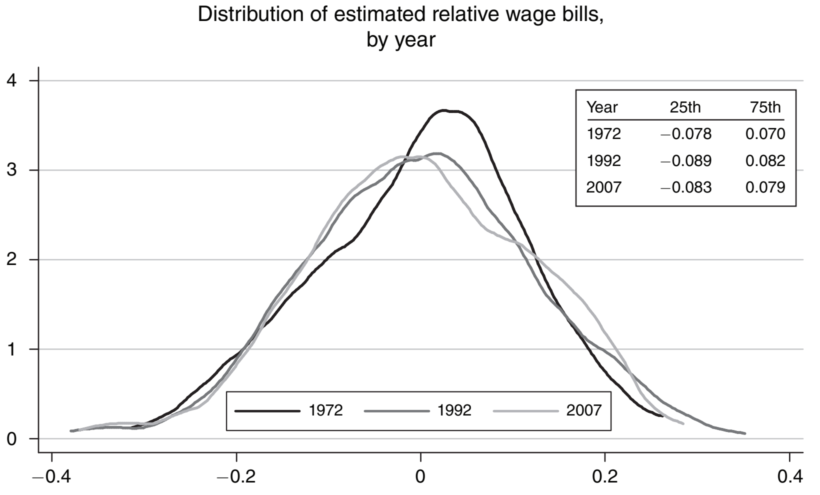

Figure 1. Distribution of Relative Wage Bill Coefficients ($\hat{\alpha}_r$), by Year

Note: Relative wage bills constrained to sum to 1 in each year.

Table 2—Relative Wage Bill Transitions over Time

	1992			
	Significantly lower	Insignificant	Significantly higher	Total
1972				
Significantly lower	45	4	18	67
Insignificant	13	0	4	17
Significantly higher	21	8	57	86
Total	79	12	79	170

	2007			
	Significantly lower	Insignificant	Significantly higher	Total
1972				
Significantly lower	50	5	20	75
Insignificant	10	0	5	15
Significantly higher	20	5	55	80
Total	80	10	80	170

Notes: Top panel reports the transition matrix between regions' estimated wage bill sign and statistical significance between 1972 and 1992. Bottom panel reports transition between 1972 and 2007.

in the figure, the number of regions in the third quartile declines over time, with the number of regions in the second and fourth quartiles growing disproportionately. In 1972, the number of regions in each quartile is $\{43, 41, 43, 43\}$; for 1992 and 2007, they are $\{47, 46, 29, 48\}$ and $\{45, 50, 26, 49\}$, respectively.

In Table 2, we report transition probabilities between relative wage bills' sign and statistical significance from 1972–1992 and 1972–2007. We find substantial persistence in the pattern of departures from relative factor price equality over time.

