NBER WORKING PAPER SERIES

A QUANTITATIVE ANALYSIS OF SUBSIDY COMPETITION IN THE U.S.

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Working Paper 20975
http://www.nber.org/papers/w20975

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
February 2015

I am grateful to Kerem Cosar, Jonathan Dingel, Owen Zidar, and seminar participants at various universities and conferences for very helpful comments and suggestions. This work is supported by the Business and Public Policy Faculty Research Fund at the University of Chicago Booth School of Business. The usual disclaimer applies. The views expressed herein are those of the author and do not necessarily reflect the views of the National Bureau of Economic Research.

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JEL No. F12,F13,R12,R58

ABSTRACT

What motivates regional governments to subsidize firm relocations and what are the implications of the subsidy competition among them? In this paper, I address these questions using a quantitative economic geography model which I calibrate to U.S. states. I show that states have strong incentives to subsidize firm relocations in order to gain at the expense of other states. I also show that subsidy competition creates large distortions so that there is much to gain from a cooperative approach. Overall, I find that manufacturing real income can be up to 3.9 percent higher if states stop competing over firms.

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1 Introduction

U.S. cities, counties, and states spend substantial resources on subsidies trying to attract firms. According to a New York Times database which I describe in detail later on, expenditures for such subsidies range from \$33.4 million per year in Nevada to \$19.1 billion per year in Texas and total \$80.4 billion per year nationwide. This amounts to \$12 per citizen per year in Nevada, \$759 per citizen per year in Texas, and \$254 per citizen per year nationwide. Regional governments provide these subsidies using a variety of policy instruments including tax abatements, cash grants, loans, and so on.

What motivates regional governments to subsidize firm relocations and what are the implications of the subsidy competition among them? In this paper, I address these questions using a quantitative economic geography model which I calibrate to U.S. states. I show that states have strong incentives to subsidize firm relocations in order to gain at the expense of other states. I also show that subsidy competition creates large distortions so that there is much to gain from a cooperative approach. Overall, I find that manufacturing real income can be up to 3.9 percent higher if states stop competing over firms.

The key mechanism in my analysis is an agglomeration externality in the New Economic Geography tradition which derives from an interaction of internal increasing returns and trade costs. In particular, consumers benefit from being close to firms because this gives them access to cheaper final goods. Similarly, firms benefit from being close to firms because this gives them access to cheaper intermediate goods. By subsidizing firm relocations, states try to foster local agglomeration at the expense of other states which gives rise to the beggar-thy-neighbor character of their subsidies.

Naturally, gaining at the expense of other states is much harder if all states try to do this at the same time. While some states still gain from a subsidy war, the subsidies also create distortions which move the country inside its efficiency frontier. The most important one is that subsidies make intermediate goods too cheap relative to the efficient benchmark which leads to excessive entry of firms. Moving from the worst-case scenario of fully noncooperative subsidies to the best-case scenario of zero subsidies yields the 3.9 percent gain in manufacturing real income mentioned above.

While I emphasize agglomeration forces in the New Economic Geography tradition, I also show that the model has an isomorphic representation featuring external increasing returns to scale. This implies that an analysis based on other agglomeration forces such as technological spillovers or thick labor markets would yield similar results. While agglomeration forces are the main drivers of the policy results, they are not the only determinants of the location of economic activity. In particular, I also allow for heterogeneity in locational fundamentals such as productivities, trade costs, and amenities.

Despite the resulting richness of the model, I show that it can be calibrated quite parsimoniously to the U.S. economic geography. In particular, I leverage a technique from the international trade literature which has come to be known as "exact hat algebra". In addition to a small number of structural parameters, I only need data on interstate trade flows, government subsidies, and the distribution of workers across U.S. states. This circumvents serious identification problems and ensures that all counterfactuals are computed relative to a benchmark which perfectly matches the data I provide.

I am not aware of any comparable analysis of optimal policy in a spatial environment. Related quantitative work such as Gaubert (2014) and Serrato and Zidar (2014) takes policy as given whereas I endogenize it by appealing to optimizing governments. Related theoretical work such as Baldwin et al (2005) restricts attention to highly stylized models whereas I attempt to connect my analysis to data using "exact hat algebra" techniques.[1] Redding (2014) and Caliendo et al (2014) also use "exact hat algebra" techniques in economic geography environments but do not focus on policy.

My analysis is heavily influenced by the trade agreements literature in the spirit of Bagwell and Staiger (1999). In particular, I calculate optimal subsidies, Nash subsidies, and efficient subsidies just like trade policy scholars calculate optimal tariffs, Nash tariffs, and cooperative tariffs. Indeed, the optimal subsidy argument I make here builds upon the optimal tariff argument I present in Ossa (2011). Moreover, the quantitative techniques I leverage here to analyze subsidy wars draw from the quantitative techniques I use in Ossa (2014) to study

[1] Gaubert (2014) quantifies the aggregate effects of subsidies given by the national government to lagging regions in France. Serrato and Zidar (2014) estimate the incidence of state corporate taxes on the welfare of workers, landowners, and firms in the U.S.. Baldwin et al (2005) analyze tax competition in a range of stylized New Economic Geography models. See also Greenstone et al (2010) and Kline and Moretti (2014) for related empirical analyses.

tariff wars.

The agglomeration economies emphasized in this paper are based on the seminal New Economic Geography contributions of Krugman (1991) and Krugman and Venables (1995). The finding that my model is isomorphic to one with external increasing returns is related to the results of Allen and Arkolakis (2014). Venables (1987) was the first to explore why governments might have an incentive to induce firm relocations even though his work focused on international trade and not economic geography.

The remainder of the paper is organized as follows. In section 2, I lay out the theoretical framework describing the basic setup, the equilibrium for given subsidies, the general equilibrium effects of subsidy changes, and the agglomeration and dispersion forces at work. In section 3, I turn to the calibration, explaining how I choose the model parameters, what adjustments I make to the model, and how I deal with possible multiplicity. In section 4, I perform the main analysis, exploring the welfare effects of subsidies, optimal subsidies, Nash subsidies, and cooperative subsidies.

