Factor Price Equality and the Economies of the United States

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Abstract

Do New York and Nashville face the same pressures from increased trade? This paper considers the role of international trade in shaping the product mix and relative wages for regions within the US. Using the predictions from a Heckscher-Ohlin trade model, we ask whether all the regions in the US face the same relative factor prices. Using the production side of the HO model, we derive a general test of relative factor price equality that is robust to unobserved regional productivity differences, unobserved regional factor quality differences, and variations in production technology across industries. Using data from 1972-1992, we reject the the hypothesis that all regions face the same relative factor prices in favor of an alternative with at least three distinct factor price cones. Sorting regions into cones with similar relative factor prices, we find that industry mix varies systematically across the groups. Regions that switch cones over time have more churning of industries.

1. Introduction

Do workers in New York and Nashville face the same benefits and costs from increased international trade? Does a firm's survival depend upon where in the US it is located? If the US is a single, tightly integrated market, then the answer to these questions should be no: with workers and capital receiving the same returns everywhere, and with technology and inputs free to cross state and county borders, a shock to any part of the US affects the whole country. However, if relative wages vary across regions, then the possibility exists for differential dislocation in Nashville and New York due to trade and globalization.

Our research challenges the view of the US as a seamless, integrated economy. Using the implications of the Heckscher-Ohlin trade model as a framework, we derive a general test of relative factor price equality for US regions that is robust to unobserved regional productivity differences, unobserved regional factor quality differences, and variations in production technology across industries. Using regional plant level manufacturing data from 1972-1992, we reject the hypothesis that all regions in the US face the same relative factor prices. We also find that regional product mix varies with relative factor rewards. In the language of trade theory, we find that the US contains multiple cones of diversification.[1]

While the concept of multiple factor price cones is usually applied across countries, it is substantially more controversial when considering regions within a relatively flexible economy such as the US. It is easy to imagine that the relative similarity of endowments, regulations and markets combined with the mobility of capital, technology, and even labor within the US would make it likely that relative price differences are at best transitory. In that scenario, the regions of the US would occupy a single factor price cone. However, work in the convergence of regional incomes within the US finds slow movements of relative per worker income levels, suggesting that either factor endowments or relative factor prices are at best converging slowly.[2]

An important question in pursuing research of this nature is why or

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[1] The word 'cone' refers to the set of endowment vectors that all select the same mix of products.

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

whether migration effectively integrates the various US labor markets. Topel (1986) provides a dynamic model and evidence for the effects of local demand conditions on wage levels and the inducement to migration. He argues that higher income workers are more mobile and move in response to local demand shocks of sustained duration. In contrast, lower income workers are largely constrained from moving and see substantial movements in their wages. The existence of increasing marginal costs of out-migration allows for persistence differences in relative wages. In Topel's framework, demand shocks are region-specific but of undefined origin. In this paper, we argue that the existence of multiple relative factor price cones within the US is at least partly responsible for the heterogeneity in industry composition. Variations in industry location due to factor price differences provide a source of heterogenous local demand shocks.

Developing an understanding of both the current and past structure of relative wages across US regions is important for a variety of mainstream research questions. Most obvious is the relevance for the literature on wage inequality itself. Much of the literature from both the labor and international trade perspectives has assumed that wage inequality varies across and within socioeconomic groups and industries but not across regions. Recently this assumption of regional homogeneity has been the subject of research. Focusing on the heterogeneity of relative wage movements at the regional level, Lee (1999) and Bernard and Jensen (2000a) both find substantial variation in wage inequality movements and levels across US states. We provide a direct test of the similarity of relative factor prices across regions and over time.

The implications of multiple relative factor price regions extend into the industrial organization and productivity literatures as well. If regions in the US face substantially different factor prices, then many estimates of industry production functions that assume common factor prices are misspecified. This is likely to feed into calculations of productivity and markups at both the plant and industry levels.

In this paper, we add to a growing literature on factor price equality. This research began with Samuelson (1949), who noted that two countries' factor rewards will be equal if their endowments vary less than industry input intensities. This insight, derived from a model with two goods and two factors, sparked efforts by Mckenzie (1955), Dixit and Norman (1980), Wu (1987) and Deardorff (1992) to generalize the necessary conditions for factor price equality to an arbitrary number of countries, goods and factors. Debaere and Demiroglu (1997) find a violation of these conditions in a cross section of countries, and interpret this result as evidence that developed and developing countries inhabit distinct cones of diversification. In compementary work, Repetto and Ventura (1998) show that international productivity-adjusted wages vary significantly across countries in a manner consistent with the existence of a multiple cone world.

More recent efforts have investigated alternate implications of factor price equality as well as its applicability to regions within countries. Schott (1999, 2000), for example, finds that countries tend to enter and exit sectors in a manner consistent with movement through multiple cones of diversification. Digging deeper into this Rybczynski adjustment mechanism, Bernard and Jensen (2000b) find that US plant closures occur more frequently in regions that are experiencing rapidly changing relative factor supplies and in industries with factor requirements at odds with the new supplies. Hanson and Slaughter (1999), on the other hand, find that US state factor supply changes are largely absorbed by changes in production technique that are common across states, an outcome they argue is consistent with productivity-adjusted factor price equality. In this paper we suggest that regional variation in relative factor prices is an important, unexplored component of how the US adjusts to both changes in factor supplies and the pressures of international trade.

Finally, our investigation of regional factor price equalization complements existing research in economic geography. That body of work, nicely surveyed by Hanson (2000), focuses on the agglomeration of economic activity and its effect on the spatial variation of wages, employment and production. Our approach is most closely related to that of Kim (1995, 1999), who finds that long-run trends US regional industry specialization are consistent with regional comparative advantage. Our emphasis in this paper on skilled-to-unskilled wage disparity, as well as the overlap of industries across regions, however, is unique.

The rest of the paper is organized as follows: section 2 outlines the implications of the multiple cone Heckscher-Ohlin equilibrium and summarizes the extent of regional variation in the United States. Section 3 details the relevant theorems on factor price equality and develops the testable implications. In Section 4, we discuss possible problems with existing techniques to test for relative factor price equality and outline our empirical methodology. Section 5 presents the results from the empirical tests of relative factor price equality for 1972 and 1992 and offers additional evidence on the relation between industry structure and factor prices. We look for variation in industry mix across factor price cones in Section 6. Section 7 concludes.

2. Single versus Multiple Cone Heckscher-Ohlin Equilibria

The easiest way to build intuition for single versus multiple cone equilibria is to assume there are just two factors of production and that the world is even in the sense that regions produce just two goods at every stage of their economic development. Such a world is captured by the Lerner (1952) diagram displayed in figure 1. This figure contains unit value isoquants for four sectors, Apparel, Textiles, Machinery and Chemicals, in a world with two factors, capital (K) and labor (L). Chemicals is the most capital intensive sector while Apparel is the most labor intensive sector. To keep things simple, all sectors are assumed to have Leontief technology.

Under standard Heckscher-Ohlin assumptions (Dixit and Norman 1980), the four sectors delineate three cones of diversification, the word cone referring to the set of endowment vectors that all select the same mix of products. Because production of a good outside of the cone in which a region resides results in negative profit, GDP-maximizing regions produce only the two goods anchoring their cones. In this respect, each of the three cones in figure 1 represents a standard, two good - two factor single cone equilibrium: if all US regions were located in the middle cone, for example, only Machinery and Textiles would be produced by the United States, with each region's ratio of the two outputs depending upon their relative capital abundance. As drawn, regions 1 and 4 each have a distinct product mix, with capital abundant region 4 producing relatively capital intensive Machinery and Chemicals and labor abundant region 1 manufacturing relatively labor intensive Apparel and Textiles. Note that regions in neighboring cones produce one good in common.

As cones increase in capital intensity, wages rise and capital rental rates decline. This change in relative factor rewards can be seen by connecting isoquants with their respective isocost lines. Unit value isoquants are tangent to their respective isocost lines under perfect competition. One such isocost line, tangent to Machinery and Textiles, is present in the diagram. Note that the absolute value of the slope of this line indicates the ratio of wages to capital rental rates; since the isocost lines become steeper as countries move from the most labor abundant cone to the most capital abundant cone, relative wages rise.

Figure 2 provides a summary of the empirical implications of single and multiple cone equilibria under the basic assumptions outlined in this section. These implications change if the world is uneven, if production requires more than two factor inputs, or if production technologies are not Leontief. We now discuss the implications of each of these complications, in isolation.

2.1. What if There Are More Sectors than Factors?

Specialization of output across regions may not be indicative of a multiple cone equilibrium if prices are such that the number of sectors a region can produce profitably exceeds the number of factor inputs. This case is illustrated in figure 3, which exhibits a single cone of diversification anchored by four rather than two sectors. Because prices render the choice of product mix arbitrary, regions 2 and 3 may not produce the same mix of sectors even though they inhabit the same cone. Region 3, for example, might produce Chemicals and Textiles and region 2 might produce Machinery and Apparel. Unevenness also implies that regions in neighboring cones may no longer produce at least one good in common. On the other hand, there remains a link, albeit weaker, between the probability that a region produces a sector and the similarity of the region's factor endowments with the industry's input intensity.

2.2. What if Factor Inputs are Substitutable?

If production technologies allow for the substitutability of inputs, it is no longer true that regions from neighboring cones must produce common goods with identical techniques. In figure 4, for example, regions 1 and 3 both produce Textiles, but region 3 produces the sector with a more capital intensive technique. In this case, regions in the same cone use identical techniques, while regions in disparate cones use techniques that are closer to their endowments.

2.3. What if There are More Than Two Factors?

The key complication of considering higher dimensional factor spaces is that with F factors, regions can produce up to $F-1$ goods in common, and therefore identifying a particular cone's neighbors can be quite complex. The first panel of figure 5 illustrates the mechanics of generalizing a two factor HO model to three dimensions. The trick, noted by McKenzie (1955) and Leamer (1987) is to construct an endowment simplex by reducing a three dimensional factor space of capital (K), labor (L) and human capital (H) to a two dimensional simplex. This simplex is formed by intersecting the positive orthant of the factor space with a plane so that the coordinate axes of the factor space are represented by the corners of the endowment simplex, while the industry-input and country-endowment vectors are represented by points on the surface of this triangle. Thus, cones of diversification are represented by triangles on the surface of the simplex. In the figure, the shaded triangle represents a cone anchored by Machinery, Textiles and Apparel. The tilt of this triangle is determined by the three product prices and is analogous to the slope of the isocost line in the earlier Lerner diagrams.

In the figure, the production of Apparel and Textiles requires only physical capital and labor, while the manufacture of Machinery requires capital, labor and human capital (H). Note as well that approaching a corner of the endowment simplex along a ray emanating from that corner represents an increase in the use (for an industry input vector) or abundance (for an endowment vector) of that factor, holding the concentration of other factors constant. Thus, Textiles use more physical capital than Apparel, and both use the same ratio of human capital to labor, which is zero. Since factors become relatively more abundant as regions move closer to a given vertex, the associated factor rewards decline as regions move through cones. Thus, in the second panel, which describes a multiple cone equilibrium containing eight cones, the return to labor declines as one moves through the cones at the bottom of the endowment simplex from right to left.