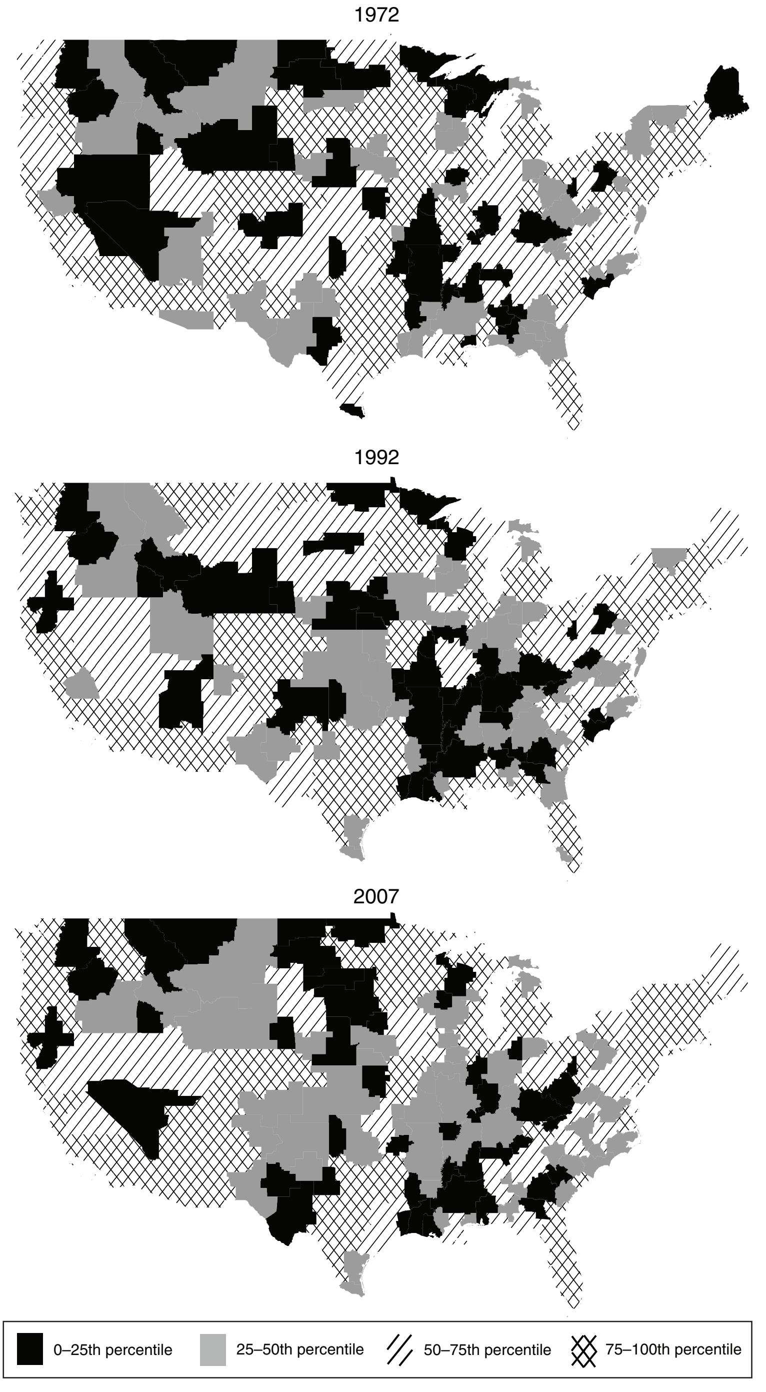

Figure 2. Geographic Distribution of Relative Wage Bill Estimates According to 1972 Quartiles, by Year

Notes: Figure classifies the relative wage bills of BEA Economic Areas in noted year according to quartiles defined by the 1972 distribution. The number of regions in each quartile are $\{43, 41, 43, 43\}$ in 1972, $\{47, 46, 29, 48\}$ in 1992, and $\{45, 50, 26, 49\}$ in 2007. The 1972 relative wage bill cutoffs are -0.079, 0.013, and 0.070.

Approximately 50 percent of regions with a positive and statistically significant departure from relative factor price equality in 1972 continue to exhibit a positive and statistically significant departure in 1992 and 2007. Similar results hold for negative and statistically significant departures. The correlation coefficients between the region fixed effects over time are 0.49 between 1972 and 1992, 0.51 between 1972 and 2007, and 0.66 between 1992 and 2007.

Finally, to address the concern that our baseline specification estimates an average within-industry difference in regional relative wage bills that is the same for all industries, we also re-estimate (28) separately for each two-digit SIC sector in 1972 and 1992 and each three-digit NAICS sector in 2007 using variation across four-digit SIC and six-digit NAICS industries, respectively. Though census disclosure requirements preclude publication of results at this level, the null hypothesis that the region fixed effects are jointly statistically insignificant is rejected at the one percent level for each sector in each year, and again we find evidence of pervasive rejections of bilateral relative factor price equality.

Taken together, the results of this section provide strong evidence of persistent and increasing disparities in productivity-adjusted relative factor prices. Although the United States is typically viewed as having high levels of labor mobility relative to other nations, and although we examine regions at a relatively high level of spatial disaggregation, relative factor price equality is decisively rejected.

V. Discussion

A. *Relative Wages*

While our test for relative factor price equality holds under general assumptions about factors, production, and markets, further intuition about the pattern of departures from relative factor price equality comes from consideration of a CES production technology with a common elasticity of substitution between factors of production across all industries. In this special case, from equations (16) and (28), the relationship between our estimates and relative wage bills in regions r and b under the alternative hypothesis of non-RFPE is given by

$$e^{\hat{\alpha}_r} = \eta_{rb}^{\hat{NP}} = \gamma_{rb}^{\hat{NP}}\left[(\gamma_{rb}^{\hat{NP}})^{1/(\rho-1)}\right]. \tag{29}$$

Assuming an elasticity of substitution $\sigma = 1/(1-\rho)$, we can use this expression to decompose the relative wage bills $(\hat{\alpha}_r)$ estimated in the previous section into two parts: productivity-adjusted relative wages, $\gamma_{rb}^{\hat{NP}}$, and productivity-adjusted relative factor use, $(\gamma_{rb}^{\hat{NP}})^{1/(\rho-1)}$.

