Trade and the Spatial Distribution of Unemployment

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Abstract

How does productivity improvement in China affect unemployment across the US states? I develop a model of involuntary unemployment in multiple geographic locations. The model merges a quantitative general equilibrium model of international trade and spatial economy and the efficiency-wage model (Shapiro and Stiglitz, 1984). I quantify it for 27 countries and the 50 US states, and compute the counterfactual of the 5% increase in China's productivity. The model predicts that real wages increase in all the US states, but unemployment increases in 44 states, and the overall US welfare increases. The counterfactual result highlights heterogeneous effects of foreign shocks on unemployment and real wages across the US states.

1 Introduction

How does productivity improvement in China affect unemployment in the US states? Autor et al. (2013) find that unemployment increased more in commuting zones that were hit by Chinese import competition more severely. This is about effects on a commuting zone relative to others. The bottom-line effect is out of the scope of their paper, and requires quantification of a general equilibrium model.

This paper develops a static general equilibrium model of unemployment in multiple geographic locations. Specifically the model merges a standard quantitative trade and spatial model and the efficiency-wage model of Shapiro and Stiglitz (1984). The model is built on monopolistic competition with a fixed number of firms. But wages are not determined in a Walrasian labor market. Workers can shirk rather than contribute to

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production. Firms can punish shirkers by firing them, but imperfectly monitor whether an employee shirks or not. To prevent shirking, firms set a higher wage than the market clearing wage, so that higher foregone income upon being fired disciplines employees to contribute to production.

Given wages, monopolistic firms set optimal prices. Given prices and income, the constant elasticity of substitution (CES) demand system determines demand for varieties in each destination. To meet demand for all destinations, firms set production levels, which in turn determines labor demand. The total labor demand in each location is less than the labor force there, which causes unemployment. Unlike a Walrasian economy, wages do not adjust flexibly to clear labor markets. This is because wages are set to prevent shirking, whose condition does not coincide with the labor market clearing condition.

I quantify the model for 27 countries and the 50 US states. Following Dekle et al. (2007), I express a system of equations for changes from the factual equilibrium to a counterfactual. I compute the counterfactual of the 5% increase in China's productivity. The model predicts that real wages increase in all the US states, but unemployment rates increase in 44 US states. The overall US welfare increases.

The counterfactual result highlights heterogeneous effects of China's productivity improvement on the US states. If productivity in China increases by 5%, real wages increase more in states in the west coast than those in the upper midwest. Unemployment decreases only in states in the west coast and a few others, while unemployment increases in the other 44 states. Labor forces are reallocated from the heartland to the west coast and a handful of other states.

Signs of welfare changes are mixed. By the 5% increase in China's productivity, 14 countries out of 28 countries (including the US) have welfare gains, while the other 14 have welfare losses. This result is at adds with Caliendo et al. (2019), for they argue that any country in their calibration had welfare gains in response to the China shock from 2000 to 2007.

This paper contributes to general equilibrium models of international trade (Eaton and Kortum, 2002; Anderson and van Wincoop, 2003) and spatial economy (Allen and Arkolakis, 2014; Redding, 2016). In this literature, Caliendo et al. (2019) study the effect of the China shock on labor markets across the US states with a dynamic Ricardian model with migration. In their paper, individuals choose a sector to work in and a US state to live in, and sector 0 is labeled as non-employment. That is, individuals voluntarily choose non-employment. In contrast, individuals are involuntarily unemployed in this paper.

This paper is not the first attempt to apply the efficiency-wage model to international trade. Davis and Harrigan (2011) and Wang and Zhao (2015) combine the efficiency-wage model and the Melitz (2003) model. As far as I know, however, the efficiency-wage model has not been applied to a many-country quantitative trade model.

This paper belongs to literature of many-region models that comprise involuntary unemployment. Bilal (2019) develops a dynamic spatial model with job search. Goods are freely traded in his model, while trade costs are incurred between different locations in this paper. Eaton et al. (2013) assume fixed wages and endogenize employment in the Eaton-Kortum model. Rodriguez-Clare et al. (2019) introduce downward nominal wage rigidity into the multi-sector Eaton-Kortum model of Caliendo and Parro (2015). These two papers exogenously assume wage rigidity, while I rely on efficiency wages to model unemployment.

The remainder of this paper is organized as follows. Section 2 reports empirical facts on unemployment in the US states. Section 3 develops the model. Section 4 describes data and parameterization. Section 5 shows the counterfactual result. Section 6 concludes.

2 Facts on Unemployment in the US States

This sections lays out facts about unemployment across the US states. Unemployment rates are different across the US states. Figure 1 is a map of average unemployment rates from 2011 to 2019 across the US states. States with darker blue have higher unemployment rates. Nevada has the highest of 7.5%, and California has the second highest of the 7.0%. North Dakota has the lowest of 2.8%, and Nebraska has the second lowest of 3.4%. A cluster of states in the southwest including California and Nevada have high unemployment, while a cluster of states in the upper midwest have low unemployment.

Difference in unemployment across the US states is persistent. Figure 2 plots average unemployment rates from 2011 to 2019 against those from 2001 to 2010 for the US states. Observations are close to the 45 degree line, implying strong persistence of unemployment rates in the US states. The correlation coefficient is 0.86. Bilal (2019) also reports strong persistence of unemployment rates in French commuting zones.

Persistent difference in unemployment across the US states may be attributed to skill levels and sectoral composition. Guided by hypothesis, I regress unemployment rates on skill levels and sectoral shares as in the following specification

$$u_j^t = \alpha_0 + \alpha_1 \text{skilled labor share}_j^t + \sum_{k=1}^{13} \alpha_{1+k} \text{sectoral share}_{k,j}^t + \epsilon_j^t, \tag{1}$$

where u_j^t is the unemployment rate of state j in year t, skilled labor share$_j^t$ is the number of college graduates who are 25 years old or older divided by the population who is 25 years old or older, sectoral share$_{k,j}^t$ is the GDP of sector k in state j as of year t divided by the

GDP in state j as of year t, α_l ($l = 1, \cdots, 14$) are parameters, and ϵ_j^t is the disturbance. I run the regression (1) separately for two years $t = 2012, 2017$. The data for sectoral GDPs in the US states is from SAGDP2N Gross domestic product (GDP) by state of the US Bureau of Economic Analysis. The data for population who is 25 years old or older and college graduates in it is from the American Community Survey of the US Census Bureau. The data for unemployment rates for the US states is from Expanded State Employment Status Demographic Data of the US Bureau of Labor Statistics.

Table 1 reports the result for the regression (1).[1] For 2012, only constant, the share of college graduates in population, and the share of agriculture in GDP are statistically significant. The share of college graduates in population and the share of agriculture in GDP are negatively related to unemployment rates. For 2017, in addition to the shares of agriculture in GDP, the share of manufacturing in GDP and the share of arts, entertainment, recreation, accommodation and food services in GDP are also statistically significant at the 5% level, and are negatively related to unemployment rates.

However, persistent difference in unemployment across the US states is not fully attributed to skill levels and sectoral composition. The left panel of Figure 3 plots unemployment rates in 2017 against those in 2012. I observe positive relationship between them. The correlation coefficient is 0.56. Observations are below the 45 degree line, because the macroeconomic condition in 2012 was worse than that in 2017. The right panel of Figure 3 plots the residuals from the regression (1) for the year 2017 against those for the year 2012. The residuals from the two different regressions have a positive correlation, 0.52, whose magnitude is not very smaller than the correlation coefficient between the unemployment rates in 2012 and those in 2017. This suggests that variation in unemployment that is unexplained by sectoral composition and skill levels is still persistent across the US states. A possible reason is geography. The model provided in the following section pursues this possibility.

3 Model

Let N_{US} be the set of the 50 US states. Let N_{NUS} be the set of countries but the US, where the subscript NUS stands for "not the US." The economy consists of $N = N_{US} \cup N_{NUS}$. A location $j \in N$ is either a US state or a non-US country.

An individual in the US endogenously chooses a US state to live in. The mass of the labor force L_j in $j \in N_{US}$ is endogenously determined in equilibrium. Let L_{US} be the total labor force in the US. Then $\sum_{j \in N_{US}} L_j = L_{US}$. An individual in non-US country j cannot

[1] Table 2 gives a North American Industry Classification System (NAICS) 2-digit code for each industry that appears in Table 1.

emigrate from her country. Thus the mass of the labor force L_j in $j \in N_{NUS}$ is exogenously given.

A timing assumption follows. An individual in the US chooses her state to live in. Then, she may or may not be employed in her destination. She cannot emigrate from her state to another, even if she is unemployed.

This section proceeds as follows. Subsection 3.1 describes consumers' utility maximization and firms' profit maximization given the labor forces in the US states. Subsection 3.2 states location choices of individuals in the US, which pins down the distribution of the labor forces over the US states. Subsection 3.4 defines an equilibrium. Subsection 3.6 characterizes a counterfactual equilibrium in terms of changes from the factual.

3.1 Consumer and Firm Behavior

Utility maximization

If individual i lives in location $j \in N$, her utility is

$$U_{i,j} = \frac{1}{\tilde{\eta}_i} C_{i,j} A_j \nu_{i,j}, \tag{2}$$

where $C_{i,j}$ is the composite good consumed by individual i who lives in location j, $\tilde{\eta}_i$ captures the disutility from making an effort, A_j is the amenity of location j that is common to anyone, and $\nu_{i,j}$ is individual i's idiosyncratic amenity shock for location j.[2] A unit continuum of firms produce differentiated varieties in any location $k \in N$. The composite good $C_{i,j}$ for individual i in location j is defined by

$$C_{i,j} = \left(\sum_{k \in N} \int_0^1 C_{i,k,j}(\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right)^{\frac{\sigma}{\sigma-1}},$$

where $C_{i,k,j}(\omega)$ is individual i's consumption of variety ω shipped from location k to her location j, and σ is the parameter of CES. The associated price index P_j is

$$P_j = \left[\sum_{k \in N} \int_0^1 (p_k(\omega) t_{k,j})^{1-\sigma} d\omega \right]^{\frac{1}{1-\sigma}}, \tag{3}$$

where $p_k(\omega)$ is the f.o.b. price of variety ω produced in location k, and $t_{k,j}$ is the iceberg trade costs of any variety shipped from location k to location j. Note that the price of

[2] The form of the utility function (2) follows Davis and Harrigan (2011), who assume that the disutility from making an effort is multiplicative. It is slightly different from the specification in Shapiro and Stiglitz (1984), who assume that the disutilty from making an effort is subtractive.

variety ω from location k that consumers in location j face is $p_k(\omega)t_{k,j}$.