In the two dimensional Lerner diagrams above, the existence of three or more cones is enough to guarantee that at least two are not neighbors.

In higher dimensions, however, there is no guarantee that non-neighboring cones exist.[3] Intuition for this claim is provided by panel two of figure 5: in that endowment simplex, six of the eight cones produce the machinery sector.

The complex neighborliness of cones in higher dimensions means that regions with quite disparate endowments can produce sectors in common. In the figure, for example, regions 1, 2 and 3 all produce machinery even region 1 has almost no human capital to labor, region 3 has extremely high human capital to labor, and region 2 is in between. This complication limits the use of product mix as a means of empirically discerning single from multiple cone equilibria. For example, though all regions producing the same mix of goods is evidence of a single cone equilibrium, specialization does not imply a multiple cone equilibrium.

2.4. Relaxing The Basic Assumptions

If we relax the standard assumptions of the Heckscher-Ohlin model it becomes much more difficult to distinguish empirically a multiple from a single cone equilibrium. Indeed, as indicated in figure 6, we are left with three types of tests:

1. PRODUCT MIX: If all regions produce the same group of sectors, the US is characterized by a single cone equilibrium.[4] This implication is easy to verify but not very satisfying because the absence of production overlap does not imply existence of multiple cones. Figure 7, for example, reports that US regions do not in fact all produce the same mix of goods, though the extent of overlap is increasing with time. The first panel of the figure indicates that the median percent of regional participation across within a four digit Standard Industrial Classification sector rose from 28% in 1972 to 37% in 1992. Interestingly, there are some sectors that all regions produce, though it is possible that these sectors are non-tradeables. The second panel

[3] We hypothesize that non-neighboring cones will exist if there are at least $F-1$ sectors that use all F factors as inputs.

[4] Of course, this test must be performed at a reasonable level of sector disaggregation to be meaningful. In the empirical test below, we focus on four digit SIC codes which break manufacturing into approximately 480 sectors.

of the figure reports that most regions produce relatively few industries, that there are no regions that produce all industries, and that regional coverage also is increasing with time. Finally, the third panel reveals that the bilateral overlap of industries across region-pairs has also edged up with time.[5] Nevertheless, all we can conclude from this evidence is that the existence of a multiple cone equilibrium cannot be ruled out.

2. PRODUCTION TECHNIQUE: If production techniques for commonly produced goods are identical, the US is characterized by a single cone equilibrium. On the other hand, evidence that production techniques vary with regional endowments is evidence for the multiple cone model. For any pair of regions one can test whether industries produced in common have techniques that vary systematically with the differences in relative endowments.

3. RELATIVE WAGES: If relative wages vary with regional endowments in the manner suggested above, the US cannot be characterized by a single cone equilibrium. We can test this implication by regressing log relative raw wages on log relative raw endowments, or

$$\ln\left(\frac{w_{ir}^N}{w_{ir}^P}\right) = \sum_i \alpha_i + \beta \ln\left(\frac{N_r}{P_r}\right) + \epsilon_{ir},$$

where w, N, P, i and r represent wages, non-production (skilled) workers, production (unskilled) workers, industry and region, respectively. Results of this regression are reported in figure 8. They indicate that regions relatively abundant in skilled workers receive relatively lower wages in both 1972 and 1992. This result is suggestive of the failure of relative factor price equality. In the next section, we develop a stronger test that is robust to potential unobserved heterogeneity of factors across regions.

[5] Percent of sectors in common is defined as the number of sectors produced in both region r and region s divided by the maximum of the number of sectors in r and s.

3. Factor price equality across regions

We now turn to a more formal examination of factor price equality across economic regions.[6] We introduce the theorems that motivate our empirical framework and develop the testable implications of the theory under a relatively general set of assumptions.

We start by restating the Factor Price Equality theorem of Leamer (1995) which provides the basis for our null and alternative hypotheses:

Proposition 1 ***The Factor Price Equality Theorem (FPEQ).*** *Regions producing the same mix of products with the same technologies and the same product prices must have the same factor prices for identical factors.*

This theorem contains the essential, relevant prediction from the Heckscher-Ohlin trade model for our purposes. At any point in time, regions making identical products with identical technologies should face the same factor prices. If prices for identical factors differed across the regions, then the techniques and/or the products would vary. An important component of the theorem is that the relevant factor prices are those for identical factors. Differences in factor quality across the regions may induce differences in nominal factor prices but should not be taken as evidence of the failure of the prediction of the theorem.

We also want to consider a related prediction on relative factor prices which allows for the possibility that there are region-specific productivity differentials such as those discussed in Trefler (1993):

Proposition 2 ***Relative Factor Price Equality Theorem (RFPEQ).*** *Regions with different productivity levels producing the same mix of products with the same product prices must have the same relative factor prices for identical factors.*

This weakening of the original theorem allows for the likely possibility that there are region-specific differences in productivity that do not vary

[6] We use the term region to refer to the geographic unit of analysis, i.e. country, state, etc. In our empirical work on the US, this corresponds to a labor market area as defined by the Commerce Department.

across factors or goods. Under this condition the price levels of the factors would differ but the relative prices would be identical. As is obvious, Proposition 2 is necessary but not sufficient for Proposition 1.

While we will make use of the theorems in looking for deviations from factor price equality (FPEQ) and relative factor price equality (RFPEQ) across regions within the US, the theory and empirical methodology can be applied to any tests of factor price equality.

To develop our empirical framework, we impose some additional structure in the form of restrictions on the class of production functions. We restrict our analysis to the class of CES production technologies.[7] For the purposes of exposition, we consider an economy with two regions (r and s) and one homogenous industry with three inputs and a CES value-added production function. We allow for the possibility that there are unobserved productivity differences between region r and region s which affect all factors equally. In addition, we allow for unobserved differences in factor quality between the two regions. Throughout the section, subscripts refer to regions and superscripts refer to factors. We start with a value-added production function common to the industry in both regions,

$$Y_i = F\left(A_{i,}\theta_i^P P_i, \theta_i^N N_i, \theta_i^K K_i\right). \tag{1}$$

where P_i, N_i and K_i are observed production worker, non-production worker and capital inputs and $\theta_i^P P_i$, $\theta_i^N N_i$, and $\theta_i^K K_i$ are the true quality adjusted inputs in each region. A_i is a region-specific, Hicks-neutral productivity shifter. The actual production functions are CES in quality-adjusted inputs

$$Y_i = A_i \left[a_P \left(\theta_i^P P_i\right)^\rho + a_N \left(\theta_i^N N_i\right)^\rho + a_K \left(\theta_i^K K_i\right)^\rho\right]^{\frac{1}{\rho}} \tag{2}$$

where $1/1-\rho$ is the elasticity of substitution between factors.

Given price-taking in the factor market and common output prices, the

[7] In Appendix A we discuss the implications of trans-log cost functions for our empirical techniques.

first order conditions for quality adjusted factors in each region are:

$$
\begin{aligned}
w_i^P &= \frac{\partial F}{\partial\left(\theta_r^P P_r\right)} = Y_i^{1-\rho} \cdot a_P \left(\theta_i^P P_i\right)^{\rho-1} \\
w_i^N &= \frac{\partial F}{\partial\left(\theta_i^N N_i\right)} = Y_i^{1-\rho} \cdot a_N \left(\theta_i^N N_i\right)^{\rho-1} \\
w_i^K &= \frac{\partial F}{\partial\left(\theta_i^K K_i\right)} = Y_i^{1-\rho} \cdot a_K \left(\theta_i^K K_i\right)^{\rho-1}
\end{aligned} \tag{3}
$$

These three conditions give the returns for quality-adjusted factors. We maintain the assumption that factors are paid their true marginal product, i.e. they are compensated for quality. Since we are interested in the possibility of detecting deviations from factor price equality, we must pay particular attention to the difference between quantities (and prices) for observed and quality-adjusted factors.

For the purpose of exposition assume there are two regions, r and s, where region s is the reference region whose factors are taken to be the baseline quality benchmarks without loss of generality, i.e. $\theta_s^f = 1$. The two regions are in a single cone of factor price equality, FPEQ, if

$$
\begin{aligned}
w_r^P &= w_s^P \\
w_r^N &= w_s^N \\
w_r^K &= w_s^K
\end{aligned} \tag{4}
$$

all hold simultaneously. In words, this means that the quality adjusted returns are identical for all factors. RFPEQ holds if any two of the following three conditions hold:

$$
\begin{aligned}
\omega_r^{NP} &= \frac{w_r^N}{w_r^P} = \frac{w_s^N}{w_s^P} = \omega_s^{NP} \\
\omega_r^{KP} &= \frac{w_r^K}{w_r^P} = \frac{w_s^K}{w_s^P} = \omega_s^{KP} \\
\omega_r^{KN} &= \frac{w_r^K}{w_r^N} = \frac{w_s^K}{w_s^N} = \omega_s^{KN}.
\end{aligned} \tag{5}
$$

Note that the conditions for both FPEQ and RFPEQ are for quality-adjusted factor prices which cannot be observed in practice. In the following sections we develop empirical implications of RFPEQ and FPEQ for variables we can observe.

3.1. Implications of RFPEQ

We start by developing the testable implications for relative factor price equality. Absent any ability to correctly adjust for factor quality differences, the observed relative labor wages in the two regions will be given by

$$\begin{aligned}\tilde{\omega}_r^{NP} &= \frac{w_r^N \theta_r^N N_r}{N_r} / \frac{w_r^P \theta_r^P P_r}{P_r} = \frac{w_r^N \theta_r^N}{w_r^P \theta_r^P} \\ \tilde{\omega}_s^{NP} &= \frac{w_s^N N_s}{N_s} / \frac{w_s^P P_s}{P_s} = \frac{w_s^N}{w_s^P} \neq \tilde{\omega}_r^{NP} \text{ if } \theta_r^N \neq \theta_r^P.\end{aligned} \tag{6}$$

Under RFPEQ, the observed relative wages will only equal the true relative wages if the quality adjustments are the same for the two labor types across regions.

For observed demands of the two labor types by the industry in the two regions, under the maintained assumption of RFPEQ we can solve for the relationship between the factor ratios in the two regions,

$$\frac{N_r}{P_r} = \frac{\theta_r^P}{\theta_r^N} \cdot \frac{N_s}{P_s}. \tag{7}$$

The observed, unadjusted, input ratios will differ by exactly their relative quality adjustments.