Although the assumption of a common CES production technology is strong, a number of empirical studies in the labor economics literature have sought to estimate an aggregate elasticity of substitution between skilled and unskilled workers using various skill definitions (see, for example, Katz and Murphy 1992 and Murphy, Riddell, and Romer 1998). In their summary of this literature, Katz and Autor (1999) note that the estimated elasticity typically lies in the range of 1 to 3, with Katz and Murphy (1992) estimating an elasticity of 1.41.

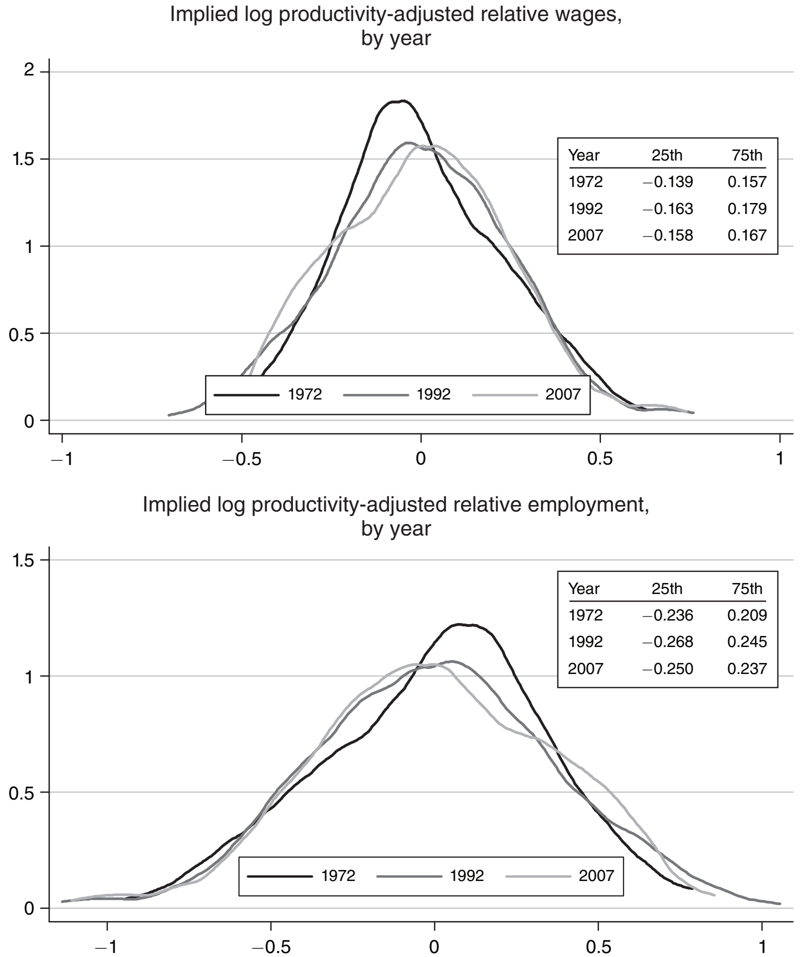

Figure 3. Distribution of log Implied Productivity-Adjusted Relative Wages and Employment under CES Production, by Year

Note: Distributions assume CES production and an elasticity of substitution of 1.5.

Here, we assume $\sigma = 1.5$ to provide a coarse approximation of the variation in productivity-adjusted relative wages and relative employment implied by our estimates of $\hat{\alpha}_r$. Under this assumption, Boston's maximum relative wage bill in 1972 (130 percent) can be decomposed into an implied productivity-adjusted relative wage of 59 percent (i.e., $\exp(1.30)^{-2}$) and implied productivity-adjusted relative employment of 220 percent (i.e., $\exp(1.30)^{3}$). Likewise, Pueblo's minimum relative wage bill in 1972 can be decomposed into an implied relative wage of 188 percent and implied relative employment of 39 percent.[22] More generally, the top and bottom panels of Figure 3 use $\sigma = 1.5$ to plot the implied distributions of relative

[22] The implied differences in relative wages and relative employment fall with the assumed elasticity of substitution. For example, using $\sigma = 2$, Boston's 130 percent relative wage bill in 1972 decomposes into a relative wage of 77 percent and relative employment of 170 percent.

productivity-adjusted relative wages and employment for each year. To increase readability of the left tail of these distributions, we plot them in log form. As illustrated in the figure, implied relative wages and relative employment vary widely across regions in all three years. Here, the increase in density in the right tail of the relative wage bill distribution in Figure 1 is manifest in the increase in density in the left and right tails in the relative wage and relative employment distributions, respectively.