Each individual is either employed or unemployed. If individual i is employed, she chooses to make an effort or to shirk. If she makes an effort, her utility is divided by $\eta > 1$, but if she shirks, she does not incur this disutility. That is, using the notation $\tilde{\eta}_i$ in equation (2),

$$\tilde{\eta}_i = \begin{cases} \eta > 1 & \text{if } i \text{ makes an effort,} \\ 1 & \text{if } i \text{ shirks.} \end{cases}$$

If individual i is unemployed, she does not incur the disutility from making an effort, $\tilde{\eta}_i = 1$.

If an individual in location j is employed (and is not caught shirking), she receives the nominal wage w_j. If she is unemployed, she receives the nominal home production $b_j P_j$, where b_j is the real home production in location j.

Besides the wage or home production, no matter whether she is employed or not, an individual receives a share of profits. Let π_j be total profits of firms in location j. If she lives in non-US country $j \in N_{NUS}$, she receives the share of profits $\frac{\pi_j}{L_j}$. If she lives in US state $j \in N_{US}$, she receives the share of profits $\frac{\pi_{US}}{L_{US}}$, where $\pi_{US} = \sum_{k \in N_{US}} \pi_k$ is total profits in the US. In other words, anyone in non-US country $j \in N_{NUS}$ owns the same share of ownership of firms in her country j. Anyone in the US owns the same share of ownership of firms in the US, no matter which state she lives in.

The nominal income for individual i in location j, $I_{i,j}$, is

$$I_{i,j} = \begin{cases} w_j + \frac{\pi_j}{L_j} & \text{if } i \text{ is employed in } j \in N_{NUS}, \\ b_j P_j + \frac{\pi_j}{L_j} & \text{if } i \text{ is unemployed in } j \in N_{NUS}, \\ w_j + \frac{\pi_{US}}{L_{US}} & \text{if } i \text{ is employed in } j \in N_{US}, \\ b_j P_j + \frac{\pi_{US}}{L_{US}} & \text{if } i \text{ is unemployed in } j \in N_{US}. \end{cases} \tag{4}$$

Then, the budget constraint for individual i in location $j \in N$ is

$$\sum_{k \in N} \int_0^1 p_k(\omega) t_{k,j} C_{i,k,j}(\omega) d\omega \leq I_{i,j}. \tag{5}$$

To solve utility maximization, first I consider consumers' choice of consumption bundle subject to the budget constraint. Then I turn to consumers' choice on whether to make an effort or not.

Individual i's demand for variety ω shipped from location k to her location j, $C_{i,k,j}(\omega)$, is

$$C_{i,k,j}(\omega) = \left(\frac{p_k(\omega)t_{k,j}}{P_j}\right)^{-\sigma}\left(\frac{I_{i,j}}{P_j}\right). \tag{6}$$

Since the budget constraint (5) is binding, the CES demand aggregator for individual i in location j, $C_{i,j}$, satisfies

$$P_j C_{i,j} = I_{i,j}. \tag{7}$$

Any firm in location j can catch shirking with probability $q_j \in (0,1)$. If a shirker is caught, she is fired and ends up unemployed. Her shirking is not caught with probability $1 - q_j$, then the shirker receives the same wage w_j as those who make an effort. The parameter q_j represents imperfect contract in the labor market in location j.

Substituting $C_{i,j} = \frac{I_{i,j}}{P_j}$ into utility (2), I obtain the following expressions for indirect utilities. If individual i in location j is unemployed, her indirect utility is

$$\begin{aligned} \left(b_j + \frac{\pi_j}{L_j P_j}\right) A_j \nu_{i,j} \quad &\text{for } j \in N_{NUS}, \\ \left(b_j + \frac{\pi_{US}}{L_{US} P_j}\right) A_j \nu_{i,j} \quad &\text{for } j \in N_{US}. \end{aligned} \tag{8}$$

If individual i in location j is employed and makes an effort, her indirect utility is

$$\begin{aligned} \frac{1}{\eta}\left(\frac{w_j}{P_j} + \frac{\pi_j}{L_j P_j}\right) A_j \nu_{i,j} \quad &\text{for } j \in N_{NUS}, \\ \frac{1}{\eta}\left(\frac{w_j}{P_j} + \frac{\pi_{US}}{L_{US} P_j}\right) A_j \nu_{i,j} \quad &\text{for } j \in N_{US}. \end{aligned} \tag{9}$$

If individual i in location j is employed and shirks, her expected indirect utility is

$$\begin{aligned} (1 - q_j) \cdot \left(\frac{w_j}{P_j} + \frac{\pi_j}{L_j P_j}\right) A_j \nu_{i,j} + q_j \cdot \left(b_j + \frac{\pi_j}{L_j P_j}\right) A_j \nu_{i,j} \quad &\text{for } j \in N_{NUS}, \\ (1 - q_j) \cdot \left(\frac{w_j}{P_j} + \frac{\pi_{US}}{L_{US} P_j}\right) A_j \nu_{i,j} + q_j \cdot \left(b_j + \frac{\pi_{US}}{L_{US} P_j}\right) A_j \nu_{i,j} \quad &\text{for } j \in N_{US}. \end{aligned} \tag{10}$$

Individual i makes an effort if the indirect utility of making an effort (9) is greater than the expected indirect utility of shirking (10). She shirks if (9) is less than (10). She is indifferent between making an effort and shirking if (9) is equal to (10).

Production function

Suppose that firm $\omega \in [0,1]$ in location j hires the measure $l_j(\omega)$ of workers. If the measure $l'_j(\omega) \in [0, l_j(\omega)]$ of employees make an effort, the production of firm ω in location j, $y_j(\omega)$, is

$$y_j(\omega) = z_j \left(\frac{l'_j(\omega)}{1-\beta} \right)^{\beta} \left(\frac{m_j(\omega)}{\beta} \right)^{1-\beta}. \tag{11}$$

where z_j is the productivity that is common to all firms in location j, and $m_j(\omega)$ is the input of intermediate goods and β is the parameter that represents the labor share in total costs. The input bundle of intermediate goods is the same as consumers' composite good. Shirkers do not contribute to production.

No shirking condition

Assume that any individual receives a wage offer with probability e_j, once she chooses her location j.[3] The probabilities $\{e_j\}_{j \in N}$ are endogenously determined in general equilibrium.[4] A wage offer arrives from at most one firm to an individual. Firms have the full bargaining power, and a wage offer is a take-it-or-leave-it offer. If an individual receives a wage offer and accepts it, she will be hired by a firm. If an individual receives a wage offer and rejects it, she will be unemployed. If an individual does not receive a wage offer, she will be unemployed.

Suppose that the indirect utility of making an effort (9) and the expected indirect utility of shirking (10) are equal, that is,

$$\begin{aligned} \frac{1}{\eta}\left(\frac{w_j}{P_j} + \frac{\pi_j}{L_j P_j}\right) A_j \nu_{i,j} &= (1-q_j) \cdot \left(\frac{w_j}{P_j} + \frac{\pi_j}{L_j P_j}\right) A_j \nu_{i,j} + q_j \cdot \left(b_j + \frac{\pi_j}{L_j P_j}\right) A_j \nu_{i,j} \quad \text{for } j \in N_{NUS}, \\ \frac{1}{\eta}\left(\frac{w_j}{P_j} + \frac{\pi_{US}}{L_{US} P_j}\right) A_j \nu_{i,j} &= (1-q_j) \cdot \left(\frac{w_j}{P_j} + \frac{\pi_{US}}{L_{US} P_j}\right) A_j \nu_{i,j} + q_j \cdot \left(b_j + \frac{\pi_{US}}{L_{US} P_j}\right) A_j \nu_{i,j} \quad \text{for } j \in N_{US}. \end{aligned} \tag{12}$$

Solving this for w_j, I obtain

$$w_j = \begin{cases} \frac{1}{1-\eta(1-q_j)} \left(\eta q_j b_j P_j + (\eta - 1) \frac{\pi_j}{L_j} \right) & \text{for } j \in N_{NUS}, \\ \frac{1}{1-\eta(1-q_j)} \left(\eta q_j b_j P_j + (\eta - 1) \frac{\pi_{US}}{L_{US}} \right) & \text{for } j \in N_{US}. \end{cases} \tag{13}$$

The idiosyncratic amenity shock $\nu_{i,j}$ does not appear in the wage (13). That is, the nominal

[3] Location choices do not take place in non-US countries $j \in N_{NUS}$. Thus the timing assumption about location choices and wage offers does not apply in $j \in N_{NUS}$.

[4] I will show that e_j is the employment rate in location j, because no one rejects a wage offer in equilibrium.

wage (13) equalizes the indirect utility of making en effort and the expected indirect utility of shirking not only for individual i. but also for anyone in location j. In any firm $\omega \in [0,1]$ in location j, all employees make an effort if its wage $w_j(\omega)$ is strictly higher than (13). All employees of ω shirk if its wage $w_j(\omega)$ is strictly lower than (13).

In equilibrium, indeed, the nominal wage in location j satisfies (13). That is, any firm $\omega \in [0,1]$ offers the wage (13). I show this by the way of contradiction. Let w_j be the wage defined by (13), and $w_j(\omega)$ generically denote the wage that firm ω in location j offers. Suppose, to the contrary, that there exists firm ω such that $w_j(\omega) \neq w_j$. On the one hand, suppose that $w_j(\omega) > w_j$. Then firm ω would have an incentive to decrease the wage to, say, $w'_j(\omega) \in [w_j, w_j(\omega)) \neq \emptyset$. This is because, if the firm reduces the wage to $w'_j(\omega)$, any employee would make an effort so that the firm would sustain the production level as of $w_j(\omega)$, and the firm would reduce the labor cost. On the other hand, suppose that $w_j(\omega) < w_j$. Then no employee makes an effort, and by the production function (11), the production level is zero. The profits are non-positive. Therefore the firm has an incentive to increase the wage to $w'_j(\omega) \in [w_j, \infty)$, so that the firm can produce a positive amount of the product. Later I will see that any firm makes positive profits as long as it produces a positive amount, because of monopolistic competition with a fixed number of firms.