Now we consider the possibility that RFPEQ does not hold and let the true quality adjusted relative factor returns vary across the two regions by a multiplicative factor, γ.[8] For our three factor world, we need two γ's, γ^{NP} and γ^{KP}. The third factor price adjustment is given by

$$\gamma^{KN} = \gamma^{KP} / \gamma^{NP}. \tag{8}$$

When any $\gamma \neq 1$, then relative factor price equality fails to hold between the two regions, i.e.

$$\omega_r^{NP} = \frac{w_r^N}{w_r^P} = \gamma^{NP} \frac{w_s^N}{w_s^P} = \gamma^{NP} \omega_s^{NP}. \tag{9}$$

[8] We implicitly set region s as the benchmark region and consider factor prices relative to those in region s, i.e.

$$\gamma = \frac{\gamma_r}{\gamma_s}$$

where $\gamma_s = 1$. When we consider multiple regions in our empirical work, we must choose a base region.

In terms of observed factors, we now have

$$\frac{N_r}{P_r} = \left(\gamma^{NP}\right)^{1/(\rho-1)} \frac{\theta_r^P}{\theta_r^N} \frac{N_s}{P_s} \tag{10}$$

with similar relationships for the other factor ratios.

This equation demonstrates the crux of the problem with using observed factor inputs to test for RFPEQ. Unless the regional quality adjustment is assumed to be identical for all factors, then relative input intensities cannot reveal whether $\gamma = 1$.

In terms of observed relative wages from equation 6, we find

$$\tilde{\omega}_r^{NP} = \gamma^{NP} \cdot \frac{\theta_r^N}{\theta_r^P} \cdot \tilde{\omega}_s^{NP}. \tag{11}$$

A close examination of equations 10 and 11 is useful for building intuition. Suppose RFPEQ holds (i.e. $\gamma = 1$) and that region r non-production workers are of higher relative quality (i.e. $\theta_r^N > \theta_r^P$). Then equation 11 implies that the observed non-production to production wage ratio is higher in region r than region s. Conversely, equation 10 implies that region r uses relatively fewer non-production workers than region s. These ratios might incorrectly lead one to assume that RFPEQ fails across these two regions and that region r has higher true relative wages.

Without extra information on relative factor quality, neither observed wages nor observed factor quantities can help us disentangle the problem of RFPEQ versus differing input quality. To tackle this problem, we use data on both wages and employed factors and multiply the terms in equations 10 and 11. This gives us

$$\frac{N_r}{P_r} \frac{w_r^N \theta_r^N}{w_r^P \theta_r^P} = \left(\gamma^{NP}\right)^{\rho/(\rho-1)} \frac{N_s}{P_s} \frac{w_s^N}{w_s^P}. \tag{12}$$

The numerator in left hand side of equation 12 represents total wages paid to non-production workers in region r while the denominator is the wages paid to production workers in region r. On the right, we have the product of two terms, the non-RFPEQ adjustment factor and the ratio of the non-production to production worker wage bill in region s,

$$\frac{\text{wagebill}_r^N}{\text{wagebill}_r^P} = \left(\gamma^{NP}\right)^{\rho/(\rho-1)} \frac{\text{wagebill}_s^N}{\text{wagebill}_s^P}. \tag{13}$$

With this formulation, we do not have to separately identify the wage for the quality adjusted input and the quality adjustment factor.

For intuition, consider the following. Suppose RFPEQ holds and production workers and capital are of identical quality in the two regions. Then firms in the two regions will want to hire the same number of production workers as well as the same amount of capital per unit of output. This can be seen in equation 3. Now the firms decide how many non-production workers to hire. The first order conditions tell us that the firms will hire the same amount of quality adjusted non-production labor and more importantly they will pay the same total amount to the non-production workers for that quality adjusted input. Neither the number of non-production workers per unit of output nor the wage per non-production workers will be the same in the two regions unless the qualities are also identical.

Now allow RFPEQ to fail so that the relative wage of quality adjusted non-production workers is 50% higher in region r ($\gamma = 1.5$) and to simplify the argument let a non-production worker in region r be equal to one third of a non-production worker in region s. From equation 11, we can see that observed relative non-production wages will be 50% lower in region r even though it is a region with high true relative non-production wages. From equation 10, we can see that the relative quantity of non-production to production workers will in fact be higher in region r than in region s. From these two facts we would be likely to conclude mistakenly that region r had relatively cheap non-production workers and thus employed relatively more of them. The actual ratio of the relative wage bills depends on whether $\gamma \lesseqgtr 1$ and whether $\rho > 0$, $\rho < 0$, or $\rho = 0$.

Rejecting $\left(\gamma^{NP}\right)^{\rho/(\rho-1)} = 1$ is necessary but not sufficient to reject relative factor price equality. To see why, note that there are two ways for $\left(\gamma^{NP}\right)^{\rho/(\rho-1)}$ to equal unity. First, if RFPEQ holds, $\gamma = 1$, then $\left(\gamma^{NP}\right)^{\rho/(\rho-1)} = 1$ no matter what value ρ takes. However, if ρ is close to zero (i.e. if production is close to Cobb-Douglas), $\left(\gamma^{NP}\right)^{\rho/(\rho-1)}$ may equal unity even if γ does not. On the other hand, $\left(\gamma^{NP}\right)^{\rho/(\rho-1)} \neq 1$ can only be due to the failure of relative factor price equality, $\gamma \neq 1$. In addition, even if $\rho \neq 0$ and we reject $\left(\gamma^{NP}\right)^{\rho/(\rho-1)} = 1$, we will not be able to determine which region has the higher relative wages without making an assumption on the elasticity of substitution, $1/(1-\rho)$.[9]

To reject RFPEQ we need only to reject $\left(\gamma^{fg}\right)^{\rho/(\rho-1)} = 1$ for one pair of factors f and g because RFPEQ implies that all relative factor rewards are equal. That is, even if the non-production to production wages are equal in regions r and s, it still may be the case that the wage-rental ratios are not equal. One can use either of the remaining two relationships to examine the variation, if any, in wage-rental ratios,

$$\frac{\text{capital payments}_r}{\text{wagebill}_r^P} = \left(\gamma^{KP}\right)^{\rho/(\rho-1)} \frac{\text{capital payments}_s}{\text{wagebill}_s^P}. \tag{14}$$

Before developing our empirical framework, we explore the additional implications of factor price equality.

3.2. Implications of FPEQ

The previous section has detailed testable implications of relative factor price equality across regions. It is still possible for absolute factor price equality to fail even if RFPEQ holds. Factor-independent productivity shifters will leave relative factor prices unaltered but change the levels of the factor rewards for all factors. In this section we consider the testable implications of FPEQ.

The relationship between rewards for a given factor across regions is given by

$$\begin{aligned} w_r^N &= w_s^N \\ \left(\frac{\theta_r^N N_r}{Y_r}\right)^{\rho-1} &= \left(\frac{N_s}{Y_s}\right)^{\rho-1}. \end{aligned} \tag{15}$$

Again the regional differences in factor quality, θ_r^N, are unobserved so we cannot use the unit factor inputs to test for FPEQ. We can, however,

[9] For example, if

$$\begin{aligned} \rho &< 0, \quad \left(\gamma^{NP}\right)^{\rho/(\rho-1)} > 1 \Rightarrow \gamma^{NP} > 1 \\ \rho &> 0, \quad \left(\gamma^{NP}\right)^{\rho/(\rho-1)} > 1 \Rightarrow \gamma^{NP} < 1. \end{aligned}$$

employ the factor shares, under FPEQ

$$\frac{w_r^N \theta_r^N N_r}{Y_r} = \frac{w_s^N N_s}{Y_s} \tag{16}$$

while the failure of FPEQ, $w_r^N = \gamma_{rs}^N \cdot w_s^N$, when $\gamma_{rs}^N \neq 1$, yields

$$\frac{w_r^N \theta_r^N N_r}{Y_r} = \left(\gamma_{rs}^N\right)^{\frac{\rho}{\rho-1}} \frac{w_s^N N_s}{Y_s}. \tag{17}$$

Of course, this relationship holds for all the factors in the production function. To reject FPEQ, we need only reject $\left(\gamma^f\right)^{\rho/(\rho-1)} = 1$ for one single factor.[10] In the next section, we outline our strategy for estimation with its advantages and disadvantages relative to existing methodologies.

4. Econometric Methodology

In this section, we start by discussing possible problems that have arisen in the existing empirical literature on testing FPEQ and RFPEQ. We then outline an empirical methodology for testing the null hypothesis of one RFPEQ cone versus the alternative of multiple RFPEQ cones. In the event that the null of one cone is not rejected, we describe a related method for testing for one FPEQ cone versus the alternative of multiple FPEQ cones. In the event that the single RFPEQ cone hypothesis is rejected, we present a technique for grouping regions into cones. Finally we conclude with an assessment of the pros and cons of our empirical methodology.

4.1. Unit input requirements

Observed unit factor requirements have been used in several recent papers on testing predictions of the HO model, e.g. Hanson and Slaughter (1999) and Davis and Weinstein (1998). We argue in this section that unit

[10] As before, rejecting $\left(\gamma^f\right)^{\rho/(\rho-1)} = 1$ for a single factor is sufficient but not necessary to reject FPEQ. There are again two ways for $\left(\gamma^f\right)^{\rho/(\rho-1)}$ to equal unity. Either FPEQ holds, $\gamma = 1$, or the production function is Cobb-Douglas, i.e. ρ is close to zero. On the other hand, $\left(\gamma^f\right)^{\rho/(\rho-1)} \neq 1$ can only be due to the failure of factor price equality.

We can only use $n-1$ of the n factor share relationships in estimation because of the restriction that the factor shares sum to one.

factor requirements cannot be used to determine whether two regions have common relative factor prices unless there are (1) no regional productivity differences and (2) no differences in regional factor quality. We simplify the discussion by focusing on the special case of a Cobb-Douglas production function with two (labor) inputs (N and P), constant returns to scale, variations in regional labor quality, and regional productivity differences. The production functions for the industry in the two regions are given by

$$Y_i = A_i \left(\theta_i^N N_i\right)^{\alpha} \left(\theta_i^P P_i\right)^{1-\alpha} \ . \tag{18}$$

Each region has a Hicks-neutral productivity shifter, A_i, and the two types of labor in region r differ in quality (productivity) from those in the benchmark region, s, by multiplicative factors, θ_r^N and θ_r^P. These productivity shifters do not vary across industries within a region. Only industry value-added, Y_i and unadjusted labor inputs, N_i and P_i can be observed.