From equation (12), observed variation in relative wages under the alternate hypothesis of non-RFPE can be decomposed into the contributions of variation in productivity-adjusted relative wages and differences in relative factor productivity. Hence our estimates of productivity-adjusted relative wages under CES $(\hat{\gamma}_{rb}^{NP})$ can be used together with observed relative wages to estimate the relative productivity of nonproduction workers for each region-industry:

$$\frac{\hat{\theta}_{rj}^{N}}{\hat{\theta}_{rj}^{P}} = \frac{1}{\hat{\gamma}_{rb}^{NP}} \frac{\widetilde{w}_{rj}^{N}/\widetilde{w}_{rj}^{P}}{\widetilde{w}_{bj}^{N}/\widetilde{w}_{bj}^{P}}. \tag{30}$$

To provide an indication of the average differences in relative factor productivity across regions implied by our results, we first estimate average differences in observed relative wages using a regression directly analogous to (28),

$$\ln\left(\frac{\widetilde{w}_{rj}^{N}}{\widetilde{w}_{rj}^{P}}\right) = \beta_r + \lambda_j + \chi_{rj}, \tag{31}$$

where $\hat{\beta}_r$ captures average within-industry differences in relative wages across regions and we again cluster the standard errors by region. As in equation (28), we purge observed relative wages of industry effects by including the λ_j fixed effects. Again, we impose the normalization that the region and industry fixed effects each sum to zero, which implies that our implicit base region is the mean across regions and industries. Using (30) and (31), we estimate the average differences in relative factor productivity across regions as $\hat{\theta}_{rj}^{N}/\hat{\theta}_{rj}^{P} = \exp(\hat{\beta}_r)/\hat{\gamma}_{rb}^{NP}$.

Combining these results with our estimated differences in productivity-adjusted relative wages $(\gamma_{rb}^{\hat{NP}})$, we find that the productivity of nonproduction workers relative to production workers in Boston is 196 percent (1.45/0.74) higher than in Pueblo in 1972, and 194 percent (1.08/0.55) higher than in Grand Forks in 2007. These estimates capture all variation in the relative productivity, quality, and composition of nonproduction and production workers across regions. In Figure 4, we display the distribution of our estimates for log relative factor productivity across regions. As with relative wage bills and productivity-adjusted relative wages, we find pronounced polarization in relative factor productivity over time.

While the results of this section rely on a strong functional form assumption, and are subject to the difficulty of determining an appropriate elasticity of substitution between production and nonproduction workers, they suggest that our rejection of relative factor price equality above involves substantial differences in productivity-adjusted relative wages across regions for plausible parameter values. At the same time, these findings raise the question of how such disparities in productivity-adjusted relative factor prices can be sustained over a long time period. Potential explanations

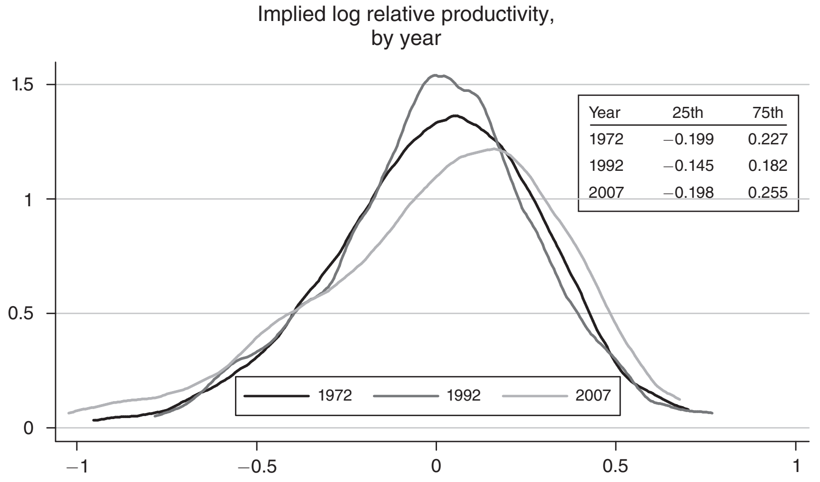

FIGURE 4. DISTRIBUTION OF IMPLIED LOG RELATIVE PRODUCTIVITY UNDER CES PRODUCTION, BY YEAR

Note: Distributions assume CES production and an elasticity of substitution of 1.5.