Since $\eta > 1$ and $0 < q_j < 1$ for any $j \in N$, the no-shirking wage (13) is strictly greater than the nominal home production,

$$w_j > b_j P_j.$$ [5]

Therefore anyone accepts a wage offer, if she receives it. As a result, e_j represents the employment rate in location j as well as the probability that an individual in location j receives a wage offer.

The measure of employees who shirk is zero, for the wage (13). Suppose, to the contrary, that a positive measure of employees of firm $\omega \in [0,1]$ shirk for the wage (13). Then the firm would increase the wage slightly, so that any employee makes an effort, then the production level and the profits would discontinuously increase. Therefore the case where a positive measure of employees shirk for the wage (13) is not sustained in equilibrium. In other words, in equilibrium, if the $l_j(\omega)$ measure of workers are hired by firm $\omega \in [0,1]$ in location j, the same $l_j(\omega)$ measure of employees make an effort, for the nominal wage (13). I refer to equation (12) as the no shirking condition, and the equilibrium nominal wage (13) as the no shirking wage.

Given the no-shirking wage (13) and the zero measure of shirkers, the unit cost for any

[5] A sufficient condition for this is $1 - 2\eta + \eta q_j < 0$. $\eta > 1$ and $0 < q_j < 1$ satisfy this.

firm in location j is

$$\frac{w_j^{\beta} P_j^{1-\beta}}{z_j}. \tag{14}$$

Suppose temporarily that the price index P_j and profits π_j are held fixed in the no-shirking wage (13) for $j \in N_{NUS}$, although they are actually general equilibrium objects. Then, two properties hold. First, the no-shirking wage w_j is increasing in η, the disutility from making an effort. If the disutility from making an effort is larger, firms have to compensate employees with a higher wage. Second, the no-shirking wage w_j is decreasing in q_j, the probability that firms catch shirking. If shirkers are more likely to be caught, workers voluntarily make an effort with a lower wage. Then firms do no longer have to offer a high wage. Now I return to the general equilibrium model where $\{P_j\}_{j\in N}$ and $\{\pi_j\}_{j\in N}$ are endogenous.

Aggregate nominal income and expenditure

The aggregate nominal income in location j, I_j, is given by

$$I_j = \begin{cases} e_j L_j\left(w_j + \frac{\pi_j}{L_j}\right) + (1-e_j)L_j\left(b_j P_j + \frac{\pi_j}{L_j}\right) & \text{for } j \in N_{NUS}, \\ e_j L_j\left(w_j + \frac{\pi_{US}}{L_{US}}\right) + (1-e_j)L_j\left(b_j P_j + \frac{\pi_{US}}{L_{US}}\right) & \text{for } j \in N_{US}. \end{cases} \tag{15}$$

This is the sum of the aggregate nominal incomes of the employed (the first term) and the unemployed (the second term).

The aggregate expenditure in location $j \in N$ is

$$X_j = I_j + \frac{1-\beta}{\beta} w_j e_j L_j, \tag{16}$$

where the first term on the right-hand side is the final absorption and the second term on the right-hand side is the purchase of intermediate goods.

Profit maximization - Constant markup

Let $C_{j,k}(\omega)$ be the aggregate demand for variety ω shipped from location j to location k. Since preferences are homothetic, by replacing an individual's nominal income $I_{i,j}$ in equation (6) with the aggregate nominal expenditure X_k, I obtain the aggregate demand for variety ω shipped from location j to location k, $C_{j,k}(\omega)$, by

$$C_{j,k}(\omega) = \left(\frac{p_j(\omega) t_{j,k}}{P_k}\right)^{-\sigma} \left(\frac{X_k}{P_k}\right). \tag{17}$$

From the viewpoint of monopolistic firm ω in location j, equation (17) means that how much the demand in location k would be if firm ω sets the f.o.b. price $p_j(\omega)$.

Note that firm ω in location k needs to ship $t_{k,j}C_{k,j}(\omega)$ to meet the demand $C_{k,j}(\omega)$ in location j, because of the iceberg trade costs $t_{k,j}$. Thus to meet the demands from all destinations, firm ω in location j must produce the amount

$$y_j(\omega) = \sum_{k\in N} t_{j,k} C_{j,k}(\omega). \tag{18}$$

Given the no-shirking wage (13), firm $\omega \in [0,1]$ in location j maximizes its profits $\pi_j(\omega)$ given by

$$\begin{aligned}
\pi_j(\omega) &= p_j(\omega) y_j(\omega) - \frac{w_j^{\beta} P_j^{1-\beta}}{z_j} y_j(\omega) \\
&= \left(p_j(\omega) - \frac{w_j^{\beta} P_j^{1-\beta}}{z_j} \right) \left(\sum_{k\in N} t_{j,k} C_{j,k}(\omega) \right) \\
&= \left(p_j(\omega) - \frac{w_j^{\beta} P_j^{1-\beta}}{z_j} \right) \left[\sum_{k\in N} t_{j,k} \left(\frac{p_j(\omega) t_{j,k}}{P_k} \right)^{-\sigma} \frac{X_k}{P_k} \right],
\end{aligned} \tag{19}$$

where the first line means revenue minus cost, the second line follows from the goods market clearing (18), and the third line follows from the CES aggregate demand (17). Taking the first order condition with respect to $p_j(\omega)$, the optimal price for any monopolistic firm ω in location j is

$$p_j(\omega) = \frac{\sigma}{\sigma-1} \frac{w_j^{\beta} P_j^{1-\beta}}{z_j}, \tag{20}$$

which is the constant markup $\frac{\sigma}{\sigma-1}$ multiplied by the unit cost. Substituting the optimal price (20) into the price index (3) (with modifying subscripts), the price index in location j is

$$P_j = \left[\sum_{k\in N} \left(\frac{\sigma}{\sigma-1} \frac{w_k^{\beta} P_k^{1-\beta}}{z_k} t_{k,j} \right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}. \tag{21}$$

Since the measure one of firms exist in each location, substituting the optimal price (20) into the profits (19), I have the aggregate profits in location j as

$$\pi_j = \frac{1}{\sigma} \sum_{k\in N} \left(\frac{\sigma}{\sigma-1} \frac{w_j^{\beta} P_j^{1-\beta} t_{j,k}}{z_j P_k} \right)^{1-\sigma} X_k \tag{22}$$

for any $j \in N$.

The aggregate labor cost is equalized to the aggregate labor income

$$\beta \frac{\sigma - 1}{\sigma} \sum_{k \in N} \left(\frac{\sigma}{\sigma - 1} \frac{w_j^{\beta} P_j^{1-\beta} t_{j,k}}{z_j P_k} \right)^{1-\sigma} X_k = w_j e_j L_j \tag{23}$$

for any $j \in N$. Usual trade models have labor market clearing conditions in value terms. They are similar to (23), but have $w_j L_j$ on the right-hand side, because usual trade models preclude unemployment, that is, $e_j = 1$. Since e_j can be less than one, I refer to (23) as the labor market unclearing condition.

3.2 Location Choices

I have stated all equilibrium conditions for non-US countries $j \in N_{NUS}$. I turn to location choices of individuals in the US.

Individual i in the US chooses a US state to live in after she draws her idiosyncratic amenity shock $\nu_{i,j}$ for $j \in N_{US}$. Individual i chooses her location to maximize her expected indirect utility. That is, individual i solves

$$\max\{V_{i,j} : j \in N_{US}\}, \tag{24}$$

where $V_{i,j}$ is her expected indirect utility of living in US state j,

$$\begin{aligned} V_{i,j} &= e_j \cdot \frac{1}{\eta} \left(\frac{w_j}{P_j} + \frac{\pi_{US}}{L_{US} P_j} \right) A_j \nu_{i,j} + (1 - e_j) \cdot \left(b_j + \frac{\pi_{US}}{L_{US} P_j} \right) A_j \nu_{i,j}, \\ &= \Phi_j \nu_{i,j}, \end{aligned} \tag{25}$$

and Φ_j is the baseline expected indirect utility of living in US state j which is common to anyone in the US

$$\Phi_j = \left[e_j \frac{1}{\eta} \left(\frac{w_j}{P_j} + \frac{\pi_{US}}{L_{US} P_j} \right) + (1 - e_j) \left(b_j + \frac{\pi_{US}}{L_{US} P_j} \right) \right] A_j \text{ for } j \in N_{US}. \tag{26}$$

Equation (25) means that the expected indirect utility of living in US state j is the weighted sum of the indirect utilities of being employed/unemployed in US state j, with the weights being the probabilities of being employed/unemployed. Note that an individual foresees that the no-shirking condition will hold and she will make an effort upon being employed.

The amenity shock $\nu_{i,j}$ follows the Fréchet distribution whose cumulative distribution function is $F(\nu) = e^{-\nu^{-\theta}}$, independently and identically across individuals i's and the US states $j \in N_{US}$. The labor force in location j is

$$L_j = \frac{\Phi_j^{\theta}}{\sum_{k \in N_{US}} \Phi_k^{\theta}} L_{US} \text{ for } j \in N_{US}. \tag{27}$$

I assume that individual i in any non-US country $j \in N_{NUS}$ also draws the amenity shock $\nu_{i,j}$ from the Fréchet distribution $F(\nu) = e^{-\nu^{-\theta}}$ independently across individuals in country j. This affects none of equilibrium outcomes, because individuals in a non-US country cannot emigrate from their country.