2 Framework

2.1 Basic setup

There are L workers who can freely move across R regions. These workers are identical in all aspects other than their preferences over local amenities so that their utilities from living in a particular region have a common and an idiosyncratic component. Specifically, the utility of worker υ from living in region i is given by:

$$U_{i\upsilon} = U_i u_{i\upsilon} \tag{1}$$

The common component captures variation in local amenities perceived by all workers, A_i, as well as variation in local per-capita final consumption, C_i^F/L_i. For example, all workers might prefer the weather in California to the weather in North Dakota and real income differences might allow all workers to afford higher per-capita consumption in Connecticut than in Mississippi:

$$U_i = A_i \frac{C_i^F}{L_i} \tag{2}$$

The idiosyncratic component captures additional variation in local amenities perceived by individual workers. For example, a given worker might have family in some regions but not in other regions. I do not explicitly model this idiosyncratic component but simply assume that workers draw random preference shocks. In particular, I posit $u_{iv} = \exp(a_{iv})$ and let workers draw a_{iv} from:[2]

$$a_{iv} \sim Gumbel\,(0, \sigma) \tag{3}$$

Final consumption is a CES aggregate over a continuum of differentiated varieties which are traded among regions. In particular, region i produces M_i differentiated varieties and all these varieties are then available in all regions subject to a trade cost. Denoting the final consumption of a given variety from region i in region j by c_{ij}^F and letting the elasticity of substitution be $\varepsilon > 1$, these assumptions imply:

$$C_j^F = \left(\sum_{i=1}^{R} \int_0^{M_i} c_{ij}^F(\omega_i)^{\frac{\varepsilon-1}{\varepsilon}} \, d\omega_i \right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{4}$$

Individual varieties are uniquely associated with individual firms so that M_i is also the number of firms located in region i. Firms interact in a monopolistically competitive fashion so that M_i is pinned down endogenously, as I explain below. Productivities are assumed to differ across regions. This is meant to allow for regional variation in fundamentals such as institutions, infrastructure, climate, and the like. Specifically, denoting firm output by q, firm input by i, productivity by φ, and fixed costs by f, I assume:

$$q_i = \varphi_i \,(i_i - f_i) \tag{5}$$

The input is comprised of labor, capital, and intermediate goods. Capital is homogenous

[2] As I will explain in more detail later on, this heterogeneity allows for a meaningful sense in which regions can benefit at the expense of other regions which is important for the mechanism I present. This would not be the case if all workers were identical and free labor mobility simply arbitraged all real income differences away. For future reference, recall that σ is proportional to the standard deviation of the Gumbel distribution so that worker heterogeneity is increasing in σ here.

and fully mobile so that regional interest rates are always equalized. Intermediate consumption is modeled analogously to final consumption. In particular, total intermediate consumption in region i, C_i^I, is a CES aggregate over all differentiated varieties with elasticity ε, just like equation (4). To be able to readily map this to the data, I choose a nested Cobb-Douglas specification with η being the share of value-added in gross production, θ^L being the labor share in value-added, θ^K being the capital share in value-added, and $\theta^L + \theta^K = 1$. Denoting the number of workers in region i by L_i, the amount of capital in region i by K_i, and recalling that the input i_i is expressed in per-firm terms, this implies:[3]

$$i_i = \frac{1}{M_i} \left(\frac{1}{\eta} \left(\frac{L_i}{\theta^L} \right)^{\theta^L} \left(\frac{K_i}{\theta^K} \right)^{\theta^K} \right)^{\eta} \left(\frac{C_i^I}{1-\eta} \right)^{1-\eta} \tag{6}$$

I assume that regional governments maximize the common component of worker utility, U_i. They thereby make their region as attractive as possible to any fixed set of workers but disregard the idiosyncratic preferences workers draw. For example, this might capture a motivation to maximize the local utility of the incumbent local median worker, the local utility of all incumbent local workers, or the local utility of the population at large. Since A_i is a parameter in equation (2), maximizing U_i is the same as maximizing local per-capita consumption. As will become clear later, maximizing local per-capita consumption is also quantitatively similar to maximizing local employment, which squares well with the key role jobs play in real-world policy debates. In the interest of brevity, I simply refer to U_i as welfare in the following taking the slight abuse in terminology as understood.

In practice, regional governments make use of a dazzling array of policy measures to provide business incentives to local firms. These include sales tax abatements, property tax abatements, corporate tax abatements, cash grants, loans, loan guarantees, free services, land sold below market value, and so on. To allow for a transparent analysis of regional policy making, I do not attempt to directly model all these policy measures but focus instead on their

[3] While I allow for intermediate goods mainly for quantitative realism, having capital in addition to labor is important even for the qualitative results. As I will explain in more detail shortly, regional governments offer cost subsidies financed by labor taxes in an attempt to attract firms. This would not work if labor was the only factor of production because workers would then effectively have to subsidize themselves. In particular, it is easy to verify that in the special case $\theta^L = \eta = 1$, a 10 percent wage subsidy would simply lead to a 10 percent higher before-subsidy wage so that the after-subsidy wage faced by firms would remain completely unchanged. Essentially, I somehow need to let governments tax a more sluggish factor and subsidize a less sluggish factor for subsidies to have the envisioned effect.

common effect on business costs. In particular, I simply assume that regional governments offer subsidies to all local firms which pay for a fraction of their overall costs. One can think of these subsidies as true place-based policies in the sense that having business operations in a particular region is all firms needs to qualify.

I model the financing of these subsidies in an equally parsimonious manner and assume that regional governments simply charge local workers a lump-sum tax. Local expenditure on final consumption, E_i^F, is therefore given by local worker income minus local subsidy costs. Local worker income consists of local labor income, $w_i L_i$, local capital income, and an interregional transfer denoted by Ω_i. I assume that each worker owns an equal share of the nation's capital stock so that local capital income is given by $\lambda_i^L rK$, where $\lambda_i^L = L_i/L$ is region i's share of the nation's workforce and K is the nation's capital stock. Letting s_i be the subsidy and E_i^I the local expenditure on intermediate consumption, local subsidy costs are simply given by $s_i \left(w_i L_i + rK_i + E_i^I\right)$ so that overall:[4]

$$E_i^F = w_i L_i + \lambda_i^L rK - s_i \left(w_i L_i + rK_i + E_i^I\right) - \Omega_i \tag{7}$$