include frictions to geographical mobility (so that real wages need not be equalized across regions),[23] different expenditure shares of nonproduction and production workers on immobile goods such as housing (so that real wage equalization for each group of workers does not necessarily imply relative wage equalization),[24] and the non-random sorting of workers by productivity across regions (since real wage equalization applies to the marginal worker rather than inframarginal workers).[25] An advantage of our methodology is that we use firm cost minimization to test the equalization of productivity-adjusted relative wages without having to specify workers' location decisions, and hence our methodology is not required to take a stand on the relative importance of each of these explanations. Nevertheless, we believe further exploration of them is an interesting area for further research.

B. *Industry Structure*

We now provide some suggestive evidence on the relationship between our estimated departures from relative factor price equality and industry structure.

Under the null hypothesis that productivity-adjusted relative factor prices are equalized between a pair of regions, the zero-profit conditions for positive production are satisfied in the same set of industries for both regions. Hence, it is feasible that they have the same industry structure. Under the alternative hypothesis that productivity-adjusted relative factor prices are not equalized, however, the zero-profit conditions for positive production cannot be satisfied in the same set of industries for both regions, which implies that they cannot specialize in exactly the same

[23] See Bound and Holzer (2000) for evidence of imperfect labor mobility within the United States.
[24] See Glaeser and Gyourko (2005) for evidence on regional variation in housing prices.
[25] See Combes, Duranton, and Gobillon (2008) for evidence on worker sorting.

mix of industries. We emphasize that these relationships between industry structure and relative factor prices are not causal, but rather capture a relationship between two endogenous variables in a zero-profit equilibrium.[26]

In our data, industry structure varies considerably between region pairs. On average across all unique bilateral region pairs, approximately one third of the larger region's industries are in common to both regions. To explore whether these differences in industry structure are related to departures from relative factor price equality, we estimate the following regressions:

$$COMMON_{rs} = \delta_0 + \delta_1 |\hat{\alpha}_r - \hat{\alpha}_s| + \delta_2 I_r + \delta_3 I_s + \psi_{rs}, \tag{32}$$

$$\Delta COMMON_{rs} = \phi_0 + \phi_1 \Delta |\hat{\alpha}_r - \hat{\alpha}_s| + \phi_2 \Delta I_r + \phi_3 \Delta I_s + \psi_{rs}, \tag{33}$$

where $COMMON_{rs}$ is the number of industries that regions r and s produce in common in a given year; $|\hat{\alpha}_r - \hat{\alpha}_s|$ is the absolute difference in the regions' estimated wage bills; I_r and I_s control for the total number of industries produced by each region; and Δ indicates a change from either 1972–1992 or 1972–2007. We estimate the above regressions as separate cross sections for each year, clustering the standard errors by region.

In the levels specification (32), we find estimated coefficients (standard errors) for δ_1 of −64.35 (1.98), −44.28 (1.87), and −63.10 (2.04) for 1972, 1992, and 2007 respectively (complete regression output is reported in the online Appendix). Using these coefficients, a pair of regions with the maximum estimated differences in relative wage bills have 37, 32, and 41 fewer industries in common, respectively.[27] In the changes specification (33), we find estimated coefficients (standard errors) for ϕ_1 of −4.83 (0.65) and −6.71 (0.62) for 1972–1992 and 1992–2007 respectively, as also reported in the online Appendix. Using these estimated coefficients, a pair of regions with the maximum estimated change in the differences in their relative wage bills produce three and four fewer industries in common between 1972 and 1992, and 1992 and 2007, respectively.[28] While only indicative, these results suggest that departures from relative factor price equality are correlated with differences in industry structure.

VI. Conclusion

This paper proposes a test for relative factor price equality that allows for factor-augmenting productivity differences that vary by factor, region, and industry. Our approach is based on cost minimization, which implies that the observed quantities chosen by firms facing observed prices contain information about factors'

[26] For an empirical analysis of multiple cones of diversification, see Debaere (2004) and Schott (2003).

[27] The maximum difference in estimated relative wage bills in 1972, 1992, and 2007 are 0.58, 0.73, and 0.65, respectively.