3.3 Welfare

Welfare in the US is given by the ex-ante expected indirect utility before individuals in the US draw idiosyncratic amenity shocks. Let W_{US} be welfare in the US, then

$$W_{US} = E\left[\max_{j \in N_{US}} V_{i,j}\right] = E\left[\max_{j \in N_{US}} \Phi_j \nu_{i,j}\right] = \Gamma\left(1 - \frac{1}{\theta}\right)\left(\sum_{j \in N_{US}} \Phi_j^{\theta}\right)^{\frac{1}{\theta}}, \tag{28}$$

where $\Gamma(\cdot)$ is the gamma function. Welfare in non-US country $j \in N_{NUS}$, W_j, is given by

$$W_j = E[V_{i,j}] = E[\Phi_j \nu_{i,j}] = \Gamma\left(1 - \frac{1}{\theta}\right)\Phi_j, \tag{29}$$

where Φ_j is the baseline expected indirect utility of living in non-US country j which is common to anyone

$$\Phi_j = \left[e_j \frac{1}{\eta}\left(\frac{w_j}{P_j} + \frac{\pi_j}{L_j P_j}\right) + (1 - e_j)\left(b_j + \frac{\pi_j}{L_j P_j}\right)\right] A_j \text{ for } j \in N_{NUS}. \tag{30}$$

3.4 Equilibrium

An equilibrium is defined to be a tuple of price indices $\{P_j\}_{j \in N}$, nominal wages $\{w_j\}_{j \in N}$, employment rates $\{e_j\}_{j \in N}$, aggregate profits $\{\pi_j\}_{j \in N}$, aggregate nominal expenditures $\{X_j\}_{j \in N}$, labor forces in the US states $\{L_j\}_{j \in N_{US}}$ that satisfies equations (13), (16) (with (15)), (21), (23), (22), (27) (with (26)). Let $n = |N|$ and $n_{US} = |N_{US}|$, where $|\cdot|$ denotes the cardinality of a set. Then this is a system of $5n + n_{US}$ equations with $5n + n_{US}$ unknowns.

3.5 Numerical Comparative Statics

I compute equilibria defined in Subsection 3.4 for various parameter values numerically.

3.6 Hat Algebra

Following Dekle et al. (2007), I characterize a counterfactual equilibrium as a solution to a system of equations for changes in endogenous variables from the factual equilibrium to a counterfactual equilibrium. For a generic variable x, let $\hat{x} = \frac{x'}{x}$ be the change in the variable x from the factual equilibrium to a counterfactual equilibrium, where x' and x are the counterfactual and factual value of the variable, respectively. In the following, I consider exogenous changes in productivity and trade costs from the factual to a counterfactual, and assume that any other parameter does not change.

Taking the ratio of (13) between a counterfactual and the factual, I obtain the changes in no-shirking wages

$$\begin{aligned} \hat{w}_j &= \frac{\eta q_j b_j P_j \hat{P}_j + (\eta - 1)\frac{\pi_j \hat{\pi}_j}{L_j}}{\eta q_j b_j P_j + (\eta - 1)\frac{\pi_j}{L_j}} \quad \text{for } j \in N_{NUS}, \\ \hat{w}_j &= \frac{\eta q_j b_j P_j \hat{P}_j + (\eta - 1)\frac{\pi_{US} \hat{\pi}_{US}}{L_{US}}}{\eta q_j b_j P_j + (\eta - 1)\frac{\pi_{US}}{L_{US}}} \quad \text{for } j \in N_{US}, \end{aligned} \tag{31}$$

where $\hat{\pi}_{US}$ is the change in the US total profits, that is,

$$\hat{\pi}_{US} = \frac{\pi'_{US}}{\pi_{US}} = \frac{\sum_{j \in N_{US}} \pi_j \hat{\pi}_j}{\sum_{j \in N_{US}} \pi_j}. \tag{32}$$

Taking the ratio of (15) between a counterfactual and the factual, the changes in aggregate nominal incomes are expressed as

$$\begin{aligned} \hat{I}_j &= \frac{e_j \hat{e}_j \left(w_j \hat{w}_j + \frac{\pi_j \hat{\pi}_j}{L_j} \right) + (1 - e_j \hat{e}_j) \left(b_j P_j \hat{P}_j + \frac{\pi_j \hat{\pi}_j}{L_j} \right)}{e_j \left(w_j + \frac{\pi_j}{L_j} \right) + (1 - e_j) \left(b_j P_j + \frac{\pi_j}{L_j} \right)} \quad \text{for } j \in N_{NUS}, \\ \hat{I}_j &= \frac{e_j \hat{e}_j \hat{L}_j \left(w_j \hat{w}_j + \frac{\pi_{US} \hat{\pi}_{US}}{L_{US}} \right) + (1 - e_j \hat{e}_j) \hat{L}_j \left(b_j P_j \hat{P}_j + \frac{\pi_{US} \hat{\pi}_{US}}{L_{US}} \right)}{e_j \left(w_j + \frac{\pi_{US}}{L_{US}} \right) + (1 - e_j) \left(b_j P_j + \frac{\pi_{US}}{L_{US}} \right)} \quad \text{for } j \in N_{US}. \end{aligned} \tag{33}$$

Then, taking the ratio of (16) between a counterfactual and the factual, the changes in aggregate expenditures are

$$
\begin{aligned}
\hat{X}_j &= \frac{I_j\hat{I}_j + \frac{1-\beta}{\beta} w_j\hat{w}_j e_j\hat{e}_j L_j}{I_j + \frac{1-\beta}{\beta} w_j e_j L_j} \text{ for } j \in N_{NUS}, \\
\hat{X}_j &= \frac{I_j\hat{I}_j + \frac{1-\beta}{\beta} w_j\hat{w}_j e_j\hat{e}_j L_j\hat{L}_j}{I_j + \frac{1-\beta}{\beta} w_j e_j L_j} \text{ for } j \in N_{US}.
\end{aligned} \tag{34}
$$

For any pair of locations $(k, j) \in N \times N$, define location k's share in location j's imports, $\gamma_{k,j}$, by

$$
\gamma_{k,j} = \frac{X_{k,j}}{\sum_{n\in N} X_{n,j}}, \tag{35}
$$

where $X_{n,j}$ denotes the aggregate trade value from location n to location j. Taking the ratio of (21) between a counterfactual and the factual, I have changes in price indices

$$
\hat{P}_j = \left[\sum_{k\in N} \gamma_{k,j}\hat{t}_{k,j}^{1-\sigma}\hat{w}_k^{\beta(1-\sigma)}\hat{P}_k^{(1-\beta)(1-\sigma)}\hat{z}_k^{\sigma-1}\right]^{\frac{1}{1-\sigma}} \quad \text{for } j \in N. \tag{36}
$$

For any pair of locations $(k, j) \in N \times N$, define location k's share in location j's exports, $\alpha_{j,k}$, by

$$
\alpha_{j,k} = \frac{X_{j,k}}{\sum_{n\in N} X_{j,n}}. \tag{37}
$$

Taking the ratio of (23) between a counterfactual and the factual, I have changes in employment

$$
\begin{aligned}
\hat{e}_j &= \hat{w}_j^{\beta(1-\sigma)-1}\hat{P}_j^{(1-\beta)(1-\sigma)}\hat{z}_j^{\sigma-1}\sum_{k\in N}\alpha_{j,k}\hat{t}_{j,k}^{1-\sigma}\hat{P}_k^{\sigma-1}\hat{X}_k \text{ for } j \in N_{NUS}, \\
\hat{e}_j &= \hat{w}_j^{\beta(1-\sigma)-1}\hat{P}_j^{(1-\beta)(1-\sigma)}\hat{z}_j^{\sigma-1}\hat{L}_j^{-1}\sum_{k\in N}\alpha_{j,k}\hat{t}_{j,k}^{1-\sigma}\hat{P}_k^{\sigma-1}\hat{X}_k \text{ for } j \in N_{US}
\end{aligned} \tag{38}
$$

Taking the ratio of (22) between a counterfactual and the factual, I obtain changes in aggregate profits

$$
\hat{\pi}_j = \hat{w}_j^{\beta(1-\sigma)}\hat{P}_j^{(1-\beta)(1-\sigma)}\hat{z}_j^{\sigma-1}\sum_{k\in N}\alpha_{j,k}\hat{t}_{j,k}^{1-\sigma}\hat{P}_k^{\sigma-1}\hat{X}_k \text{ for } j \in N. \tag{39}
$$

Let $\mu_j = \frac{L_j}{L_{US}}$ for any $j \in N_{US}$, that is, the share of state j in the total labor force in the

US. Then taking the ratio of (27) between a counterfactual and the factual, I have

$$\hat{L}_j = \hat{\mu}_j = \frac{\hat{\Phi}_j^{\theta}}{\sum_{k\in N_{US}} \mu_k \hat{\Phi}_k^{\theta}} \text{ for } j \in N_{US}, \tag{40}$$

where

$$\hat{\Phi}_j = \frac{e_j\hat{e}_j\frac{1}{\eta}\left(\frac{w_j\hat{w}_j}{\hat{P}_j} + \frac{\pi_{US}\hat{\pi}_{US}}{L_{US}\hat{P}_j}\right) + (1-e_j\hat{e}_j)\left(b_jP_j + \frac{\pi_{US}\hat{\pi}_{US}}{L_{US}\hat{P}_j}\right)}{e_j\frac{1}{\eta}\left(w_j + \frac{\pi_{US}}{L_{US}}\right) + (1-e_j)\left(b_jP_j + \frac{\pi_{US}}{L_{US}}\right)} \text{ for } j \in N_{US}. \tag{41}$$

Taking the ratio of (28), the change in the US welfare from the factual to a counterfactual, $\hat{W}_{US}$, is

$$\hat{W}_{US} = \left(\sum_{k\in N_{US}} \mu_k \hat{\Phi}_k^{\theta}\right)^{\frac{1}{\theta}}.$$

Taking the ratio of (29), the change in welfare in non-US country j from the factual to a counterfactual, $\hat{W}_j$, is

$$\hat{W}_j = \hat{\Phi}_j,$$

where, by taking the ratio of (30) between a counterfactual and the factual, $\hat{\Phi}_j$ is

$$\hat{\Phi}_j = \frac{e_j\hat{e}_j\frac{1}{\eta}\left(\frac{w_j\hat{w}_j}{\hat{P}_j} + \frac{\pi_j\hat{\pi}_j}{L_j\hat{P}_j}\right) + (1-e_j\hat{e}_j)\left(b_jP_j + \frac{\pi_j\hat{\pi}_j}{L_j\hat{P}_j}\right)}{e_j\frac{1}{\eta}\left(w_j + \frac{\pi_j}{L_j}\right) + (1-e_j)\left(b_jP_j + \frac{\pi_j}{L_j}\right)}$$

for $j \in N_{NUS}$.