Besides capturing side payments which are part of the interstate bargaining considered later on, the interregional transfers Ω_j are also needed to accommodate any excess net exports observed empirically. In particular, it is easy to show that the net exports of region i are given by $NX_i = \left(\lambda_i^K - \lambda_i^L\right) rK + \Omega_i$, where $\lambda_i^K = K_i/K$ is region i's share in the nation's capital stock. The first term, $\left(\lambda_i^K - \lambda_i^L\right) rK$, captures that some of the local returns to capital accrue to other regions whenever $\lambda_i^K > \lambda_i^L$ which follows directly from the assumption that each worker owns an equal share in the nation's capital stock. While this can explain part of region i's net exports, it typically cannot explain all of it, which is why interstate transfers are needed for internal consistency.[5]

[4] While these simplifying assumptions are necessary for a transparent analysis of regional policy making, it is also important to recognize some of the limitations they bring about. In particular, they are likely to understate the distortions created by more complex real-world subsidies and taxes so that the optimal subsides derived in this paper should probably be best viewed as an upper bound. Also, they restrict attention to subsidy competition even though corporate tax competition realistically also plays an important role. However, introducing corporate taxes would require some major modifications since firms do not make any profits and governments do not offer any public goods in the framework presented here. Also, regional subsidy expenditures actually dominate regional corporate tax revenues as I will explain shortly so that focusing on regional subsidy competition seems like a reasonable starting point.

[5] I will elaborate more on my treatment of net exports and its relation to other approaches in the literature

2.2 Equilibrium for given subsidies

Utility maximization requires that worker v chooses to live in region i if $U_{iv} > U_{jv}$ for all $j \neq i$. Given the distributional assumption (3), it is easy to show that this occurs with probability $U_i^{\frac{1}{\sigma}} / \sum_j U_j^{\frac{1}{\sigma}}$ so that the share of workers living in region i must be:

$$\lambda_i^L = \frac{U_i^{\frac{1}{\sigma}}}{\sum_{j=1}^R U_j^{\frac{1}{\sigma}}} \tag{8}$$

U_i is just amenity-adjusted per-capita final consumption which is the same as amenity-adjusted per-capita nominal final consumption expenditure deflated by the ideal price index. Recalling that per-capita nominal final consumption expenditure is given by E_i^F / L_i and denoting the ideal price index by P_i, this implies:

$$U_i = A_i \frac{E_i^F / L_i}{P_i} \tag{9}$$

The assumptions on final and intermediate consumption imply that firms face standard CES demands. In particular, letting p_i be the ex-factory price of varieties in region i and letting τ_{ij} be the iceberg trade costs incurred for shipments travelling from region i to region j, each region i firm faces the following total demand:

$$c_{ij}^F + c_{ij}^I = (p_i \tau_{ij})^{-\varepsilon} (P_j)^{\varepsilon - 1} \left(E_j^F + E_j^I \right) \tag{10}$$

Given the nested Cobb-Douglas specification from equation (6), firms optimally spend a share η of their costs on labor and capital and the remaining share $1 - \eta$ on intermediate goods. Moreover, of the share spent on labor and capital, a sub-share θ^L is devoted to labor and the remaining sub-share θ^K is devoted to capital. In combination, this implies:

$$w_i L_i = \frac{\theta^L}{\theta^K} r K_i \tag{11}$$

$$E_i^I = \frac{1 - \eta}{\eta \theta^K} r K_i \tag{12}$$

later on. To be clear, the terms exports and imports refer to interstate trade flows and not international trade flows here and throughout the paper.

Profit-maximization requires that firms exploit their monopoly power and charge a markup $\varepsilon/(\varepsilon-1)$ over marginal costs. Marginal costs depend on the productivity φ_i and on the price of the input i_i which is just a Cobb-Douglas aggregate of the prices of labor, capital, and intermediate goods, $\left((w_i)^{\theta^L}(r)^{\theta^K}\right)^{\eta}(P_i)^{1-\eta}$. Recalling that firms also receive a cost subsidy s_i and introducing the shorthand $\rho_i = 1 - s_i$, this yields:

$$p_i = \frac{\varepsilon}{\varepsilon-1}\frac{\left((w_i)^{\theta^L}(r)^{\theta^K}\right)^{\eta}(P_i)^{1-\eta}\rho_i}{\varphi_i} \tag{13}$$

Free entry requires that each firm's operating profits equal its fixed costs. Operating profits are just a share $1/\varepsilon$ of total revenues in this constant markup environment which can be computed from equation (10). Recall that fixed costs are incurred in terms of the input i_i and that all costs are subsidized at a rate $s_i = 1 - \rho_i$ so that the free entry condition can be stated as follows:

$$\frac{1}{\varepsilon}\sum_{j=1}^{R}(p_i\tau_{ij})^{1-\varepsilon}(P_j)^{\varepsilon-1}\left(E_j^F + E_j^I\right) = \left((w_i)^{\theta^L}(r)^{\theta^K}\right)^{\eta}(P_i)^{1-\eta}\rho_i f_i \tag{14}$$

This free entry condition can also be used to calculate the equilibrium number of firms. In particular, invoking market clearing, $q_i = \sum_j \tau_{ij}\left(c_{ij}^F + c_{ij}^I\right)$, and equations (5), (10), and (13), it is easy to verify that the free entry condition implies a constant firm size: $i_i = \varepsilon f_i$. In combination with equation (6), this yields $M_i = \frac{1}{\varepsilon f_i}\left(\frac{1}{\eta}\left(\frac{L_i}{\theta^L}\right)^{\theta^L}\left(\frac{K_i}{\theta^K}\right)^{\theta^K}\right)^{\eta}\left(\frac{C_i^I}{1-\eta}\right)^{1-\eta}$ which can be simplified with the help of conditions (11) and (12) to:

$$M_i = \frac{L_i}{\varepsilon f_i \eta \theta^L}\frac{w_i}{\left((w_i)^{\theta^L}(r)^{\theta^K}\right)^{\eta}(P_i)^{1-\eta}} \tag{15}$$

As one would expect, attracting firms is therefore closely related to creating jobs in this model. Moreover, the local number of firms is decreasing in the local price index. This is because a lower price index implies a better provision with intermediate goods which implies a higher C_i^I and thus a higher M_i. Of course, the price index is just the standard CES unit expenditure function so that:

$$P_j = \left(\sum_{i=1}^{R} M_i \left(p_i \tau_{ij} \right)^{1-\varepsilon} \right)^{\frac{1}{1-\varepsilon}} \tag{16}$$

Keeping in mind that $\lambda_i^L = L_i/L$ and imposing the normalization $r = 1$, equations (7), (8), (9), (11), (12), (13), (14), (15), and (16) fully characterize the equilibrium of the model, representing $9R$ equations in the $9R$ unknowns w_i, p_i, P_i, E_i^F, E_i^I, L_i, K_i, M_i, and U_i. Notice that this system can be condensed to $3R$ equations in the $3R$ unknowns λ_i^L, λ_i^K, and P_i by substituting combinations of equations (7), (9), (11), (12), (13), and (15) into equations (8), (14), and (16) and recalling that $\lambda_i^L = L_i/L$ and $\lambda_i^K = K_i/K$.