[28] In unreported results, we also find a strong affinity between regions' relative wage bills and the factor intensities of the industries that are added and dropped by regions over time. Regions with high relative wage bills (low relative wages) for nonproduction workers are more likely to add and drop nonproduction worker and production-worker intensive industries, respectively.

unobserved attributes. We show that when observed quantities and prices are multiplied, terms in factor productivity cancel, so that the equality of productivity-adjusted relative wages can be tested using data on observed relative wage bills. Since our approach is derived from cost minimization, it holds under general assumptions about factors, production, and markets, including both perfect and imperfect competition. As our test controls for unobserved differences in factor productivity, quality, and composition, it is suitable for contexts in which worker characteristics are imperfectly observed or missing, as emphasized in the recent literature on residual wage inequality.

We implement our test for relative factor price equality using data on 170 local labor markets defined by the US Bureau of Economic Analysis over a thirty-five year period spanning 1972, 1992, and 2007. Although the US is typically viewed as having high levels of labor mobility, we find substantial departures from relative factor price equality that increase in magnitude over time. While there is substantial persistence in the regions with high and low relative wage bills, the distribution of relative wage bills exhibits polarization over time, with an increase in the fraction of regions characterized by extreme high and low relative wage bills. Under additional assumptions about the production technology, the estimated differences in relative wage bills imply substantial variation in relative productivity-adjusted wages and relative worker productivity for plausible elasticities of substitution. Consistent with the predictions of a zero-profit equilibrium, we find that our estimated differences in relative wage bills are systematically related to industry structure.

Our findings of persistent departures from relative factor price equality are suggestive of frictions to geographical mobility, different expenditure shares of nonproduction and production workers on immobile goods such as housing, or the systematic sorting of workers across regions. Since our methodology is based on firm cost minimization, it does not depend on assumptions about workers' location decisions, and holds under each of these scenarios. Nevertheless, an interesting area for further research is discriminating between these and other potential explanations. More broadly, our methodology might be applied to other settings where unobserved variation in productivity, quality, or composition is an important problem for identification. A similar test based on consumer expenditure minimization, for example, could be developed to test the law of one price across geographic areas.

Appendix: Absolute Factor Price Equalization (AFPE)

This Appendix develops a test for absolute factor price equality that controls for factor-augmenting productivity differences. Like our test for relative factor price equality, it makes use of the result that terms in factor productivity cancel when observed wages and employment are multiplied. To test absolute factor price equalization (AFPE) we analyze variation across regions in the share of total payments to a factor of production in output. Though our demonstration here is for nonproduction workers, the analysis for other factors of production is analogous. Observed employment of nonproduction workers may be obtained from equations (2) and

(3). Multiplying observed employment by observed wages and dividing by output, we obtain

$$\text{(A1)} \qquad \frac{\widetilde{w}_{rj}^N \widetilde{N}_{rj}}{Y_{rj}} = \frac{w_r^N N_{rj}}{Y_{rj}} = w_r^N \frac{\partial \Gamma_j(\cdot)}{\partial w_r^N},$$

where, from the total cost function (4), $\Gamma_j(\cdot)$ is the unit cost function and $\Gamma_j(\cdot)/\partial w_r^N$ corresponds to the unit input requirement for productivity-adjusted nonproduction workers. Under the null hypothesis of AFPE, productivity-adjusted wages are equal across regions $(w_r^N = w_b^N)$ and observed wages vary in direct proportion to unobserved factor productivity $(w_{rj}^N = \theta_{rj}^N w_b^N)$, where we again choose region b as a reference region so that $\theta_{bj}^N = 1 \forall j$. Identical productivity-adjusted factor prices in turn imply that unit input requirements for productivity-adjusted factors are the same across regions. Therefore, under the null hypothesis of AFPE, factor shares in equation (A1) are equalized across regions:

$$\text{(A2)} \qquad (H_0 : AFPE), \qquad \frac{w_r^N N_{rj}}{Y_{rj}} = \frac{w_b^N N_{bj}}{Y_{bj}}.$$

Under the alternative hypothesis of non-AFPE, regions may be characterized by different productivity-adjusted factor prices and hence different unit input requirements for productivity-adjusted factors. As a result, from equation (A2), factor shares in the two regions are related as follows:

$$\text{(A3)} \qquad (H_1 : non - AFPE), \qquad \frac{w_r^N N_{rj}}{Y_{rj}} = \gamma_{rb}^N \left(\frac{\partial \Gamma_j(\cdot)/\partial w_r^N}{\partial \Gamma_j(\cdot)/\partial w_b^N} \right) \frac{w_b^N N_{bj}}{Y_{bj}}.$$

Together, equations (A2) and (A3) provide the basis for a test of the null hypothesis of AFPE, with AFPE implying a testable parameter restriction in equation (A3).