Solving for the input-output ratios in terms of the ratio of observed factor inputs in the two regions, we get

$$\frac{N_r}{Y_r} = \frac{1}{A_r}\frac{N_r}{\left(\theta_r^N N_r\right)^{\alpha}\left(\theta_r^P P_r\right)^{1-\alpha}} = \frac{1}{A_r\left(\theta_r^N\right)^{\alpha}\left(\theta_r^P\right)^{1-\alpha}}\left(\frac{N_r}{P_r}\right)^{1-\alpha} \tag{19}$$

$$\frac{N_s}{Y_s} = \frac{1}{A_s}\frac{N_s}{\left(N_s\right)^{\alpha}\left(P_s\right)^{1-\alpha}} = \frac{1}{A_s}\left(\frac{N_s}{P_s}\right)^{1-\alpha} . \tag{20}$$

Rearranging terms, we can write the observed factor inputs in terms of the observed unit factor requirements,[11]

$$\frac{N_r}{P_r} = \left(\frac{N_r}{Y_r}\cdot A_r\left(\theta_r^N\right)^{\alpha}\left(\theta_r^P\right)^{1-\alpha}\right)^{1/1-\alpha} \tag{21}$$

$$\frac{N_s}{P_s} = \left(\frac{N_s}{Y_s}\cdot A_s\right)^{1/1-\alpha} \tag{22}$$

Under the maintained hypothesis of RFPEQ, we can solve for the relationship between the observed factor ratios by equating the relative wages

[11] As constructed, both the observed factor ratios and the observed unit factor requirements may differ from the true measures in region r.

paid to the true labor inputs across the regions,[12] yielding

$$\frac{N_r}{P_r} = \frac{\theta_r^P}{\theta_r^N} \cdot \frac{N_s}{P_s}.$$

In words, the observed, unadjusted, input ratios will differ by exactly their relative quality adjustments.

Suppose RFPEQ does not hold and let the true quality adjusted relative factor returns vary across regions by a multiplicative factor, γ_r. When $\gamma_r \neq 1$, then relative factor price equality fails to hold between the two regions, i.e.

$$\omega_r^{NP} = \frac{w_r^N}{w_r^P} = \gamma_r \frac{w_s^N}{w_s^P} = \gamma \omega_s^{NP}. \tag{23}$$

In terms of observed factors ratios, we now have

$$\frac{N_r}{P_r} = (\gamma_r)^{-1} \frac{\theta_r^P}{\theta_r^N} \frac{N_s}{P_s} \tag{24}$$

and substituting equations 21 and 22 into equation 24, we can express the unit factor requirement in region r in terms of the unit factor requirement in region s,

$$\frac{N_r}{Y_r} = \left(\frac{A_s}{A_r} \left(\theta_r^N\right)^{-1} (\gamma_r)^{\alpha-1} \right) \frac{N_s}{Y_s}. \tag{25}$$

Equation 25 reveals several problems with any empirical implementation using unit input requirements to test for RFPEQ. Most importantly, there is a problem with identification in that specification 25 cannot separately identify the differences in regional Hicks-neutral productivity, A_i, differences in factor quality across regions, θ_i^N, and differences in factor prices across regions, γ_r, all of which only vary across regions. Furthermore, adding additional factors to the production function does not solve the problem but merely adds more factor-specific productivity shifters to be estimated.

[12] The first order conditions and RFPEQ yield $\omega_R^{NP} = \frac{w_R^N}{w_R^P} = \frac{w_S^N}{w_S^P} = \omega_S^{NP}$. Observed relative factor prices need not be equal in this case. The observed relative wages will only equal the true relative wages if the quality adjustments are the same for the two labor types across regions.

4.2. Testing one cone versus many (RFPEQ)

We now outline our preferred techniques for testing the competing hypotheses of one versus many cones. We start by considering the predictions from the RFPEQ theorem and then the FPEQ theorem. Finally we develop a technique for grouping regions into cones in the event that the single cone hypothesis has been rejected.

Under the null of RFPEQ across all regions, every region should have the same wagebill ratio within an industry and this should be equal to the average for the US,

$$\frac{\text{wagebill}_{ir}^{N}}{\text{wagebill}_{ir}^{P}} = \frac{\text{wagebill}_{i,US}^{N}}{\text{wagebill}_{i,US}^{P}}.$$

The simplest test is a regression of the form:

$$\ln\left(\frac{WBR_{ir}^{fg}}{WBR_{i,US}^{fg}}\right) = \sum_{r} \alpha_{r}^{fg} d_{r} + \epsilon_{ir}^{fg} \tag{26}$$

where $WBR_{i,US}^{fg}$ is the average relative wagebill for industry i in the US for a pair of factors f and g, and α_r^{fg}'s are coefficients on a vector of region dummies. Under the null hypothesis of RFPEQ, $\alpha_r^{fg} = 0$ for all regions and factor pairs. Note that in order to estimate equation 26 for any factor pair including capital, one would have to construct a measure of capital payments as they are not usually recorded directly in the data. One possible solution is construct capital payments as the residual of value-added after payments to the two types of labor,

$$\text{capital payments}_{ir} = Y_{ir} - \text{wagebill}_{iNr} - \text{wagebill}_{iPr}.$$

However, this measure is particularly noisy in the plant data that we employ. We therefore focus our empirical work on relative wages.

Second, we test RFPEQ by estimating equations 13 and 14 for all industry and region-pair combinations. We start by choosing a region to be the benchmark, i.e. $\gamma_B^{fg} = 1$. Then we run a regression of the form:

$$\ln WBR_{ir}^{fg} = \left(\frac{\rho_i}{\rho_i - 1}\right) \ln\left(\gamma_r^{fg}\right) + \ln WBR_{iB}^{fg} + \epsilon_{irB}^{fg} \tag{27}$$

or

$$\ln\left(\frac{WBR_{ir}^{fg}}{WBR_{iB}^{fg}}\right) = \sum_{r\neq B}\alpha_{rB}^{fg}d_r + \epsilon_{irB}^{fg} \tag{28}$$

where the d_r's are region dummies that equal one whenever region r is the independent variable. Testing whether the α_{rB}^{fg}'s are jointly equal to zero provides a test of the null hypothesis of a single cone versus the alternative of multiple cones. Rejecting $\alpha_{rB}^{fg} = 0$ is sufficient to reject the hypothesis of RFPEQ between regions. Any pair of regions are in the same RFPEQ cone if $\alpha_{rB}^{fg} = \alpha_{sB}^{fg}$.

When testing the null of one RFPEQ cone versus the alternative of multiple cones, we can reject the null if any region is significantly different from the benchmark region for a single factor pair. However, equation 27 cannot be run if the benchmark region has no (or few) industries in common with region r. As discussed above, this fact of no common industries by itself is not sufficient for us to categorize the regions as being in different cones. To avoid this problem in practice, and as a general robustness check, we run separate regressions allowing each region to be the benchmark region.

4.3. Testing one cone versus many (FPEQ)

If we cannot reject the one cone hypothesis for relative factor prices, it still may be the case that absolute factor prices differ. In order to test the single cone hypothesis for FPEQ, we make use of equation 17 and test $\gamma_{rs}^{i} = 1$ for each of the following two relationships

$$\frac{w_r^N\theta_r^N N_r}{Y_r} = \left(\gamma_{rs}^N\right)^{\frac{\rho}{\rho-1}}\frac{w_s^N N_s}{Y_s} \tag{29}$$

$$\frac{w_r^P\theta_r^P P_r}{Y_r} = \left(\gamma_{rs}^P\right)^{\frac{\rho}{\rho-1}}\frac{w_s^P P_s}{Y_s}. \tag{30}$$

To reject FPEQ, we need only reject $\left(\gamma^f\right)^{\rho/(\rho-1)} = 1$ for one single factor.[13] The general form of the tests outlined above for RFPEQ works equally well in testing FPEQ, with the obvious substitution of the factor share in total costs in place of the relative wagebills. As before, the caveats about choosing benchmark regions apply.

[13] We can only use $n-1$ of the n factor share relationships in estimation because of the restriction that the factor shares sum to one.

4.4. *Grouping regions into cones*

If we reject the hypothesis that there is a single factor price cone, we must consider how to allocate regions to cones, i.e. which regions do face the same relative factor prices. We start with our specification using the entire US as the benchmark for an industry.

Our grouping procedure for a factor pair in a year is as follows:

1. Regress region-industry relative wagebills on that for the US (equation 26).
2. Any region that has a significantly higher wagebill ratio, i.e. $\hat{\alpha}_r^{fg} > 0$, is placed in a High group while regions with significantly lower wagebill ratios, i.e. $\hat{\alpha}_r^{fg} < 0$, are placed in a Low group. All remaining regions are placed in the Middle group. The only decision variable is the appropriate p-value.
3. Run equation 26 separately for each group of regions using only the regions in the cone to construct the benchmark wagebill ratio.
4. If no regions have coefficients significantly different from zero, then stop and use the three groups as cones.
5. If a region rejects, it is moved to a higher or lower group and repeat steps 3 and 4 until no regions switch groups.[14]

This method has the advantage that the number of groups is chosen endogenously and all industries are used in allocating regions to groups. It has the disadvantage that two regions may end up in the same group even though their wagebill ratios are significantly different from one another. Alternative grouping procedures could use the pairwise regression coefficients from equation 28. Using these coefficients presents the problem that for 3 regions, A, B, and C, regions A and C may be significantly different from each other but neither may be significantly different from region B.

[14] If, in this subsequent set of regressions, a region in the Low group has an estimated coefficient significantly less than zero, then we can create a new Lower group. Similarly for positive rejections in the High group. If a region cycles back and forth between groups over subsequent iterations, we can create an additional intermediate group.

4.5. Econometric Issues

In this section we consider econometric issues that may cause us to mistakenly reject RFPEQ. Product misclassification can cause us to reject RFPEQ spuriously. To see why, suppose that industry i comprises two goods, j and k, and that good j is non-production worker intense relative to good k by a factor of η_{ir}(e.g. stylish dress shirts versus ordinary dress shirts).[15] In addition, to keep things simple, assume there are no factor quality differences either across regions or between factors within a region, so that all θ's are equal to zero. If region r produces good j and region s produces good k^{16}, then instead of equations 11 and 10 we have

$$\begin{aligned}\frac{N_{jr}}{P_{jr}} &= \left(\gamma^{NP}\right)^{1/(\rho-1)} \cdot \eta_{ir} \cdot \frac{N_{ks}}{P_{ks}} \\ \tilde{\omega}_{jr}^{NP} &= \gamma^{NP}\tilde{\omega}_{ks}^{NP}\end{aligned}$$

In words, while relative wages must still be equal in the two regions, relative intensities differ by η_{ir}. As a result, when we compute relative wage bills for equation 12, we need to account for η_{ir}

$$\begin{aligned}\frac{N_r}{P_r}\frac{w_r^N\theta_r^N}{w_r^P\theta_r^P} &= \eta_{ir}\left(\gamma^{NP}\right)^{\rho/(\rho-1)}\frac{N_s}{P_s}\frac{w_s^N}{w_s^P} \\ WBR_{ir}^{NP} &= \eta_{ir}\left(\gamma^{NP}\right)^{\rho/(\rho-1)}WBR_{i,US}^{NP}\end{aligned}$$

Clearly, $\eta_{ir} \neq 1$ can cause us to reject RFPEQ even if $\gamma^{NP} = 1$. Indeed, $\eta_{ir} \neq 1$ also can cause us to fail to reject RFPEQ even if $\gamma^{NP} \neq 1$. To minimize the problem of product misclassification, we use the most detailed industry data we can assemble by region.