An equilibrium in changes is defined to be a tuple of changes in price indices $\{\hat{P}_j\}_{j\in N}$, nominal wages $\{\hat{w}_j\}_{j\in N}$, employment rates $\{\hat{e}_j\}_{j\in N}$, aggregate profits $\{\hat{\pi}_j\}_{j\in N}$, aggregate nominal expenditures $\{\hat{X}_j\}_{j\in N}$ and labor forces in the US states $\{\hat{L}_j\}_{j\in N_{US}}$ that satisfies equations (31), (34) (with (33)), (36), (38), (39), (40) (with (41)). This is a system of $5n+n_{US}$ equations with $5n+n_{US}$ unknowns. I refer to this system of equations as hat algebra, following Costinot and Rodriguez-Clare (2014).

4 Taking the Model to Data

This section details data source and how parameters and factual values in the hat algebra are assigned from the data. I consider the 5% increase in China's productivity. I do not have to assign productivity, amenity and trade costs to compute this counterfactual because the hat algebra cancels them out. However, some parameter values and the factual equilibrium values remain to be assigned.

The elasticity of substitution σ is in (36), (38) and (39). Following Broda and Weinstein (2006), I set the elasticity of substitution $\sigma = 4$.[6]

Trade values are needed in (35) and (37). I collect trade values among 27 non-US countries and the 50 US states as of 2012. The trade values among the 80 locations constitute the 77×77 matrix whose (j,k) element is the trade value from location j to location k, $X_{j,k}$. Trade values between non-US countries come from the United Nations comtrade database. Trade values between the US states and the non-US countries come from the US Census Bureau U.S. Import and Export Merchandise trade statistics on USA trade online. Trade values between the US states are from the commodity flow survey that is uploaded on the US Census Bureau American Fact Finder. A problem is that 288 values out of $50 \times 50 = 2500$ are missing in the US inter-state trade data. Suppose that the trade value from US state k to US state j as of 2012, $X_{k,j}^{2012}$, is missing. Then if I have the trade value from k to j as of 2007, say $X_{k,j}^{2007}$, I fill the missing value $X_{k,j}^{2012}$ with

$$X_{k,j}^{2007} \times g_{US}^{2007,2012},$$

where $g_{US}^{2007,2012} = 1.12$ is the growth rate of the US nominal GDP from 2007 to 2012. This procedure fills 194 missing values out of 288. I set zeros for the remaining 94 missing trade values among the US states, which are 3.8% of all the 2500 inter-state trade values. Some of international trade values and trade values between non-US countries and US states are zeros or missing in the data sources. I set zeros for missing values in them. After all, I have 129 zero values in the 77×77 whole trade value matrix. That is, 2% of the trade values are zeros in my data.

Given the parameter value $\sigma = 4$ and trade values, I back out aggregate profits in each location using

$$\pi_j = \frac{1}{\sigma} \sum_{k \in N} X_{j,k}$$

for any $j \in N$. This equation is implied by (22).

Factual levels of nominal wages $\{w_j\}_{j \in N}$ are needed in (33), (34), (41). The nominal wages of all the non-US countries but China come from OECD's data of average annual wages as of 2012. The average nominal wages of the OECD countries are measured in national currency units such as euros for EU and yens for Japan, and I translate them in terms of the US dollars with the nominal exchange rates in 2012. The nominal wage in China as of 2012 is taken from China Labour Statistical Yearbook 2016. Again I translate it in terms of the US dollars with the nominal exchange rate. For the nominal wages for the

[6] The mean of the point estimates for the elasticities of substitution for US imports across SITC-3 industries is 4, as in pp. 568, Table IV of Broda and Weinstein (2006). The elasticity of substitution varies across SITC-3 industries from 1.2 of thermionic cold cathode to 22.1 of crude oil.

US states, I use the data of average annual pays from Bureau of Labor Statistics Quarterly Census of Employment and Wages.

Factual levels of labor forces $\{L_j\}_{j \in N}$ are needed in (33), (34), (38) and (41). Labor forces in the non-US countries come from the World Bank. Labor forces in the US states are taken from US Bureau of Labor Statistics Local Area Unemployment Statistics.

The factual levels of employment rates $\{e_j\}_{j \in N}$ are needed in (33), (34) and (41). For any location j, the employment rate e_j satisfies $e_j = 1 - u_j$, where u_j denotes the unemployment rate. Therefore it is sufficient to have unemployment rates to assign the factual employment rates to the hat algebra. I obtain the unemployment rates in the non-US countries except China at the World Bank Open Data, where the data, in turn, is from the ILOSTAT database of International Labour Organization (ILO). The unemployment rate in China as of 2012 is taken from China Labour Statistical Yearbook 2016.[7] The unemployment rates of the US states come from the US Bureau of Labor Statistics Expanded State Employment Status Demographic Data, as I referred to in Section 2.

The labor share in total costs β is in (34), (36), (38) and (39). The labor market unclearing condition (23) implies

$$\beta = \frac{\sigma}{\sigma - 1} \frac{w_j e_j L_j}{\sum_{k \in N} X_{j,k}}$$

for any $j \in N$. Since all values on the right-hand side are already given, I could compute the value of the right-hand side. However, the value of the right-hand side varies for different locations j's. I rather take an average of the right-hand side across locations. That is, I compute β by

$$\beta = \frac{1}{n} \sum_{j \in N} \frac{\sigma}{\sigma - 1} \frac{w_j e_j L_j}{\sum_{k \in N} X_{j,k}} = 0.51.$$

The value 0.51 is close to Alvarez and Lucas (2007)'s preferred value of 0.5 for the labor share.

I assign the data of nominal unemployment benefits to nominal home production $\{b_j P_j\}_{j \in N}$ in (31), (33) and (41). The data of unemployment benefits in 2012 come from three sources. First, the data of the unemployment benefits in the non-US countries except China come from OECD.Stat Net Replacement Rates in unemployment. The website provides the percentages that an unemployed person can receive from unemployment insurance relative to her previous wage that she received before unemployment. This data is provided for a variety of countries, wage levels and spells of unemployment. For example, I can obtain how much an unemployed single person receives from unemployment insurance if

[7] In the data of the World Bank-ILO, the unemployment rate of China in 2012 is 4.6%. In the China Labour Statistical Yearbook 2016, it is 4.1%. I use the value of 4.1%.

she has been unemployed for 1 year and had received the national average wage before unemployment. I use the value of insurance payment for this profile (single, unemployed for 1 year, previous in-work earnings of the national average wage) to assign the values of unemployment benefits for non-US countries except China. Second, I assume that unemployed people receive 20% of the wage in China, based on the description in Qian (2014), because I cannot find the data of unemployment benefits of China in sources from the government or public organizations. He says ”Benefits, which could be valid for as long as 104 weeks, can account up to about 20% of average wage.” Thus assuming that anyone unemployed receives 20% of the average wage admittedly overstates the unemployment benefits in China. Third, the data of the unemployment benefits in the US states come from UI Replacement Rates Report by the US Department of Labor, Employment and Training Administration. The webpage presents the replacement rate which is defined by the weighted average of

$$\frac{\text{the weekly benefit amounts (WBA)}}{\text{the claimants' normal hourly wage times 40 hours}}.$$ [8]

The replacement rate is the weighted average rather than the simple average across unemployed people because each unemployed person has a different spell of unemployment. The weights are lengths of unemployment spells. I multiply the average nominal wage of a US state by the replacement rate to compute the level of the nominal unemployment benefit in the US state.

The values of the disutility from making an effort η and the probabilities that firms detect shirking $\{q_j\}_{j\in N}$ are needed in (31), (33) and (41). I set $\eta = 1.05$, which is admittedly arbitrary. This means that making an effort reduces utility by 5% relative to shirking, if consumption and amenity are held fixed. Later I will compare the result of $\eta = 1.05$ with those of $\eta = 1.01, 1.1$. Rewriting (13), $\eta = 1.05$ and the factual values that I have assigned together determine the values of $\{q_j\}_{j\in N}$ by

$$\begin{aligned} q_j &= \frac{(\eta - 1)\left(\frac{\pi_j}{L_j} + w_j\right)}{\eta(w_j - b_j P_j)} \quad \text{for } j \in N_{NUS}, \\ q_j &= \frac{(\eta - 1)\left(\frac{\pi_{US}}{L_{US}} + w_j\right)}{\eta(w_j - b_j P_j)} \quad \text{for } j \in N_{US}. \end{aligned} \tag{42}$$

Table 3 reports the detection probabilities in non-US countries $\{q_j\}_{j\in N_{NUS}}$ associated with $\eta = 1.05$. Switzerland has the highest of 0.27, whereas China and Italy have the lowest of 0.08. Figure 4 presents the detection probabilities in the US states $\{q_j\}_{j\in N_{US}}$ associated

[8] This replacement rate is defined to be the ”replacement ratio 1” at the webpage.

with $\eta = 1.05$. The US states have smaller variation than the non-US countries, ranging from 0.16 in Kansas and Iowa to 0.11 in New York and Illinois.

Now the hat algebra (31), (34) (with (33)), (36), (38), (39) and (40) (with (41)) is equipped with all the parameters and the factual values to compute counterfactuals.

5 Counterfactual Result

Based on the model in Section 3 and the data and the parameter values in Section 4, I compute the counterfactual of the 5% increase in China's productivity.

Figure 5 represents the percent changes in real wages across the US states $\left\{\frac{\hat{w}_j}{\hat{P}_j}\right\}_{j\in N_{US}}$. Real wages increase in all the states. States with dark blue have large increases in real wages, while states with light blue have small increases. California has the largest increase in the real wage of 0.13%, and Tennessee has the second largest increase of 0.10%. On the other hand, Alaska has the smallest increase in the real wage of 0.0487%, and Louisiana has the second smallest increase of 0.0493%. I observe gradation from the west coast with dark blue to the upper midwest with light blue.