2.3 General equilibrium effects of subsidy changes

While the above representation of the equilibrium can in principle be used to analyze the effects of regional subsidies, the practical difficulty is that it depends on a large set of unknown parameters which are all hard to measure empirically. Most notably, it requires information on the technology parameters φ_i and f_i, the preference parameters A_i, and the matrix of bilateral trade barriers τ_{ij}, and the difficulty of obtaining this information has arguably been one of the main obstacles to progress in this area.

I circumvent this difficulty by expressing the equilibrium conditions in changes using what is sometimes referred to as "exact hat algebra". This method is now standard in the international trade literature and has also recently been applied in economic geography settings by Redding (2014) and Caliendo et al. (2014). The main idea is not to calculate the endogenous variables as a function of subsidy levels but to compute changes in the endogenous variables as a function of subsidy changes. The advantage is that many parameters then either drop out of the equilibrium conditions altogether or appear in combinations which can be linked to readily measurable observables.

To develop some intuition, it is useful to consider the basic price index equation $P_j = \left(\sum_i M_i \left(p_i \tau_{ij} \right)^{1-\varepsilon} \right)^{\frac{1}{1-\varepsilon}}$ and ask what would happen if, say, region j's subsidy changed from s_j to s_j'. The result would be that all endogenous variables adjusted so that now $P_j' = \left(\sum_i M_i' \left(p_i' \tau_{ij} \right)^{1-\varepsilon} \right)^{\frac{1}{1-\varepsilon}}$. Dividing this by the original equation for P_j yields the price index change $\hat{P}_j = \left(\sum_i \frac{M_i(p_i\tau_{ij})^{1-\varepsilon}}{\sum_m M_m(p_m\tau_{mj})^{1-\varepsilon}} \hat{M}_i\left(\hat{p}_i\right)^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$, where $\hat{P}_j = P_j'/P_j$ and so on. This, in turn, implies $\hat{P}_j = \left(\sum_i \frac{T_{ij}}{\sum_m T_{mj}} \hat{M}_i\left(\hat{p}_i\right)^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$, where $T_{ij} = M_i\left(p_i\tau_{ij}\right)^{1-\varepsilon}\left(P_j\right)^{\varepsilon-1}\left(E_j^F + E_j^I\right)$ is the value of trade flowing from region i to region j. This says that changes in P_j are expenditure share weighted averages of changes in M_i and p_i and shows how an equation that originally included unobservable trade costs τ_{ij} can be rewritten entirely in terms of observable trade flows T_{ij}.

I now apply this technique to the equilibrium conditions above. It is useful to start by taking note of some additional equilibrium relationships which are necessary to express all conditions in terms of observables. First, free entry and cost minimization imply that total revenues have to be equal to total costs after the subsidy which implies $w_iL_i = \frac{\theta^L\eta}{\rho_i}\sum_n T_{in}$, $rK_i = \frac{\theta^K\eta}{\rho_i}\sum_n T_{in}$, $E_i^I = \frac{1-\eta}{\rho_i}\sum_n T_{in}$, and $rK = \sum_i\sum_n \frac{\theta^K\eta}{\rho_i}T_{in}$. Second, total purchases have to be equal to total expenditures so that $\sum_m T_{mi} = E_i^F + E_i^I$ which yields $E_i^F = \sum_m T_{mi} - \frac{1-\eta}{\rho_i}\sum_n T_{in}$. Finally, recall from above that $NX_i = \left(\lambda_i^K - \lambda_i^L\right)rK + \Omega_i$ so that the interregional transfers are $\Omega_i = \sum_n\left(T_{in} - T_{ni}\right) - \left(\lambda_i^K - \lambda_i^L\right)rK$. I will not substitute these relationships explicitly in the following so keep in mind that w_iL_i, rK_i, rK, E_i^I, E_i^F, and Ω_i are simple functions of the observables T_{ij}, λ_i^L, and λ_i^K.

Given this background, it should be easy to verify that equations (7), (8), (9), (11), (12), (13), (14), (15), and (16) can be rewritten in changes to obtain a system of $9R$ equations in the $9R$ unknowns $\hat{w}_i$, $\hat{p}_i$, $\hat{P}_i$, $\hat{E}_i^F$, $\hat{E}_i^I$, $\hat{\lambda}_i^L$, $\hat{\lambda}_i^K$, $\hat{M}_i$ and $\hat{U}_i$. Again, this can be reduced to a system of $3R$ equations in the $3R$ unknowns $\hat{\lambda}_i^L$, $\hat{\lambda}_i^K$, and $\hat{P}_i$ following the same procedure as above. Introducing a shorthand for subsidy costs, $S_i = s_i\left(w_iL_i + rK_i + E_i^I\right)$, and total expenditure, $E_i = E_i^F + E_i^I$, the basic $9R$ equations take the following form. Notice that I allow for exogenous changes in subsidies as well as in interregional transfers which will be useful later on:

$$\hat{E}_i^F = \frac{w_iL_i}{E_i^F}\hat{w}_i\hat{\lambda}_i^L + \frac{\lambda_i^L rK}{E_i^F}\hat{\lambda}_i^L - \frac{S_i}{E_i^F}s_i'\left(\frac{w_iL_i}{S_i}\hat{w}_i\hat{\lambda}_i^L + \frac{rK_i}{S_i}\hat{\lambda}_i^K + \frac{E_i^I}{S_i}\hat{E}_i^I\right) - \frac{\Omega_i'}{E_i^F} \tag{17}$$