As always, measurement error is of concern. However, our two specifications for testing RFPEQ minimize the problems with measurement error. With the US as the base in equation 26, under the null hypothesis measurement error in the regressor should be minimized. In equation 28 estimated over pairs of regions, we can check for problems due to measurement error by looking at the reverse regressions, i.e. switching base regions.

[15] In our CES framework, $\eta_{ir} \neq 1$ is a violation of the assumption that production technologies are identical within industries across regions.

[16] The two regions might produce different goods due to the output indeterminacy discussed in section 3.1.2.

5. Empirical Results

In this section we describe our data set and present results from the tests of relative factor price equality.

5.1. Data

The data cover the years 1972-1992 and come from the Longitudinal Research Database of the Bureau of the Census. We use data only from the Census of Manufactures which is conducted every fifth year on all manufacturing plants in the lower 48 states.[17] We make use of the information on quantities of and total payments to two types of labor. We exclude plants that have non-positive value-added or any non-positive inputs. In addition, we exclude all Standard Industrial Classification (SIC) codes that represent miscellaneous products within an industry, i.e. SICs 39xx or xxx9, to reduce the possibility that we are comparing different goods within an industry. This leaves us with 385 of the original 458 4-digit SIC industries.

As is well known, the LRD only collects wage information on two categories of workers, production and non-production. However, we avoid the usual criticism that dividing workers into production and non-production groups imperfectly classifies them according to skill as our methodology is robust to unobserved differences in regional factor quality. More important for our purposes is that any imperfections in the allocation of workers to production and non-production categories be similar across regions within an industry.

A separate dimension of the data that we exploit in this paper is that of geography. Almost all previous work on trade and geographic heterogeneity within the US has used state data. We prefer to work with groups of counties that correspond more closely with regional labor markets. To this end, we use the Labor Market Areas constructed by the Bureau of Economic Analysis based on common commuting patterns. In the 48 states in our sample there are 181 LMAs. Working with the LMA as the unit of geographic analysis has several advantages in that it allows labor markets to cross state lines and admits the possibility of multiple labor markets within large states.

[17] We exclude so-called administrative records. Administrative records typically contain the smallest establishments and do not have data on inputs.

To run our tests for relative factor price equality, we aggregate the variables into region-industry cells before constructing wagebill ratios.

5.2. Testing RFPEQ

In Figure 9, we report the results from equation 26 using the US as the base region. For both 1972 and 1992 we easily reject the null hypothesis that all the regions have the same relative wagebills. In 1972, 47 (60) regions have relative wagebills significantly different from the US at the 5 (10) percent level. In 1992, 83 regions reject at the 5 percent level and 97 at the 10 percent level. This is sufficient to reject the single factor price cone hypothesis across regions within the US. In fact, for both years we see regions that reject on each side of zero, i.e. regions with significantly higher relative wagebills and regions with significantly lower relative wagebills suggesting that there are at least three separate factor price regions in the US.[18]

We can now answer the question posed at the outset. Nashville and New York have significantly different relative wagebills for non-production and production workers, and thus significantly different relative wages. In fact, in 1972 the relative wagebill in Nashville is 11 percent below the US average while that for New York is 15% above. To map the estimated coefficients into differences in relative factor prices, we need to make assumptions about the elasticity of substitution. Figure 10 reports relative factor prices for the two labor markets with $1/(1-\rho)$ equal to $1/2$ and 2 in 1972 and 1992. Nashville and New York do indeed have different exposure to external shocks as they have significantly different relative factor prices. With these elasticities, relative wages in New York and Nashville differ by 30%-85%. Left unresolved is whether the exposure comes through differences in their product mix or through differences in the factor intensity of production. In section 6, we examine whether variations in factor prices correspond to variations in industries across regions.

Our other test for relative factor price equality is the set of bivariate regressions in equation 28. However, there are far too many coefficients to report, 32580 in total for each year after allowing every region to be

[18] We will restrict our analysis to 3 factor price cones although results not reported here suggest that there may be an additional lower cone in both 1972 and 1992.

the base.[19] Figure 11 shows the patterns of rejections for region-pairs in 1972.[20] Darker shades indicate lower p-values. From the figure, we can see groups of regions with few rejections and groups with large numbers of rejections. In 1972, 21.4 percent of the region-pairs reject relative factor price equality at the 10 percent level, while 8.1 percent reject at the 5 percent level. Every region rejects with at least 8 other regions. In 1992, 30.0 percent of the region pairs reject relative factor price equality at the 10 percent level, 11.2 percent reject at the 5 percent level. Every region rejects with at least 10 other regions.

Both sets of results provide strong evidence against the single cone hypothesis for the US. Next we group regions into factor price cones.

5.3. Putting regions in cones

From Figure 9, we know that the single cone hypothesis can be easily rejected. Using those results and the methodology described above, we can produce factor price cones within the US based on relative wages for 1972 and 1992.[21] Regions with significantly higher wagebill ratios are grouped in cone 1. For 1972, there are eight regions in this upper cone including large, urban labor markets such as New York City, Chicago, and Los Angeles. Regions with significantly lower wagebill ratios are placed in cone 3 with the remaining regions in cone 2. In 1972 there are 52 regions in cone 3. Figure 12 shows the three cones on a map of the US for 1972. Black shading indicates that the relative wagebill for the region was significantly higher than that for the US. Cross-hatching indicates that the relative wagebill was significantly lower.

For 1992, there are 15 regions in the upper cone, 84 in the middle and 82 in the lowest cone. Figure 13 maps the three cones for 1992. Again black and cross-hatching indicate significantly higher and significantly lower relative wagebills respectively.

[19] We also are prevented by the disclosure rules (Title XIII) of the Bureau of Census from reporting the coefficients.

[20] The regions have been sorted by a distance measure calculated from pairwise rejections at the 10% level.

[21] The initial 1972 regression in figure 1 produced a stable grouping of regions. Iterations on the 1992 initial groups produced oscillations, with regions switching back and forth between cones. We chose groups based on the initial regression reported in figure 26.

There is a large amount of movement between cones over the period with most movers leaving the middle cone as shown in Figure 14. 19 regions moved to a higher relative wagebill cone and 42 regions moved to a lower relative wagebill cone. This movement over time to the extreme factor price cones is somewhat surprising given the usual assumption that regions in the US are becoming more integrated and thus more likely to face the same relative factor prices. However, the distribution of regions across cones does not tell us whether factor prices are moving farther apart. The cones themselves could be moving closer together even as regions become more evenly distributed across cones.

To check this, we look at the distribution of coefficients from our regressions with the US as the base. Figure 15 shows the histogram of coefficients for 1972 and 1992. While regions were separating into cones, the overall dispersion of relative wagebills did narrow slightly during the period, as we would expect if the US were becoming more integrated. However, the reduction was not sufficient to suggest that relative wages were substantially more equal across regions. To examine what was happening to the cones themselves, we report the means and standard deviations of the estimated coefficients by cone in Figure 16. While cones were becoming more similar in terms in relative wages, the within cone distributions were tightening.

From the coefficients using the US as a base, we can ask whether the average pair of regions has a larger or smaller difference in relative wagebills in 1972 and 1992. The distance between regions as measured by the significance of the wagebill rejections is increasing, however, the average distance between regions based on the regression coefficients is decreasing from 0.121 to 0.109. Comparing the average distance between pairs of regions in the high and low cones, we find that it decreased from 0.302 in 1972 to 0.260 in 1992.

The results in this section provide strong evidence against the hypothesis that all regions in the US face identical relative factor prices. In addition, while a number of regions have moved across factor price cones, there remain at least three distinct relative factor price cones even in 1992. In the next section, we explore another dimension of the HO model and ask whether the differences in factor prices are correlated with industry mix in the regions.

6. RFPEQ and Product Mix

As described above, an additional implication of multiple factor price cones is that regions in non-neighboring cones are expected to have distinct mixes of goods. By determining the relationship between product mix overlap and cone assignments for pairs of regions, we can provide a robustness check on our results.[22] More specifically, we estimate the number of industries two regions have in common as a function of their cone assignments

$$I_{rs} = \alpha + \beta_{11} D^{12}_{rs} + \beta_{12} D^{13}_{rs} + \beta_{13} D^{23}_{rs} + \beta_r I_r + \beta_s I_s + \epsilon_{rs} \quad (31)$$

where I_{rs} is the number of industries that regions r and s produce in common, D^{cd}_{rs} is a dummy equalling unity when regions are from different cones and I_r and I_s are the number of industries produced by region r and s, respectively.

Results of this estimation for 1972 and 1992 are reported Figure 17 and indicate that regions have fewer industries in common when they are members of different cones. If one region is in Cone 1 (high) and the other is in Cone 2 (middle), the pair have 9 fewer industries in common in 1972 and 15 fewer industries in common in 1992 than two regions residing in the same cone. These numbers represent roughly 9% and 15% of the average number of industries per region in the two years. More importantly, regions with a cone between them have 17 and 19 fewer industries in common in 1972 and 1992, respectively.[23]

As noted above, between 1972 and 1992 one third of the 181 LMA regions switched cones. A dynamic interpretation of HO product mix implications suggests that regions which switch cones over time drop old industries and add new ones. We can test this implication of the model

[22] All our estimates to this point have been based on industries that exist in both regions.

[23] There are at least two reasons why the product mix of regions in the first and third cones is not wholly distinct. First, because we focus on just two labor inputs, it is possible, in a higher dimensional setting, that our first and third cones actually do share a border. Second, it is possible that the four digit SIC aggregation used in our analysis obscures product heterogeneity at lower levels of aggregation. A more complete analysis of product mix is necessary to determine the importance of these explanations.

by estimating

$$A_r = \alpha + \beta_d J_r + \epsilon_r \tag{32}$$

where A_r is the portion of industries that region r added or dropped between 1972 and 1992 relative to the number producing in 1972 and D_r is the number of cones a region jumps between. Results of this estimation are reported in Figure 18. They indicate that each cone a region jumps increases the fraction of industries added or dropped by 14%.

These results provide confirming evidence that differences in relative factor prices across regions have important implications for the responses to apparently common global shocks.

7. Conclusions

In this paper, we provide a general methodology to test for factor price equality across economies. Under the usual HO assumptions of common products, common product prices, and common technologies, we develop testable implications of the Factor Price Equality Theorem and the Relative Factor Price Equality Theorem for a broad class of production technologies. Unlike previous attempts to formulate tests for FPEQ and RFPEQ, our testing methodology is robust to sources of unobserved heterogeneity that are likely to be present in any cross-country or cross-region data, including differences in regional productivity, unobserved regional factor quality, and variations in production technology. Our empirical methodology can be applied to any cross-region data set with factor payment information and sufficient industry detail.

We test for relative factor price equality across labor markets in the US in both 1972 and 1992. In both years, we soundly reject the null hypothesis that all regions face the same relative factor prices. In particular, we find that relative wages vary considerably across the US. Using a methodology to group regions into cones of factor price insensitivity, we find at least three such cones in the US in both years. Over time, numerous regions have switched cones with most moving to one of the extreme factor price groups. However, on balance regions are slightly closer together in terms of relative factor prices in 1992 than in 1972 as the cones themselves have moved closer together.