Figure 6 represents the percent changes in real profits across the US states $\left\{\frac{\hat{\pi}_j}{\hat{P}_j}\right\}_{j\in N_{US}}$. Real profits increase in only 10 states including states in the west coast. Real profits decrease in the other 40 states. States with the darkest blue have increases in real profits, and states with the other colors have decreases. Alaska has the largest increase in the real profits of 0.91%, and California has the second largest increase of 0.58%. On the other hand, Hawaii has the largest decrease in the real profits of 0.40%, and South Dakota has the second largest decrease of 0.35%. I observe gradation from the west coast with dark blue to the heartland with light blue.

Figure 7 represents the percentage point changes in unemployment across the US states. Unemployment decreases only in 6 states including states in the west coast. Unemployment increases in the other 44 states. States with the lightest blue have decreases in unemployment, while states with the other colors have increases. Hawaii has the largest increase in unemployment of 0.32 percentage points, and Wyoming has the second largest of 0.25 percentage points. On the other hand, Alaska has the largest decrease in unemployment of 0.52 percentage points, and Washington has the second largest decrease of 0.26 percentage points. Again I observe gradation from the west coast with dark blue to the heartland with light blue.

My model predicts that California has a decrease in unemployment in response to the productivity improvement in China, while Caliendo et al. (2019) argue that California has the largest increase in non-employment among the US states in response to the China shock from 2000 to 2007. A possible reason for the difference in prediction is sectors. The model in this paper has a single sector, while their model has multiple sectors. Computers and electronics have a large sectoral share in both California and China, and demands for computers and electronics shift from California to China, as China's productivity rises. This reduces labor demands in California in their model. In contrast, since my model does not have multiple sectors, the competition in the computers and electronics sector does not happen. My quantification just picks up geographic proximity between California and China, thus unemployment in California decreases as China's productivity rises.

Figure 8 represents the percent changes in labor forces across the US states. Labor forces increase in only 9 states including states in the west coast. Labor forces decrease in the other 41 states. States with the darkest blue have increases in labor forces, while states with the other colors have decreases. Alaska has the largest increase in the labor force of 0.31%, and California has the second largest increase of 0.27%. On the other hand, South Dakota has the largest decrease in the labor force of 0.16%, and Wyoming has the second largest decrease of 0.14%. Once again, I observe gradation from the west coast with dark blue to the heartland with light blue.

Table 4 shows changes in equilibrium outcomes across countries. The first column reports the percent changes in real wages. Real wages increase in all countries. The second column reports the percent changes in real profits. Real profits increase in 10 out of 27 non-US countries. The third column reports the percentage point changes in unemployment. Unemployment decreases only in China and South Korea, and increases in the other 25 non-US countries. A problem is that unemployment decreases by 5.6 percentage points in China. This is impossible because the unemployment rate in China is 4.1% in the data for 2012. The model can predict an impossible counterfactual value of an unemployment rate because (23), the equation that pins down employment rates, does not discipline employment rates to be in $[0,1]$. The fourth column reports the percent changes in welfare. Welfare increases in 14 countries out of 28 countries (including the US), while welfare decreases in the other 14 countries. This result is at odds with Caliendo et al. (2019), for Caliendo et al. (2019) argue that the China shock increases welfare in all countries in their calibration.

Table 5 shows the percent changes in the US welfare in response to the 5% increase in China's productivity for $\eta = 1.01, 1.05, 1.1$. As the disutility from making an effort, η, increases from 1.01 to 1.1, the percent change in the US welfare increases. The productivity improvement in China has a favorable and an unfavorable effect on the US. The favorable effect is that the US can import cheaper goods. The unfavorable effect is that unemployment increases in most states. η does not affect the price index, thus does not change the magnitude of the former (favorable) effect. But a high η makes working less attractive, thus mitigates the latter (unfavorable) effect. In total, a high η enhances the US welfare gains from China's productivity improvement.

6 Conclusion

This paper develops a model of involuntary unemployment in multiple geographic locations. The model merges a general equilibrium model of international trade and spatial economy and the efficiency-wage model of Shapiro and Stiglitz (1984). I quantify the model for 27 countries and the 50 US states. The counterfactual simulation of the 5% increase in China's productivity highlights its heterogeneous effects on real wages and unemployment across the US states.

Directions for future research follow. In the model, no-shirking wages (13) are a function of price indices, profits and parameters, not employment rates. Thus there is no substantial feedback from labor market tightness to wages. A desirable equilibrium property would be that wages increase as labor markets become tighter, as in standard models of search and matching.

The model does not discipline unemployment rates to be in $[0,1]$. Indeed, the model predicts an impossible counterfactual value of the unemployment rate in China in Section 5. It is desirable for a model to have a realistic unemployment rate in the range of $[0,1]$.

Unemployment rates are different across sectors in the US data. For example, unemployment rates range from 0.0% in petroleum and coal products manufacturing to 11.5% in agriculture as of March 2019.[9] Moreover, the model in this paper has a single sector, so it cannot decompose effects of foreign shocks on labor markets into sectoral composition and geography. It seems fruitful to extend sectoral labor market dynamics of Artuç et al. (2010) and Caliendo et al. (2019) to accommodate unemployment.

The model in this paper is static. But a dynamic model is necessary to trace labor market adjustment over time. Moreover, since Mortensen and Pissarides (1994), macro-labor literature including Bilal (2019) decomposes employment into job creation and job destruction, which also requires dynamics. Although this paper adopts the efficiency-wage model, a possible approach would be to combine a quantitative trade model and a search and matching model, because quantitative models based on search and matching prevail.

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Figure 1: Average Unemployment Rates from 2011 to 2019 across the US States

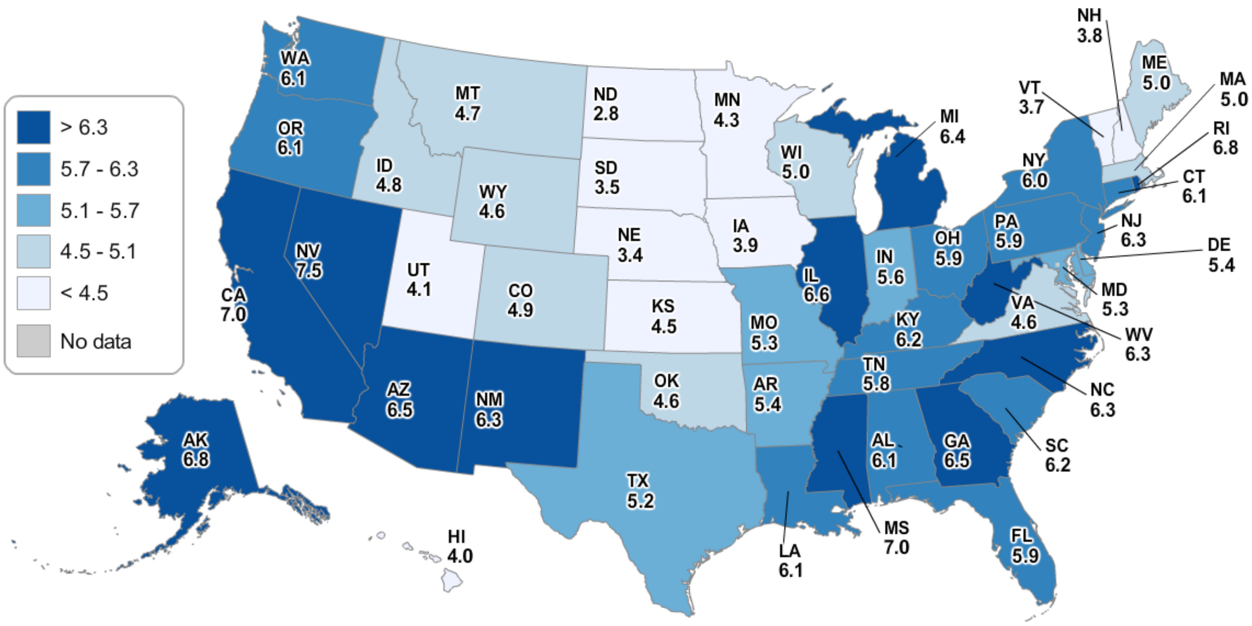

Figure 2: Average Unemployment Rates from 2011 to 2019 against Those from 2001 to 2010 across the US States