$$\hat{\lambda}_i^L = \frac{\left(\hat{U}_i\right)^{\frac{1}{\sigma}}}{\sum_{j=1}^R \lambda_j^L\left(\hat{U}_j\right)^{\frac{1}{\sigma}}} \tag{18}$$

$$\hat{U}_i = \frac{\hat{E}_i^F / \hat{\lambda}_i^L}{\hat{P}_i} \tag{19}$$

$$\hat{w}_i \hat{\lambda}_i^L = \hat{\lambda}_i^K \tag{20}$$

$$\hat{E}_i^I = \hat{\lambda}_i^K \tag{21}$$

$$\hat{p}_i = (\hat{w}_i)^{\theta^L \eta} \left(\hat{P}_i\right)^{1-\eta} \hat{\rho}_i \tag{22}$$

$$\sum_{j=1}^{R} \frac{T_{ij}}{\sum_{n=1}^{R} T_{in}} \left(\hat{P}_j\right)^{\varepsilon-1} \left(\frac{E_j^F}{E_j} \hat{E}_j^F + \frac{E_j^I}{E_j} \hat{E}_j^I\right) = (\hat{p}_i)^{\varepsilon} \tag{23}$$

$$\hat{M}_i = \hat{\lambda}_i^L \frac{\hat{w}_i}{(\hat{w}_i)^{\theta^L \eta} \left(\hat{P}_i\right)^{1-\eta}} \tag{24}$$

$$\hat{P}_j = \left(\sum_{i=1}^{R} \frac{T_{ij}}{\sum_{m=1}^{R} T_{mj}} \hat{M}_i \left(\hat{p}_i\right)^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}} \tag{25}$$

While rewriting the equilibrium conditions in changes therefore allows me to avoid having to estimate the parameters φ_i, f_i, A_i, and τ_{ij}, it also ensures that I compute all counterfactuals from a benchmark which perfectly matches observed regional employment, regional production, regional subsidies, and interregional trade. Essentially, it imposes a restriction on the set of unknown parameters $\{\varphi_i, f_i, A_i, \tau_{ij}\}$ such that the predicted λ_i^L and T_{ij} exactly match the observed λ_i^L and T_{ij} given the observed s_i and the model parameters $\left\{\theta^L, \theta^K, \eta, \varepsilon, \sigma\right\}$. Notice that this method does not deliver any estimates of $\{\varphi_i, f_i, A_i, \tau_{ij}\}$ without imposing further restrictions due to the high dimensionality of the parameter space. However, such estimates are also not needed for any of the calculations performed in this paper so that I do not push further ahead on this front.

2.4 Agglomeration and dispersion forces

The above framework belongs to the class of New Economic Geography models in that it features agglomeration forces resulting from the interaction of firm-level increasing returns, transport costs, and factor mobility. The main intuition is that workers want to be close to firms and firms want to be close to firms in order to have access to cheaper goods for final and intermediate use. While this will be familiar to most readers from the seminal contributions of Krugman (1991) and Krugman and Venables (1995), it can also be seen quite clearly from the above equilibrium conditions. In particular, if firms relocate to region j the price index falls in region j if region j realistically spends more on local varieties than on varieties from other regions (equation 25, other things equal). This then makes region j more attractive for workers (equation 19, other things equal) as well as firms (equation 24, other things equal) thereby potentially inducing further relocations.

As discussed extensively in the related theoretical and empirical literature, this formulation of agglomeration economies has a number of attractive features. For example, Fujita et al (2001) emphasize that it does not simply assume agglomeration economies with reference to imprecise notions such as localized spillover effects but instead explains them by appealing to concrete concepts such as firm-level increasing returns, transport costs, and factor mobility. Also, empirical studies such as Redding and Sturm (2008) and Handbury and Weinstein (forthcoming) provide direct evidence supporting its main underlying mechanisms by showing that local market access matters for local economic activity and that larger regions tend to have lower variety-adjusted price indices.

While I therefore continue to emphasize New Economic Geography forces, it is useful to note that the model can also be interpreted as an Armington model with external increasing returns to scale. In particular, suppose instead that each region makes one differentiated variety under conditions of perfect competition subject to the aggregate production function $Q_i = \varphi_i (I_i)^{1+\phi}$, where outputs, Q_i, and inputs, I_i, are now represented in capital letters to emphasize that they refer to aggregate quantities. $\phi_i > 0$ is an external increasing returns parameter which captures that local productivity is increasing in local employment taking all production factors into account. This could reflect any agglomeration economy including the localized knowledge spillovers, localized thick markets for specialized skills, or localized backward and forward linkages Alfred Marshall famously proposed.

Keeping the rest of the model unmodified, I show in Appendix 1 that such an Armington model is isomorphic to the above New Economic Geography model under the assumption that the external increasing returns to scale parameter satisfies $\phi = 1/(\varepsilon - 1)$. Intuitively, the local price index is decreasing in local employment in both models, with the mechanism operating through changes in variety in the New Economic Geography model and through changes in productivity in the Armington model. This also explains the particular restriction delivering the isomorphism since variety changes enter the price index with an exponent $1/(\varepsilon - 1)$ in the New Economic Geography model while employment changes translate into productivity changes with an exponent ϕ in the Armington model.

Regardless of whether one adopts the New Economic Geography or the Armington interpretation, the model always features worker heterogeneity as its key dispersion force. Intuitively, it gets harder to attract workers to a particular region the more workers there already are since workers select into regions according to their idiosyncratic preference draws. As a result, firms have to pay higher wages if they want to entice more workers to relocate which then ultimately decreases their profitability. Indeed, notice that $1/\sigma$ can be interpreted as an elasticity of relative regional labor supply since equation (18) implies $\ln\left(\lambda_i^L/\lambda_j^L\right) = (1/\sigma)\ln(U_i/U_j)$. Recall that σ captures the extent of worker heterogeneity by determining the standard deviation of their preference draws.[6]