Sorting regions into cones, we look for the predicted relationship from HO trade theory between industry mix and factor prices. While most labor market areas have substantial numbers of industries in common, regions in different factor price cones have 9-19 percent fewer industries in common. Regions that switch cones over time have greater churning of industries. This variation in industry mix provides a direct mechanism for variation in the transmission of external shocks. In particular, our results suggest that we should not expect to find homogenous responses to external shocks throughout the US.

A FPEQ and generalized cost functions

In this appendix, we consider tests of FPEQ for alternate cost functions using the factor share methodology developed for the CES production function.

A1. The translog cost function

The translog cost function with constant returns to scale is given by

$$\log c(\mathbf{w}, Y) = a_0 + \sum_{i=1}^{k} a_i \log w_i + \sum_{i=1}^{k} \sum_{j=1}^{k} b_{ij} \log w_i \log w_j + \log Y. \quad (33)$$

Subject to the usual restrictions to ensure homogeneity in prices, the factor shares, $s_i = w_i x_i / c(\mathbf{w}_i, Y)$, are linear in the parameters and are given by

$$sh_i = a_i + \sum_{j=1}^{k} b_{ij} \log w_j. \quad (34)$$

Under the null of FPEQ, factor shares will be equal in different regions so long as the cost functions are identical, i.e. identical technologies. However, the failure of FPEQ will lead to variations in factor shares across regions.[24] For example, if $w_{ir} = \gamma_{j,rs} w_{is}$ across regions r and s, then the relationship between the factor shares in the two regions are given by

$$\begin{aligned} sh_{ir} &= a_i + \sum_j b_{ij} \log w_{jr} \\ &= a_i + \sum_j b_{ij} \log \gamma_{j,rs} w_{js} \\ &= \sum_j b_{ij} \log \gamma_{j,rs} + sh_{is}. \end{aligned} \quad (35)$$

Note that, as in the CES case, using factor shares to test for FPEQ avoids any problems with unobserved differences in factor quality, the factor prices

[24] It is not possible to derive a simple test for RFPEQ under the assumption of a translog cost function using relative factor shares.

are for quality adjusted factors. Unlike the CES case, the difference in factor shares is linear in the factor price differences, not multiplicative. In addition, there is no way to back out the relative factor prices if more than one factor price varies across regions. However, the basic test remains the same in that the failure of factor shares to be the same within an industry is sufficient to reject FPEQ.

A2. The Diewert cost function

The Diewert cost function with constant returns to scale is given by

$$c(\mathbf{w}, Y) = Y \cdot \left[\sum_{i=1}^{k} \sum_{j=1}^{k} b_{ij} \left(w_i w_j \right)^{1/2} \right].$$

The factor shares are given by

$$sh_i = \frac{w_i \cdot \sum_{j=1}^{k} b_{ij} \left(w_i / w_j \right)^{1/2}}{\left[\sum_{i=1}^{k} \sum_{j=1}^{k} b_{ij} \left(w_i w_j \right)^{1/2} \right]}.$$

Again the null of FPEQ holds when factor shares are equal across regions.

$$sh_{1r} = \frac{w_{1s}\gamma_{rs} \cdot \sum_{j=1}^{k} b_{1j} \left(w_{1s}\gamma_{rs} / w_{js} \right)^{1/2}}{\left[\sum_{j=1}^{k} b_{1j} \left(w_{1s}\gamma_{rs} w_{js} \right)^{1/2} + \sum_{i=2}^{k} \sum_{j=1}^{k} b_{ij} \left(w_{is}\gamma_{rs} w_{js} \right)^{1/2} \right]} \neq sh_{1s}.$$

Again, while significant differences in factor shares are sufficient to reject FPEQ, obtaining estimates of the γ's is not possible without imposing additional structure on the cost function.

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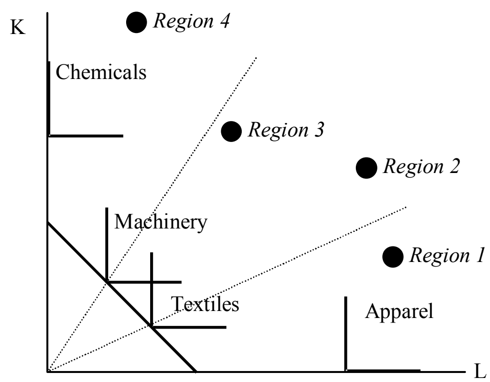

Figure 1: Heckscher-Ohlin Specialization

	Standard Assumptions: Two-Factors, Evenness, Leontief Technology	
	Single Cone	Multiple Cone
Sectoral Participation	Each region produces all possible sectors	No region produces all possible sectors; Regions produce sectors whose techniques are similar to their endowments
Production Overlap Within Cone	Total	Total
Production Overlap Across Cones		Partial for neighboring cones; Zero for non-neighboring cones
Production Techniques	Identical	Identical
Factor Rewards	All regions offer same rewards	Rewards vary by cone

Figure 2: Testing Factor Price Equality – Standard Assumptions

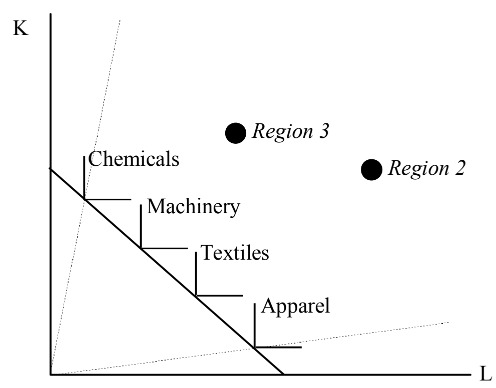

Figure 3: Unevenness

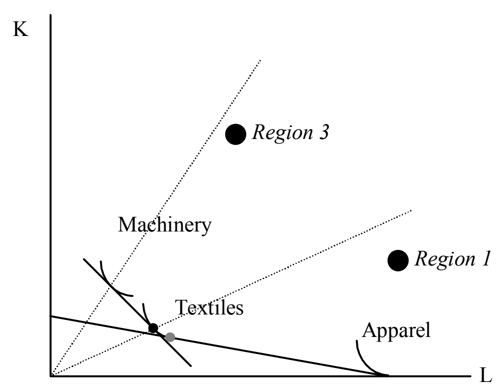

Figure 4: Substitutability

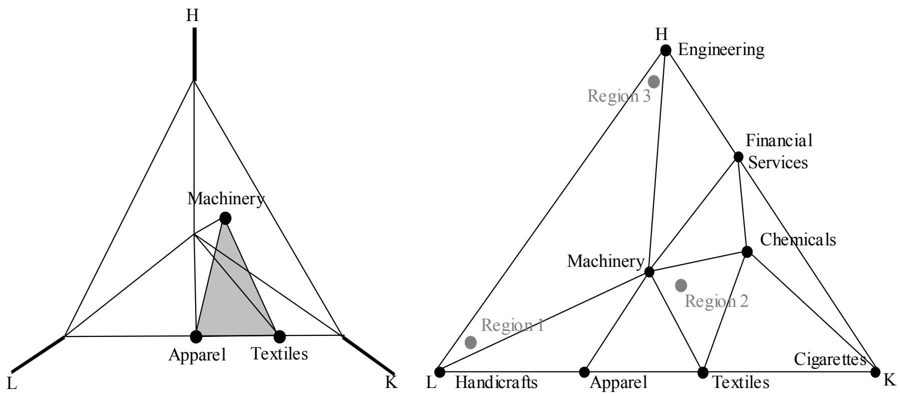

Figure 5: Heckscher-Ohlin Specialization with Many Factors and Goods

	Relaxed Assumptions: Many Factors, UnevenNess, Non-Leontief Technology	
	Single Cone	Multiple Cone
Sectoral Participation	Arbitrary specialization in subsets of all possible sectors	No region produces all possible sectors; Arbitrary specialization in subsets of all possible sectors
Production Overlap Within Cone	Arbitrary	Arbitrary
Production Overlap Across Cones		Arbitrary for neighboring cones; Zero for non-neighboring cones
Production Techniques	Identical	Identical within cone; Vary with endowments across cones
Factor Rewards	All regions offer same rewards	Rewards vary by cone

Figure 6: Testing Factor Price Equality – Relaxed Assumptions

		Min	Median	Max
Percent of Regions per SIC4 Industry	1972	1	28	100
	1992	3	37	100
Percent of Industries per Region	1972	5	27	95
	1992	8	38	94
Precent of Bilateral Industry Overlap Across Region-Pairs	1972	5	32	94
	1992	8	37	95

Figure 7: Industry Overlap Across US Regions

	1972	1992
$\ln(N_r/P_r)$	-0.05	-0.01
StdErr	0.01	0.01
P-Value	0.00	0.13
Obs	22,217	25,134
R^2	0.15	0.13

Figure 8: Regressing Regional Relative Wages on Regional Endowments, $\ln\left(\frac{w_{ir}^N}{w_{ir}^P}\right) = \sum_i \alpha_i + \beta \ln\left(\frac{N_r}{P_r}\right) + \epsilon_{ir}$