REFERENCES

Autor, David H., David Dorn, and Gordon Hanson. Forthcoming. "The China Syndrome: Local Labor Market Effects of Import Competition in the United States." *American Economic Review*.

Autor, David H., Lawrence F. Katz, and Melissa S. Kearney. 2008. "Trends in U.S. Wage Inequality: Revising the Revisionists." *Review of Economics and Statistics* 90 (2): 300–323.

Barro, Robert, and Xavier Sala-i-Martin. 1991. "Convergence across States and Regions." *Brookings Papers on Economic Activity* 21 (1): 107–58.

Berman, Eli, John Bound, and Zvi Griliches. 1994. "Changes in the Demand for Skilled Labor within U.S. Manufacturing: Evidence from the Annual Survey of Manufactures." *Quarterly Journal of Economics* 109 (2): 367–97.

Bernard, Andrew B., and J. Bradford Jensen. 2000. "Understanding Increasing and Decreasing Wage Inequality." In *The Impact of International Trade on Wages*, edited by Robert C. Feenstra, 227–61. Chicago: University of Chicago Press.

Bernard, Andrew B., J. Bradford Jensen, and Peter K. Schott. 2004. "Assessing the Impact of Trade Liberalization on Import-Competing Industries in the Appalachian Region." http://mba.tuck.dartmouth.edu/pages/faculty/andrew.bernard/arc.pdf.

Bernard, Andrew B., J. Bradford Jensen, and Peter K. Schott. 2006. "Survival of the Best Fit: Exposure to Low-Wage Countries and the (Uneven) Growth of U.S. Manufacturing Plants." *Journal of International Economics* 68 (1): 219–37.

Bernard, Andrew B., Stephen J. Redding, and Peter K. Schott. 2007. "Comparative Advantage and Heterogeneous Firms." *Review of Economic Studies* 74 (1): 31–66.

Bernard, Andrew B., Stephen J. Redding, and Peter K. Schott. 2013. "Testing for Factor Price Equality with Unobserved Differences in Factor Quality or Productivity: Dataset." *American Economic Journal: Microeconomics*. http://dx.doi.org/10.1257/mic.5.2.135.

Bound, John, and Harry J. Holzer. 2000. "Demand Shifts, Population Adjustments, and Labor Market Outcomes during the 1980s." *Journal of Labor Economics* 18 (1): 20–54.

Carlino, Gerald A., and Leonard O. Mills. 1993. "Are U.S. Regional Incomes Converging? A Time Series Analysis." *Journal of Monetary Economics* 32 (2): 335–46.

Combes, Pierre-Philippe, Gilles Duranton, and Laurent Gobillon. 2008. "Spatial Wage Disparities: Sorting Matters!" *Journal of Urban Economics* 63 (2): 723–42.

Courant, Paul N., and Alan V. Deardorff. 1992. "International Trade with Lumpy Countries." *Journal of Political Economy* 100 (1): 198–210.

Cuñat, Alejandro. 2000. "Can International Trade Equalize Factor Prices?" Unpublished.

Davis, Donald R., and David E. Weinstein. 2001. "An Account of Global Factor Trade." *American Economic Review* 91 (5): 1423–53.

Davis, Donald R., David E. Weinstein, Scott C. Bradford, and Kazushige Shimpo. 1997. "Using International and Japanese Regional Data to Determine When the Factor Abundance Theory of Trade Works." *American Economic Review* 87 (3): 421–46.

Deardorff, Alan V. 1994. "The Possibility of Factor Price Equalization, Revisited." *Journal of International Economics* 36 (1–2): 167–75.

Debaere, Peter. 2004. "Does Lumpiness Matter in an Open Economy?" *Journal of International Economics* 64 (2): 485–501.

Debaere, Peter, and Ufuk Demiroglu. 2003. "On the Similarity of Country Endowments." *Journal of International Economics* 59 (1): 101–36.

Dixit, Avanash, and Victor Norman. 1980. *Theory of International Trade*. Cambridge, UK: Cambridge University Press.

Farber, Henry. 1986. "The Analysis of Union Behaviour." In *Handbook of Labor Economics*, Vol. 2, edited by Orley Ashenfelter and Richard Layard, 1039–89. Amsterdam: North-Holland.