3 Calibration

3.1 Parameterization

I apply this model to analyze subsidy competition among U.S. states, focusing on manufacturing in the lower 48 states in the year 2007. I construct the matrix of interstate trade flows from the 2007 Commodity Flow Survey scaled to match state-level manufacturing production from the 2007 Annual Survey of Manufacturing. Using the publicly available Commodity Flow Survey data, I begin by constructing a matrix of interstate freight shipments. I use the reported values which aggregate over all modes of transport and all included industries in order to avoid having to deal with the many missing values there are at finer levels of detail. In the end, there are still about 8 percent missing values, all pertaining to interstate rather

[6] New Economic Geography models in the tradition of Helpman (1998) feature local fixed factors such as housing as their key dispersion force. While it would be technically straightforward to also incorporate this into the model, I prefer not complicate my analysis any further by having more than one dispersion force. Recall that assuming worker heterogeneity is necessary to make sure that regional welfare differences generated by business incentives do not simply get arbitraged away. Moreover, introducing housing would also add a number of empirical challenges. Most notably, I will perform my analysis at the state level and it is not obvious how one would appropriately model state level housing supply. In any case, I provide results for a wide range of σ in sensitivity checks in the hope to be able to accommodate most readers' priors on the right calibration of state level dispersion forces.

than intrastate flows.

I interpolate these missing interstate flows using the standard gravity equation my model implies: $T_{ij} = M_i (p_i \tau_{ij})^{1-\varepsilon} (P_j)^{\varepsilon-1} E_j$. In particular, I estimate this equation by regressing log trade flows on origin fixed effects, destination fixed effects, and standard proxies for trade costs, namely log distance between state capitals and a dummy for whether i and j share a state border. Reassuringly, the estimation delivers a positive common border coefficient and a plausible distance elasticity of trade flows of -1.01. The correlation between predicted values and observed values is 96 percent so I feel comfortable using the predicted values to replace the 8 percent missing values discussed above.

I then scale these freight shipments to ensure they add up to the total manufacturing shipments reported in the Annual Survey of Manufacturing for each state. On average, the total freight shipments implied by the Commodity Flow Survey are almost 2.5 times larger than the total manufacturing shipments reported in the Annual Survey of Manufacturing. In part, this simply reflects the fact that the aggregate freight shipments I use from the Commodity Flow Survey include all goods captured by the Standard Classification of Transported Goods which includes not just manufacturing goods. However, the Commodity Flow Survey also double-counts trade flows if they are shipped indirectly, say first from i to m and then from m to j. In any case, notice that trade shares and not trade flows enter into equations (17) - (25) so that these scalings only matter if they affect different states differentially.

I calculate the vector of state-level subsides from the New York Times' Business Incentive Database compiled by Story et al (2012). It lists the annual values of business incentives awarded by U.S. cities, counties, and states, including sales tax abatements, property tax abatements, corporate tax abatements, cash grants, loans, loan guarantees, and free services. Overall, it suggests that U.S. regional governments give up \$80.4 billion per year which far exceeds the \$52.0 billion of state corporate tax revenues collected in 2007.

Unfortunately, the value of subsidies going to manufacturing firms is not straightforward to determine since many incentive programs are not classified by industry. To obtain at least a rough estimate, I take the value of subsidies going explicitly to manufacturing (around 32 percent), disregard all subsidies going explicitly to agriculture, oil, gas and mining, and film and allocate the residual (about 53 percent) to manufacturing based on manufacturing shares in state GDP obtained from the Bureau of Economic Analysis.

In order to bring these subsidy measures in line with their representation in the theory, I express them in ad valorem terms by simply dividing total subsidy expenditures by total manufacturing shipments for each state. The resulting subsidy rates range from 0.0 percent for Nevada to 5.4 percent for Vermont and have a mean of 0.7 percent. Figure 1 illustrates how these rates vary across states with darker states offering higher subsidies. As can be seen, my estimates do not reveal any clear geographic pattern with the exception that Vermont (5.4 percent), Oklahoma (4.2 percent), Nebraska (3.5 percent), and Texas (3.2 percent) clearly stand out.

I obtain the vector of labor shares λ_i^L from the 2007 Annual Survey of Manufacturing. In particular, I simply calculate the total number of U.S. manufacturing workers and determine the share of those employed in a particular state. These shares range from 0.03 percent for Wyoming to 10.98 percent for California and their geographic distribution is illustrated on the map in Figure 2. As can be seen, manufacturing is mainly concentrated in California, Texas, and the traditional manufacturing belt states stretching all the way from New York to Illinois. Also, there is generally little manufacturing activity in the Interior West of the country.

I estimate the shares of labor and capital in value added and the share of value added in gross production from the 2007 input-output tables of the Bureau of Economic Analysis. In particular, I calculate the share of labor in value added as the share of employee compensation in value added net of taxes. The share of capital in value added is then given by the share of gross operating surplus in value added net of taxes which is just the residual. Aggregating over all manufacturing industries, I find $\theta^L = 0.57$ and $\theta^K = 0.43$.

When calculating the share of value added in gross production, I have to recognize that my model does not directly map into published input-output tables for two reasons. First, I do not have any investment in my model while the published input-output tables distinguish between purchases which are depreciated immediately and purchases which are capitalized on the balance sheet. Second, I only have manufacturing industries in my model while the published input-output tables encompass the entire economy.

I deal with the first issue by scaling all rows in the main body of the use table by one plus the ratio of private fixed investment to total intermediates. By doing so, I effectively treat all purchases firms make as intermediate consumption which matters mostly for durable goods industries such as machinery. Otherwise, I would essentially assume that firms do not value cheap access to machinery only because they do not classify them as intermediate consumption but instead capitalize them on their balance sheets. I deal with the second issue by simply cropping the input-output table to include only manufacturing industries. Using this procedure, I find $\eta = 0.58$.

I obtain the demand elasticity from Oberfield and Raval (2014). Using microdata from the 1987 U.S. Census of Manufactures, these authors back out industry-level demand elasticities from carefully constructed measures of markups using the condition that markups should equal $\varepsilon / (\varepsilon - 1)$. They report these demand elasticities in Table VII of their online appendix and I use the simple average implying $\varepsilon = 4$. As should be expected, the results turn out to be highly sensitive to the assumed value of ε so I also provide results for a range of alternative values.