LMA	Region	1972	1992	LMA	Region	1972	1992	LMA	Region	1972	1992
1	bangor, me	-0.095	-0.08	62	parkersburg, wv	-0.06	-0.055	123	austin, tx	0.084	0.032
2	portland, me	-0.037	0.021	63	wheeling, wv	-0.278*	-0.204*	124	waco, tx	-0.015	-0.135***
3	burlington, vt	-0.107	-0.131*	64	youngstown, oh	-0.068	-0.064	125	dallas, tx	0.049	0.031
4	boston, ma	0.106*	0.138*	65	cleveland, oh	0.061	0.034	126	wichita falls, tx	-0.012	-0.127
5	providence, ri	0.104***	0.084***	66	columbus, oh	-0.086**	-0.068**	127	abilene, tx	-0.053	-0.022
6	hartford, ct	0.102***	0.121*	67	cincinnati, oh	0.063	0.124*	128	san angelo, tx	-0.372*	0.008
7	albany, ny	0.053	0.008	68	dayton, oh	-0.014	0.037	129	san antonio, tx	0.019	-0.035
8	syracuse, ny	-0.074	0.025	69	lima, oh	-0.156***	-0.187*	130	corpus christi, tx	0.051	-0.039
9	rochester, ny	0.031	0.025	70	toledo, oh	-0.024	-0.074**	131	brownsville, tx	-0.237***	-0.105
10	buffalo, ny	-0.07	-0.013	71	detroit, mi	0.059	0.025	132	odessa, tx	-0.021	0.011
11	binghamton, ny	-0.164*	-0.097***	72	saginaw, mi	-0.026	-0.021	133	el paso, tx	-0.078	-0.139*
12	new york, ny	0.151*	0.159*	73	grand rapids, mi	0.055	0.025	134	lubbock, tx	0.07	-0.048
13	scranton, pa	-0.193*	-0.144*	74	lansing, mi	-0.028	-0.025	135	amarillo, tx	-0.107	-0.04
14	williamsport, pa	-0.191*	-0.079**	75	south bend, in	-0.043	-0.056	136	lawton, ok	-0.334*	-0.236***
15	erie, pa	0.016	-0.055	76	fort wayne, in	-0.024	-0.093***	137	oklahoma city, ok	-0.019	-0.066
16	pittsburgh, pa	-0.106***	-0.085***	77	kokomo, in	-0.112	-0.156*	138	tulsa, ok	-0.036	-0.066
17	harrisburg, pa	-0.081**	-0.144*	78	anderson, in	-0.149***	-0.18*	139	wichita, ks	-0.022	-0.036
18	philadelphia, pa	0.004	0.069***	79	indianapolis, in	-0.057	-0.018	140	salina, ks	-0.385*	-0.276*
19	baltimore, md	0.043	0.058	80	evansville, in	-0.188*	-0.132*	141	topeka, ks	-0.216***	-0.069
20	washington, dc	0.037	-0.073**	81	terre haute, in	-0.167***	-0.208*	142	lincoln, ne	-0.026	-0.143***
21	roanoke, va	-0.035	-0.141*	82	lafayette, in	-0.214*	-0.235*	143	omaha, ne	-0.053	-0.143*
22	richmond, va	-0.072	-0.117*	83	chicago, il	0.122*	0.094*	144	grand island, ne	-0.126	-0.108
23	norfolk, va	0.005	0.055	84	champaign, il	-0.075	-0.051	145	scottsbluff, ne	-0.44*	-0.112
24	rocky mount, nc	-0.146***	-0.115***	85	springfield, il	-0.044	-0.097	146	rapid city, sd	0.059	0.12
25	wilmington, nc	0.084	-0.12***	86	quincy, il	-0.09	-0.297*	147	sioux falls, sd	0.074	-0.143***
26	fayetteville, nc	-0.094	-0.315*	87	peoria, il	-0.083	-0.057	148	aberdeen, sd	-0.132	-0.253*
27	raleigh, nc	0.052	0.037	88	rockford, il	0.086	-0.036	149	fargo, nd-mn	-0.172**	-0.075
28	greensboro, nc	0.041	-0.079***	89	milwaukee, wi	0.035	0.088***	150	grand forks, nd	-0.011	-0.033
29	charlotte, nc	-0.006	0.013	90	madison, wi	-0.213*	-0.038	151	bismarck, nd	-0.064	0.054
30	asheville, nc	-0.135**	-0.107***	91	la crosse, wi	-0.049	0.005	152	minot, nd	-0.148	0.039
31	greenville, sc	-0.004	-0.083***	92	eau claire, wi	-0.221***	-0.138***	153	great falls, mt	-0.134	-0.1
32	columbia, sc	0.013	-0.123***	93	wausau, wi	-0.112	-0.137***	154	missoula, mt	-0.19	-0.151***
33	florence, sc	-0.137**	-0.177*	94	appleton, wi	0.018	-0.009	155	billings, mt	0.129	-0.067
34	charleston, sc	0.12	0.038	95	duluth, mn	-0.164***	-0.193*	156	cheyenne, wy	-0.151	-0.116
35	augusta, ga	-0.019	-0.073	96	minneapolis, mn	0.054	0.077***	157	denver, co	0.078**	0.072**
36	atlanta, ga	-0.036	-0.038	97	rochester, mn	0.084	-0.107	158	colorado springs,	-0.093	-0.059
37	columbus, ga	-0.128**	-0.121***	98	dubuque, ia	-0.142**	-0.283*	159	grand junction, co	-0.058	-0.033
38	macon, ga	-0.131**	-0.192*	99	davenport, ia	-0.054	-0.111***	160	albuquerque, nm	-0.012	-0.056
39	savannah, ga	0.056	-0.15*	100	cedar rapids, ia	-0.052	-0.021	161	tucson, az	-0.117	0.018
40	albany, ga	-0.074	-0.098**	101	waterloo, ia	-0.113	-0.158*	162	phoenix, az	0.024	-0.07**
41	jacksonville, fl	-0.165*	-0.042	102	fort dodge, ia	-0.042	-0.119**	163	las vegas, nv	-0.235***	-0.052
42	orlando, fl	0.001	0.026	103	sioux city, ia	-0.085	-0.166*	164	reno, nv	-0.231*	0.032
43	miami, fl	0.048	0.055	104	des moines, ia	-0.01	-0.034	165	salt lake city, ut	-0.09**	-0.036
44	tampa, fl	0.132*	0.117*	105	kansas city, mo	0.026	-0.002	166	pocatello, id	-0.136	-0.118**
45	tallahassee, fl	-0.147	0.093	106	columbia, mo	-0.178***	-0.106**	167	boise city, id	-0.011	-0.104**
46	pensacola, fl	-0.091	-0.13***	107	st. louis, mo	-0.004	-0.09***	168	spokane, wa	-0.058	-0.085**
47	mobile, al	-0.154***	-0.076	108	springfield, mo	-0.168*	-0.154*	169	richland, wa	-0.173	-0.192*
48	montgomery, al	-0.053	-0.108***	109	fayetteville, ar	-0.257*	-0.193*	170	yakima, wa	-0.293*	-0.214*
49	birmingham, al	-0.028	-0.085***	110	fort smith, ar	-0.15**	-0.102**	171	seattle, wa	-0.052	0.076***
50	huntsville, al	-0.129**	-0.142*	111	little rock, ar	-0.191*	-0.166*	172	portland, or	0.005	0.004
51	chattanooga, tn	-0.131***	-0.121*	112	jackson, ms	-0.113***	-0.114***	173	eugene, or	-0.096	-0.034
52	johnson city, tn	-0.142***	-0.19*	113	new orleans, la	0.018	0.002	174	redding, ca	0.052	-0.165***
53	knoxville, tn	-0.033	-0.146*	114	baton rouge, la	-0.082	-0.037	175	eureka, ca	-0.249**	0.048
54	nashville, tn	-0.108***	-0.148*	115	lafayette, la	-0.11	-0.228*	176	san francisco, ca	-0.005	0.138*
55	memphis, tn	-0.118*	-0.192*	116	lake charles, la	0.061	-0.113	177	sacramento, ca	0.021	-0.009
56	paducah, ky	-0.148	-0.248*	117	shreveport, la	-0.052	-0.063	178	stockton, ca	-0.26*	-0.118*
57	louisville, ky	-0.082	-0.094***	118	monroe, la	-0.188***	-0.127**	179	fresno, ca	-0.006	-0.061
58	lexington, ky	-0.168***	-0.104***	119	texarkana, tx	-0.219*	-0.236*	180	los angeles, ca	0.103*	0.15*
59	huntington, wv	-0.102	-0.079	120	tyler, tx	-0.154***	-0.127*	181	san diego, ca	0.008	0.138*
60	charleston, wv	-0.13	-0.04	121	beaumont, tx	0.003	-0.2*				
61	morgantown, wv	-0.242*	-0.224*	122	houston, tx	0.048	0.035				

**Significant at 10% level; **Significant at 5% level; ***Significant at 1% level.*

Figure 9: Relative Wagebill Ratios [US=base] (OLS)

year	difference in relative wagebills	elasticity of substition	relative wage (NYC)	relative wage (Nashville)
1972	0.259	0.5	1.68	1
	0.259	2.0	1	1.30
1992	0.307	0.5	1.85	1
	0.307	2.0	1	1.36