Friedman, Thomas L. 2005. *The World is Flat*. London: Penguin Books.

Glaeser, Edward, and Joseph Gyourko. 2005. "Urban Decline and Durable Housing." *Journal of Political Economy* 113 (2): 345–75.

Greene, William H. 2002. *Econometric Analysis*. New York: Prentice Hall.

Hanson, Gordon H., and Matthew J. Slaughter. 2002. "Labor-Market Adjustment in Open Economies: Evidence from US States." *Journal of International Economics* 57 (1): 3–29.

Heckman, James, Anne Layne-Farrar, and Petra Todd. 1996. "Human Capital Pricing Equations with an Application to Estimating the Effect of Schooling Quality on Earnings." *Review of Economics and Statistics* 78 (4): 562–610.

Helpman, Elhanan, and Paul Krugman. 1985. *Market Structure and Foreign Trade: Increasing Returns, Imperfect Competition and the International Economy*. Cambridge, MA: MIT Press.

Juhn, Chinhui, Kevin M. Murphy, and Brooks Pierce. 1993. "Wage Inequality and the Rise in the Returns to Skill." *Journal of Political Economy* 101 (3): 410–42.

Katz, Lawrence, and David Autor. 1999. "Changes in the Wage Structure and Earnings Inequality." In *Handbook of Labor Economics*, Vol. 3A, edited by Orley Ashenfelter and David Card, 1463–1555. Amsterdam: North-Holland.

Katz, Lawrence, and Kevin Murphy. 1992. "Changes in Relative Wages, 1963–1987: Supply and Demand Factors." *Quarterly Journal of Economics* 107 (1): 35–78.

Lawrence, Robert Z., and Matthew J. Slaughter. 1993. "International Trade and American Wages in the 1980s: Giant Sucking Sound or Small Hiccup." *Brookings Papers on Economic Activity: Microeconomics* 23 (2): 161–226.

Layard, Richard, Stephen Nickell, and Richard Jackman. 1991. *Unemployment: Macroeconomic Performance and the Labour Market*. Oxford, UK: Oxford University Press.

Leamer, Edward E. 1987. "Paths of Development in the Three-Factor, *n*-Good General Equilibrium Model." *Journal of Political Economy* 95 (5): 961–99.

Lee, David S. 1999. "Wage Inequality in the United States during the 1980s: Rising Dispersion or Falling Minimum Wage?" *Quarterly Journal of Economics* 114 (3): 977–1023.

Lemieux, Thomas. 2006. "Increasing Residual Wage Inequality: Composition Effects, Noisy Data, or Rising Demand for Skill?" *American Economic Review* 96 (3): 461–98.

McKenzie, Lionel W. 1955. "Equality of Factor Prices in World Trade." *Econometrica* 23 (3): 239–57.

Murphy, Kevin M., W. Craig Riddell, and Paul M. Romer. 1998. "Wages, Skills and Technology in the United States and Canada." In *General Purpose Technologies and Economic Growth*, edited by Elhanan Helpman, 283–309. Cambridge, MA: MIT Press.

Pierce, Justin, and Peter Schott. Forthcoming. "Concording U.S. Harmonized System Categories to U.S. SIC and NAICS Industries." *Journal of Economic and Social Measurement.*

Repetto, Andrea, and Jaume Ventura. 1998. "The Leontief-Trefler Hypotheses and Factor Price Insensitivity." Unpublished.

Samuelson, Paul. 1949. "International Factor-Price Equalisation Once Again." *Economic Journal* 59 (234): 181–97.

Schott, Peter K. 2003. "One Size Fits All? Heckscher-Ohlin Specialization in Global Production." *American Economic Review* 93 (3): 686–708.

Schott, Peter K. 2008. "The Relative Sophistication of Chinese Exports." *Economic Policy* (23) 53: 5–49.

Topel, Robert H. 1986. "Local Labor Markets." *Journal of Political Economy* 94 (3): S111–43.

Topel, Robert H. 1994. "Regional Labor Markets and the Determinants of Wage Inequality." *American Economic Review* 84 (2): 17–22.

Trefler, Dan. 1993. "International Factor Price Differences: Leontief Was Right!" *Journal of Political Economy* 101 (6): 961–87.

Wu, Ho-Mou. 1987. "The Equalization of Factor Prices in General Equilibrium When Commodities Outnumber Factors." *Journal of International Economics* 23 (3/4): 343–56.