The vectors of capital shares λ_i^K and interregional transfers Ω_i can be calculated directly from the model's equilibrium conditions. As mentioned earlier, firms spend a share $\eta\theta^K$ of their total revenues on capital which, taking into account subsidies, implies $rK_i = \frac{\eta\theta^K}{\rho_i} \sum_n T_{in}$. Knowing rK_i, it is then easy to calculate λ_i^K since free capital mobility implies $\frac{rK_i}{\sum_m rK_m} = \frac{K_i}{\sum_m K_m}$. Moreover, recall that net exports are given by $NX_i = \left(\lambda_i^K - \lambda_i^L\right) rK + \Omega_i$ so that $\Omega_i = \sum_n \left(T_{in} - T_{ni}\right) - \left(\lambda_i^K - \lambda_i^L\right) rK$. I will elaborate on my treatment of Ω_i in the next section. I will also explain how I calibrate σ further below.

3.2 Adjustments

Before applying the framework to calculate counterfactuals, I make two further adjustments. First, I use the model to purge the trade data from the interregional transfers Ω_i following my approach in Ossa (2014). This helps me circumvent serious interpretational issues arising from the fact that I would otherwise have to take a stance on the units in which interregional transfers are held fixed. Second, I introduce a federal subsidy on intermediate purchases which exactly offsets the markups charged by firms. This allows me to focus on the beggar-thy-neighbor aspects of state subsidies by eliminating distortions in relative prices which state subsidies would otherwise also affect.

A common practice in the quantitative trade literature is to hold interregional transfers fixed in all counterfactuals. However, this then requires a decision in what units they are to be measured which often appears to be made unconsciously by simply choosing a numeraire. To see this, notice that equation (7) implies that consumers' real income includes a term Ω_i/P_i so that it makes a difference whether Ω_i is held fixed in terms of, say, P_i or P_j. Unfortunately, this choice of units can seriously affect the quantitative results given the large trade imbalances typically found in interregional and international trade datasets so that it seems reasonable to adopt an alternative approach.

Here, I follow my approach in Ossa (2014) and first use the model to purge the trade data from the interregional transfers and then work with the purged data subsequently. Notice that this could be done by setting $\Omega_i' = 0$ and $s_i' = s_i$ in equations (17) - (25) and then calculating the implied trade flows using $\hat{T}_{ij} = \hat{M}_i \left(\hat{p}_i\right)^{1-\varepsilon} \left(\hat{P}_j\right)^{\varepsilon-1} \hat{E}_j$. However, I use a slightly modified version of the model in an attempt to minimize the difference between the purged data and the original data. In particular, I treat λ_i^L as exogenous by setting $\hat{\lambda}_i^L = 1$ and dropping equation (18). This can be thought of as a short-run version of the model in which workers do not move in response to real income shocks.

The result of this calculation is summarized in Figure 3. The horizontal axis measures the ratio of exports to imports in the original data while the vertical axis measures the same ratio in the purged data. Recall that the terms exports and imports refer to interstate shipments and not international shipments throughout the entire paper. As can be seen, there are large trade imbalances in the original data which are much reduced after setting $\Omega_i' = 0$. Recall that there are trade imbalances even without interregional transfers in the model to the extent that $\lambda_i^L \neq \lambda_i^K$ which is why trade imbalances are not entirely eliminated upon setting $\Omega_i' = 0$ here.

Figures 4-7 provide additional details on the adjustments resulting from setting $\Omega_i' = 0$. In particular, Figure 4 shows that there are no major changes in the general pattern of interstate trade flows. Similarly, Figure 5 shows that the pattern of own trade shares remains broadly unchanged.[7] Figure 6 shows that adjustments in regional wages play an important role in

[7] A region's own trade share is defined as the share of purchases this region makes from itself and will play

the sense that wages fall sharply in states that experience large increases in their net exports due to large original trade deficits. Notice that changes in wages are equivalent to changes in regional capital stocks in this version of the model given equation (20) and the restriction that $\hat{\lambda}_i^L = 1$. This then also shows up in changes in regional capital labor ratios, as illustrated in Figure 7.[8]

I introduce a federal subsidy on intermediate consumption in order to counteract a relative price distortion faced by firms. This distortion can be seen immediately from the pricing equation (13). Since factor markets are perfectly competitive but goods markets are monopolistically competitive, firms face competitive factor prices but purchase intermediate goods at a markup $\varepsilon / (\varepsilon - 1)$. As a result, the relative prices P_i / w_i and P_i / r are higher than in the competitive benchmark so that the laissez-faire equilibrium is inefficient. Notice that this issue does not arise with respect to final consumption because relative prices are undistorted from the final consumers' perspective. This is because all firms charge the same markup $\varepsilon / (\varepsilon - 1)$ so that the relative price between any two varieties is exactly the same as it would be in a perfectly competitive setting.

If left uncorrected, this distortion implies that state subsidies not only induce firm relocations but also have an efficiency enhancing effect. This is because they lower p_i relative to w_i and r and therefore also P_i relative to w_i and r, as can be seen from equations (13) and (16). While this is not necessarily a problem, I feel that it distracts from the main argument of the paper, namely that states impose subsidies in an attempt to gain at one another's expense. I therefore introduce a federal subsidy on intermediate consumption $s^I = 1/\varepsilon$ which lowers the intermediate goods prices faced by firms by a factor $\rho^I = 1 - s^I = (\varepsilon - 1) / \varepsilon$ and

an important role later on.

[8] Caliendo et al (2014) have recently suggested an alternative way of dealing with aggregate trade imbalances. In particular, they do not assume that each worker owns an equal share of the nation's capital stock but instead make workers' asset holdings dependent on their state of residence. For example, workers in Florida are assumed to own a larger share of the nation's assets which then allows them to finance their state's trade deficit. The authors show that one can calibrate state-specific ownership shares in that manner to largely explain the observed trade deficits. I believe that this approach is not well suited for my particular application for two main reasons. First, a large share of the trade deficits in my sample are likely to be explained by differences in sectoral composition rather than life cycle considerations. For example, the likely reason why Indiana's manufacturing net exports are so much larger than Montana's is that manufacturing plays a much more important role in Indiana's economy than in Montana's thus leading to mirroring trade imbalances in other sectors such as service. Second, making capital ownership shares state-dependent introduces the awkward feature that workers' asset holdings change whenever they switch locations and I am concerned that this might distort my policy analysis. For example, workers would then benefit from moving to Florida simply because this would give them a larger ownership share in the nation's assets.

thereby exactly undoes the markup distortion. I assume that this subsidy is again financed in a lump-sum fashion with each worker paying exactly the same so that federal taxes do not distort workers' location decisions in any way.