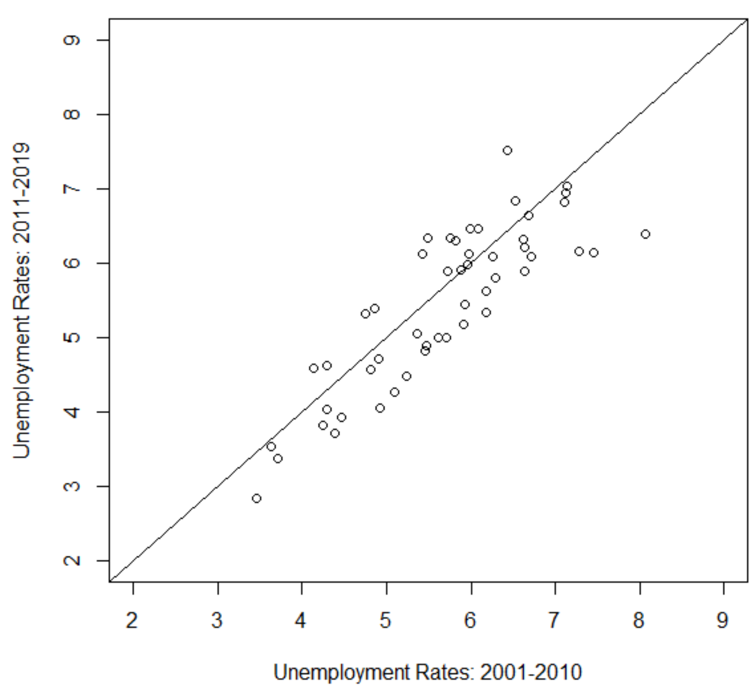

Figure 3: Unemployment Rates and Residuals in 2012 and 2017

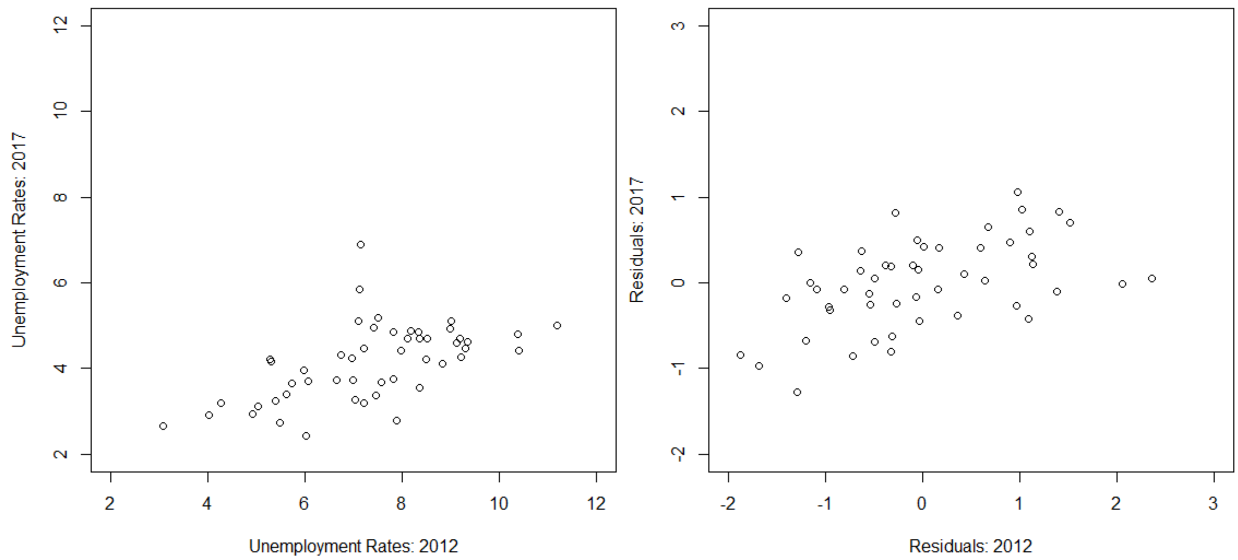

Figure 4: Detection Probabilities for the US States $\{q_j\}_{j \in N_{US}}$ Associated with $\eta = 1.05$

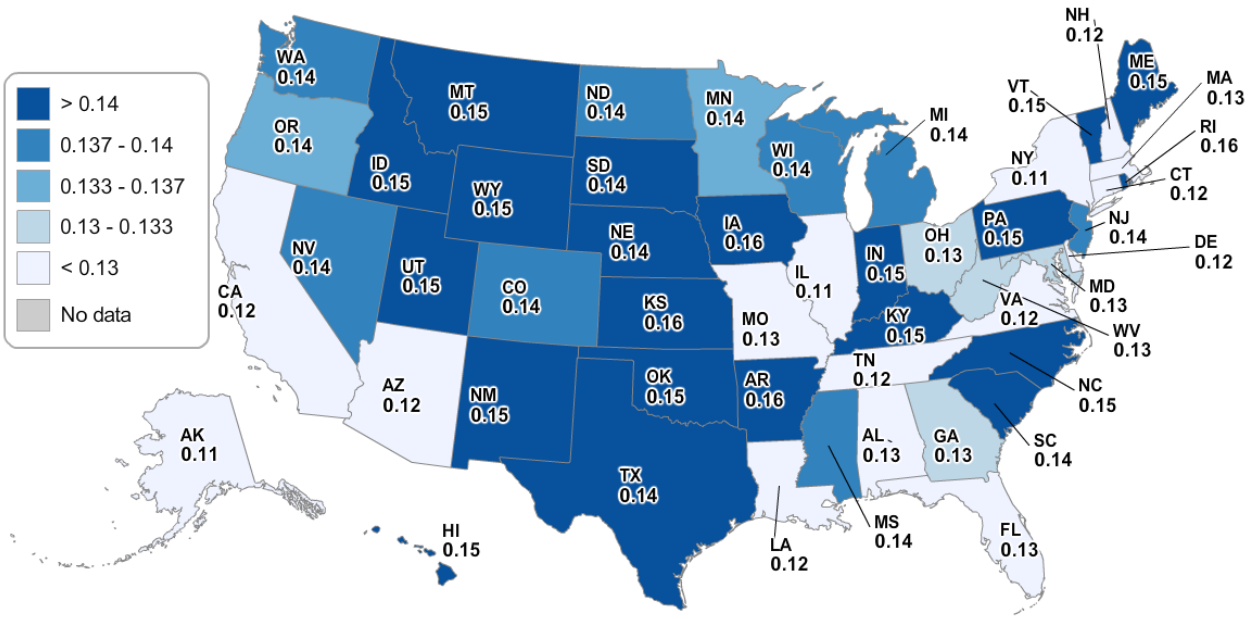

Figure 5: % Changes in Real Wages in the US States in Response to 5% Increase in China's Productivity

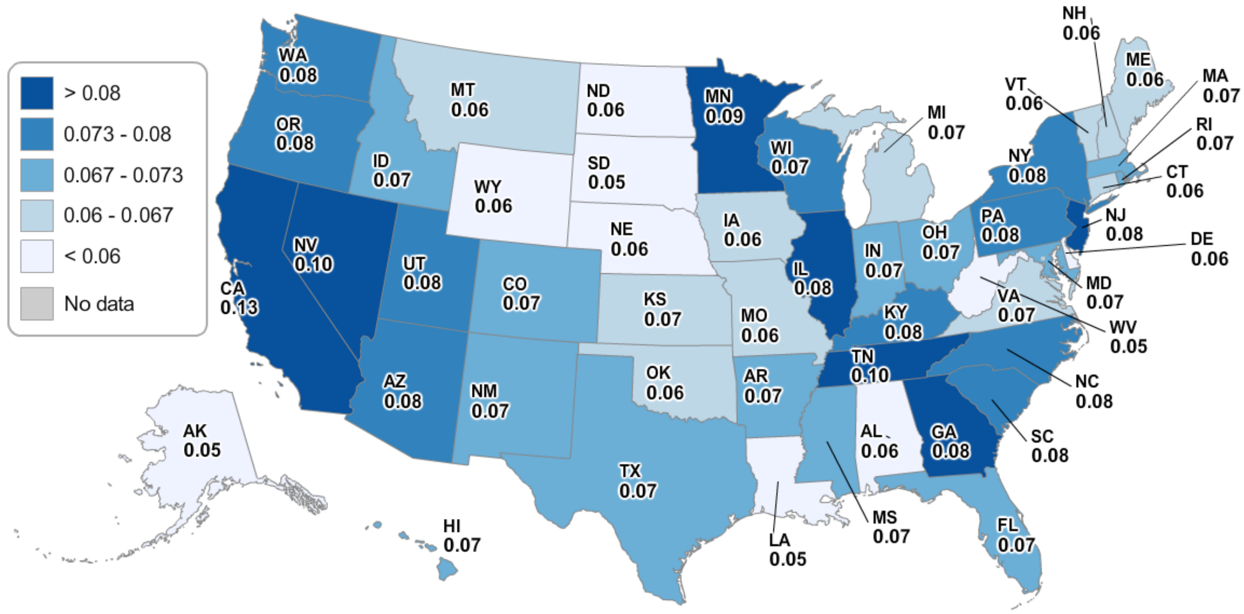

Figure 6: % Changes in Real Profits in the US States in Response to 5% Increase in China's Productivity

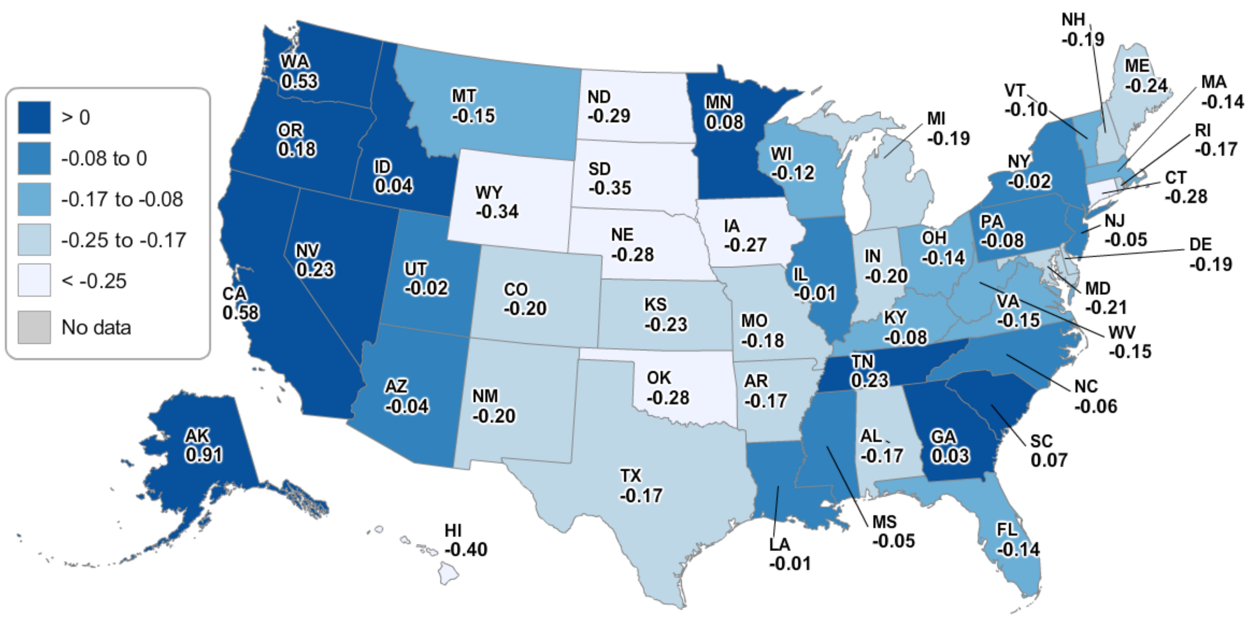

Figure 7: Percentage Point Changes in Unemployment in the US States in Response to 5% Increase in China's Productivity