Figure 10: Differences in relative factor prices in NYC and Nashville

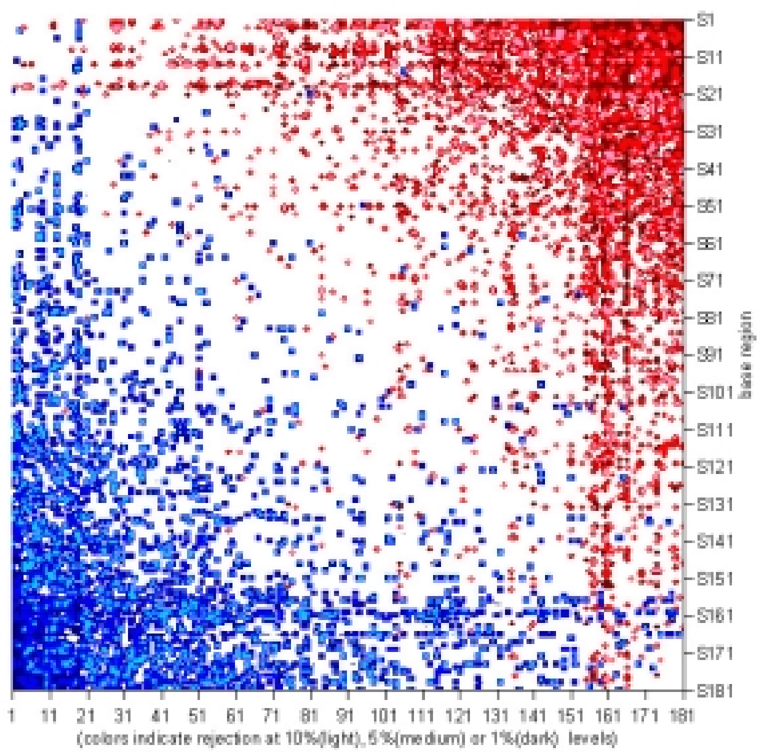

Figure 11: Pairwise Regional Regressions - 1972

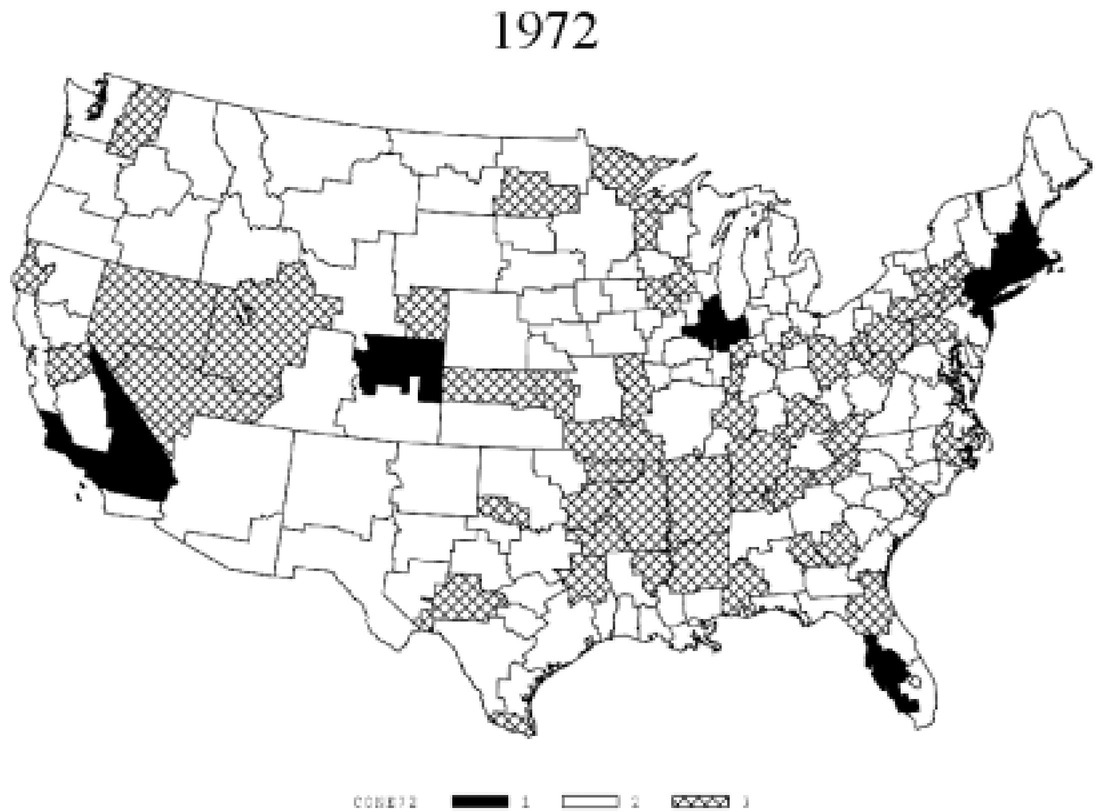

Figure 12: Labor Market Areas and Cones - 1972

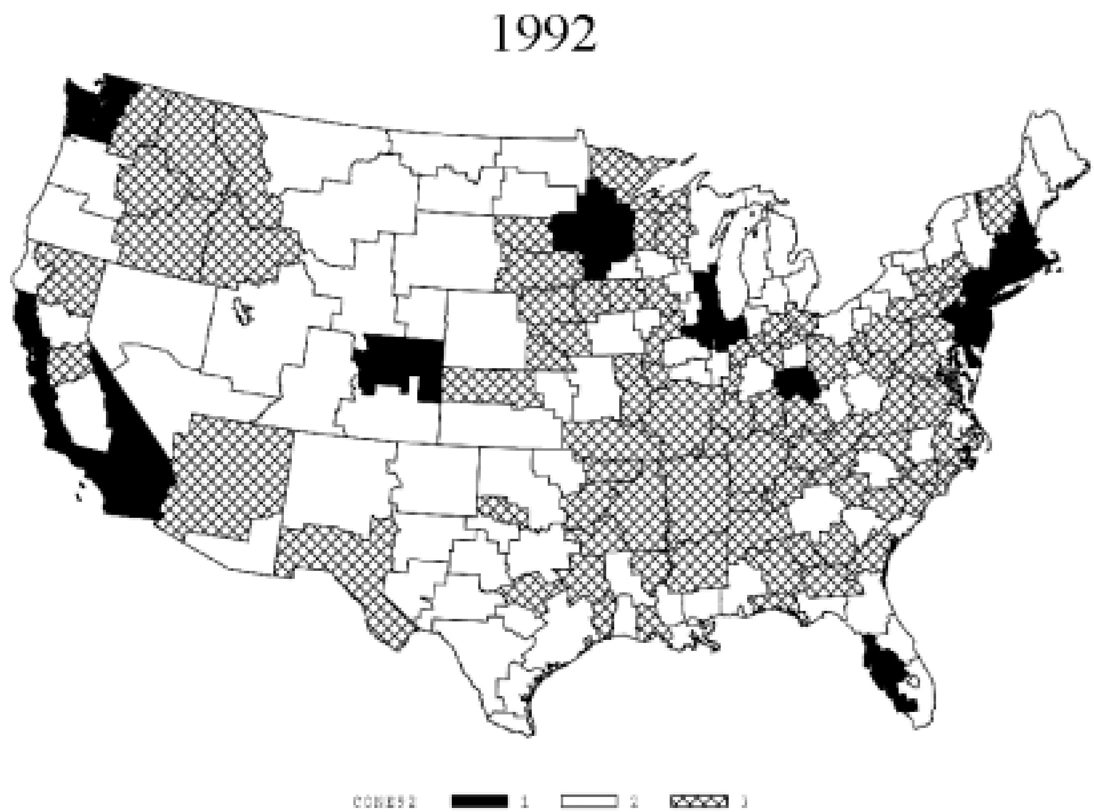

Figure 13: Labor Market Areas and Cones - 1992

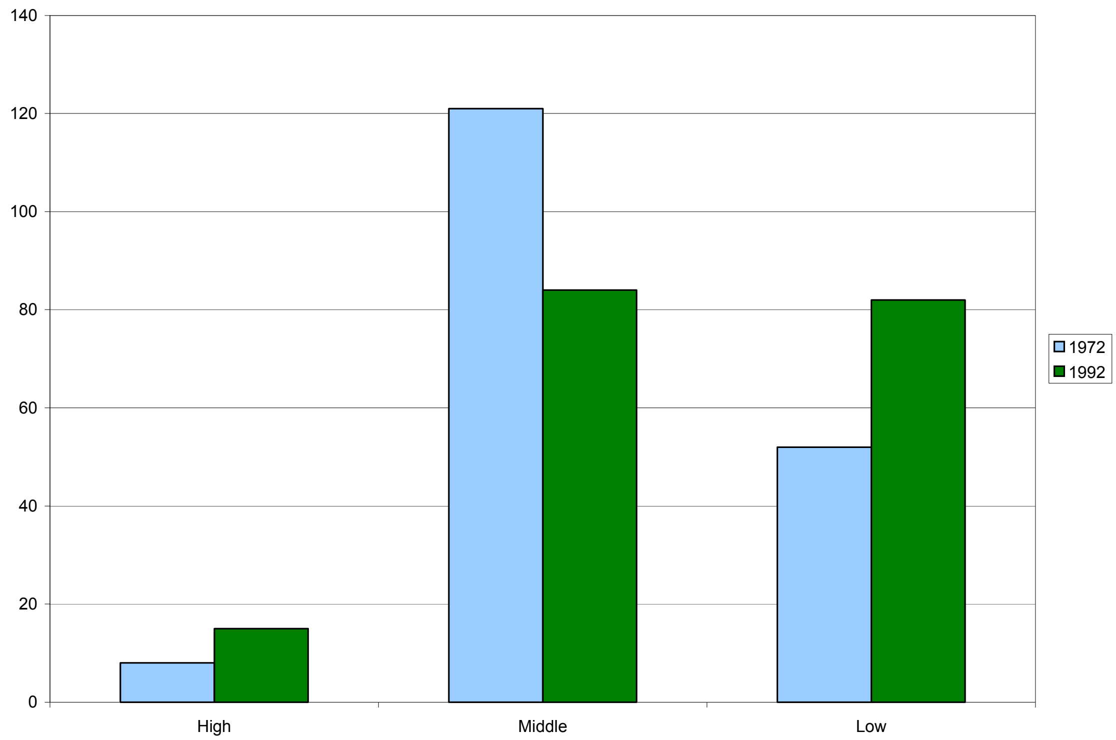

Figure 14: Distribution of Regions across Cones

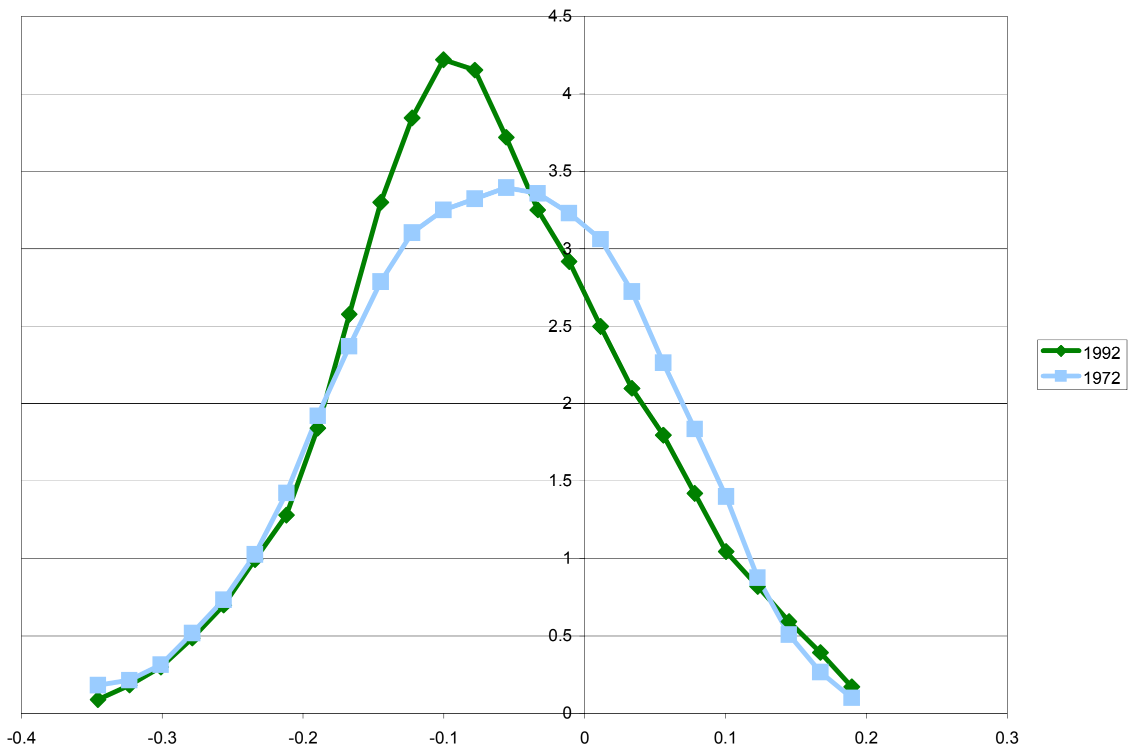

Figure 15: Relative Wagebill Density across Regions

Cone	N	Mean	St. Dev.
		1972	
High	8	0.112	0.022
Middle	121	-0.028	0.067
Low	52	-0.190	0.076
		1992	
High	15	0.110	0.031
Middle	84	-0.024	0.052
Low	82	-0.150	0.056

Figure 16: Estimated Coefficients by Cone (US=base)

	1972	1992
Cone 1 and Cone 2	-9.1	-15.6
	1.1	*1.0*
Cone 2 and Cone 3	-1.8	-3.0
	0.3	*0.3*
Cone 1 and Cone 3	-17.5	-19.3
	1.5	*0.8*
Industries in *r*	0.4	0.5
	0.004	*0.003*
Industries in *s*	0.3	0.4
	0.003	*0.003*
Constant	-26.3	-51.1
	0.5	*0.6*
Observations	16471	16471
R-squared	0.80	0.85

Robust standard errors in italics.

Figure 17: Common Industries (OLS)

Number of Cones Jumped	0.137
	0.067
Constant	0.875
	0.036
Observations	181
R-squared	0.02

Robust standard errors in italics.

Figure 18: Percentage of Industries Dropped/Added (OLS)