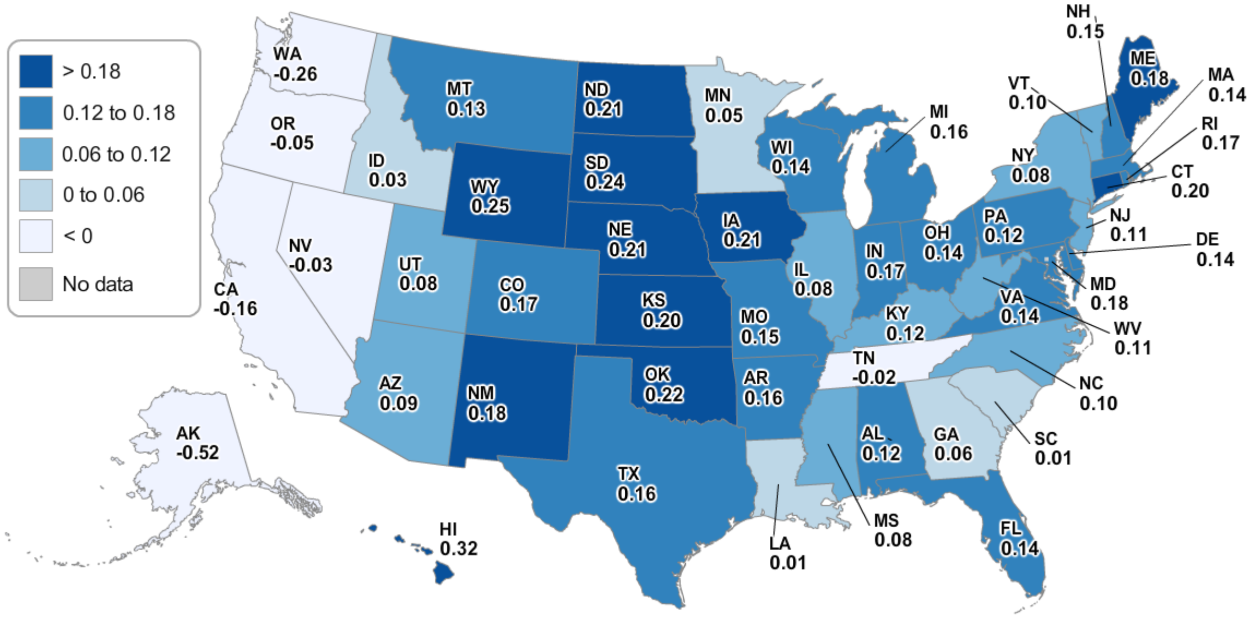

Figure 8: % Changes in Labor Forces in the US States in Response to 5% Increase in China's Productivity

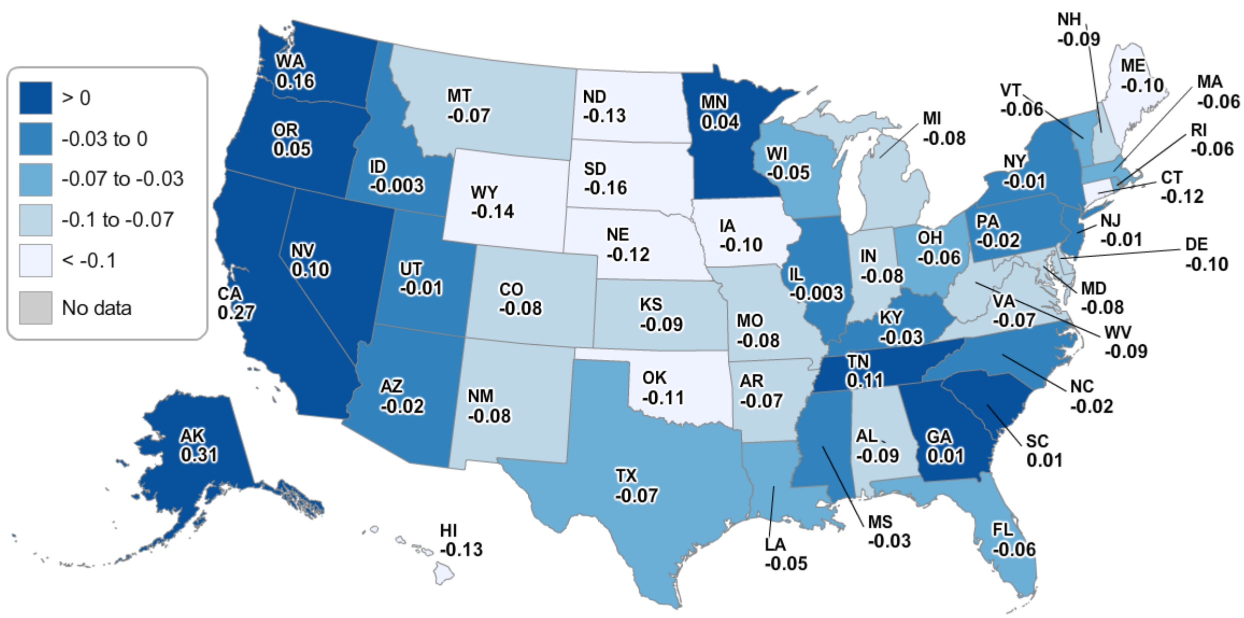

Table 1: Regression of Unemployment Rates on Skilled Labor Shares and Sectoral Shares

	Unemployment Rate	
	2012	2017
College graduates	−15.519***	−12.902***
	(5.624)	(2.874)
Agriculture, forestry, fishing and hunting	−49.552***	−35.060***
	(14.973)	(10.917)
Mining, quarrying, and oil and gas extraction	−17.091	−8.460
	(10.742)	(6.811)
Utilities	−27.260	−31.946
	(47.705)	(24.085)
Construction	−56.423	−22.966*
	(36.402)	(12.874)
Manufacturing	−10.610	−10.548**
	(8.627)	(4.874)
Wholesale trade	24.949	−3.075
	(16.682)	(8.939)
Retail trade	−28.910	−18.062
	(29.549)	(15.247)
Transportation and warehousing	−24.575	−4.773
	(20.256)	(8.580)
Information	2.382	2.808
	(16.110)	(7.450)
Finance, insurance, real estate, rental, and leasing	−13.277	−8.449*
	(9.073)	(4.911)
Professional and business services	−6.000	−4.257
	(15.608)	(8.246)
Educational services, health care, and social assistance	−13.854	−5.649
	(13.511)	(7.149)
Arts, entertainment, recreation, accommodation,	12.349	−14.727**
and food services	(11.808)	(6.769)
Other services (except government)	−174.037	−111.677*
	(106.417)	(57.651)
Constant	25.739***	18.608***
	(8.514)	(4.717)
Observations	50	50
R^2	0.673	0.661
Adjusted R^2	0.529	0.511

Note: *p<0.1; **p<0.05; ***p<0.01

2012 NAICS 2 digit codes corresponding to industry descriptions are given in Table 2.

Table 2: Industry Description and 2012 NAICS 2-digit Codes

Description	NAICS 2-digit
Agriculture, forestry, fishing and hunting	11
Mining, quarrying, and oil and gas extraction	21
Utilities	22
Construction	23
Manufacturing	31-33
Wholesale trade	42
Retail trade	44-45
Transportation and warehousing	48-49
Information	51
Finance, insurance, real estate, rental, and leasing	52, 53
Professional and business services	54, 55, 56
Educational services, health care, and social assistance	61, 62
Arts, entertainment, recreation, accommodation, and food services	71, 72
Other services (except government)	81

Table 3: Detection Probabilities for non-US Countries $\{q_j\}_{j \in N_{NUS}}$ Associated with $\eta = 1.05$

Country	q_j	Country	q_j
Australia	0.10	Italy	0.08
Belgium	0.21	Japan	0.12
Canada	0.09	Korea, South	0.09
China	0.08	Netherlands	0.26
Czech Republic	0.14	New Zealand	0.10
Denmark	0.19	Norway	0.22
Estonia	0.15	Poland	0.14
Finland	0.18	Slovakia	0.11
France	0.22	Slovenia	0.11
Germany	0.18	Spain	0.17
Greece	0.10	Sweden	0.14
Hungary	0.18	Switzerland	0.27
Ireland	0.12	United Kingdom	0.11
Israel	0.09		

Table 4: Changes in Equilibrium Outcomes of Countries in Response to 5% Increase in China's Productivity

Country	Real Wage %	Real Profits %	Unemployment p.p.	Walfare %
Australia	0.13	0.10	0.03	0.10
Belgium	0.08	-0.03	0.10	0.01
Canada	0.07	-0.02	0.09	-0.01
China	7.42	13.65	-5.56	12.63
Czech Republic	0.13	0.10	0.02	0.11
Denmark	0.06	-0.13	0.18	-0.04
Estonia	0.09	0.03	0.06	0.04
Finland	0.07	-0.07	0.12	-0.01
France	0.06	-0.14	0.18	-0.05
Germany	0.09	0.03	0.06	0.05
Greece	0.04	-0.08	0.09	-0.06
Hungary	0.04	-0.05	0.08	-0.04
Ireland	0.08	-0.02	0.08	0.01
Israel	0.07	-0.03	0.09	-0.01
Italy	0.05	-0.03	0.07	-0.03
Japan	0.10	0.06	0.04	0.07
Korea, South	0.25	0.26	-0.01	0.26
Netherlands	0.09	0.09	0.01	0.09
New Zealand	0.11	0.08	0.03	0.08
Norway	0.06	-0.15	0.20	-0.06
Poland	0.07	-0.03	0.09	0.00
Slovakia	0.10	0.03	0.06	0.04
Slovenia	0.07	-0.04	0.10	-0.02
Spain	0.05	-0.16	0.16	-0.07
Sweden	0.05	-0.11	0.14	-0.06
Switzerland	0.08	-0.05	0.13	0.01
United Kingdom	0.06	-0.08	0.12	-0.04
United States				0.05

Table 5: The US Welfare Changes from the 5% Increase in China's Productivity for Three Values of η

η	1.01	1.05	1.1
% Change in the US Welfare	0.047	0.052	0.058