This modification affects the equilibrium conditions (7) - (16) and (17) - (25) in a number of ways. Most immediately, the budget constraint (7) becomes $E_i^F = w_i L_i + \lambda_i^L r K - s_i \left(w_i L_i + r K_i + \rho^I E_i^I \right) - \lambda_i^L s^I \sum_m E_m^I - \Omega_i$ and the pricing equation (13) changes to $p_i = \frac{\varepsilon}{\varepsilon - 1} \frac{\left((w_i)^{\theta^L} (r)^{\theta^K} \right)^{\eta} \left(\rho_i^I P_i \right)^{1-\eta} \rho_i}{\varphi_i}$.[9] I list the complete system of equations with federal subsidies in levels and changes in Appendix 2 and work with this modified system henceforth. However, I also occasionally present results setting $s^I = 0$ in the paper to clarify how the assumption of federal subsidies affects the results.

Figure 8 illustrates the main point of this discussion. In particular, it aggregates all states into one region and plots how welfare varies with state subsidies with and without federal subsidies of the kind described above. Because there is now only one region, the only substantive difference between state subsidies and federal subsidies is that state subsidies lower firms' labor, capital, and intermediate costs while federal subsidies lower firms' intermediate costs only. As can be seen, the optimal state subsidy is zero with federal subsidies but positive otherwise. This illustrates that there is indeed an inefficiency in the laissez-faire equilibrium which the federal subsidy corrects.[10]

3.3 Multiplicity

This model generally has multiple equilibria as is usually the case for New Economic Geography models. Intuitively, economic activity can agglomerate in either of multiple regions if dispersion forces are sufficiently weak. This is illustrated in Figure 9 for which I have aggregated U.S. states into two regions, East and West, with the Mississippi being the dividing line. The vertical axis depicts worker heterogeneity as measured by σ which parameterizes the model's key dispersion force. The horizontal axis depicts the share of workers working in the East as computed from $\lambda_i^{L\prime} = \lambda_i^L \hat{\lambda}_i^L$ after solving the system of equilibrium conditions in changes leaving all model parameters unchanged.

[9] As can be seen from the modified budget constraint, I assume that the state subsidies are applied to the after-federal-subsidy expenditure on intermediate consumption.

[10] This figure is drawn under the assumption of $\sigma = 1.5$ which I will justify below.

As can be seen, the model indeed has multiple equilibria for sufficiently low values of σ. The vertical line at $\lambda_i^L = 0.62$ simply represents the factual situation which is always an equilibrium by construction. However, the equilibrium conditions have two additional solutions for sufficiently low values of σ, one representing an agglomeration in the East and the other representing an agglomeration in the West. Notice how the agglomerations get more extreme the weaker is the dispersion force in the model. While the alternative equilibria are close to the factual one for $\sigma = 0.8$, more than 90 percent of the manufacturing labor force agglomerates in East or West for $\sigma = 0.5$.

Figure 10 turns to the stability of these equilibria by plotting the share of workers located in East against workers' incentives to move East for $\sigma = 0.5$ and $\sigma = 1.5$. Workers incentives to move East are captured by the adjusted welfare gap $\frac{\hat{U}_i}{\left(\hat{\lambda}_i^L\right)^\sigma} - \frac{1}{2}\left(\frac{\hat{U}_i}{\left(\hat{\lambda}_i^L\right)^\sigma} + \frac{\hat{U}_j}{\left(\hat{\lambda}_j^L\right)^\sigma}\right)$ for $i = East$ and $j = West$ which is positive whenever workers would be better off from moving East. This follows straightforwardly from equation (18) and is again calculated using a version of the model which treats λ_i^L as exogenous. As can be seen, the factual equilibrium is only stable if it is also unique which is consistent with the theoretical literature. Of course, stability is a loose concept in a static model and should be interpreted cautiously.

While the threshold level of σ ensuring uniqueness and stability is easy to determine in the above East and West example, it is much harder to identify in the full model with 48 states. This is because it is then no longer feasible to simply compute the set of all possible equilibria due to the high dimensionality involved. To identify the threshold level of σ in the full model, I therefore resort to a more heuristic approach. In particular, I use a large number of random guesses to see for which σ the algorithm converges to other equilibria. Also, I explore a large number of perturbations to the factual equilibrium to see for which σ it becomes unstable. Overall, I am unable to find multiple equilibria for $\sigma \geq 1.5$ so that I treat $\sigma = 1.5$ as the threshold level in the full model.

I rule out multiple equilibria in all of the following by focusing on values of σ exceeding this threshold. In particular, I work with $\sigma = 1.5$ as my default but also always provide extensive sensitivity checks throughout the analysis. While I impose this restriction mainly to minimize complexity, it also helps me avoid a number of unrealistic features which the model would otherwise have. Specifically, the factual equilibrium would become unstable and alternative equilibria would involve extreme agglomerations similar to what I illustrated in Figures 9 and 10. Of course, ruling out multiple equilibria precludes me from capturing any "big push" ambitions regional governments might have. However, most business incentives are arguably offered to achieve more modest objectives such as creating local jobs or generating local spillovers effects.[11]

4 Analysis

4.1 Welfare effects of subsidies

Figure 11 summarizes what happens if Illinois unilaterally deviates from its factual subsidy indicated by the vertical line. The top panel depicts Illinois' welfare change as well as the average of the welfare changes of all other states. The center panel shows the change in the number of firms in Illinois as well as the average of the changes in the number of firms in all other states. The bottom panel summarizes the effects on the shares of labor and capital employed in Illinois. As can be seen, Illinois gains from a subsidy increase at the expense of other states. Also, this welfare gain comes along with firms, labor, and capital relocating to Illinois.

These welfare changes are driven by a combination of home market and terms-of-trade effects. Essentially, Illinois gains by attracting firms from other states because this reduces Illinois' price index and increases Illinois' wage relative to other states. This can be best explained with reference to a decomposition emerging from the theory. In particular, I show in the Appendix 3 that around $s_i = s_i^I = \Omega_i = NX_i = 0$ the welfare effects of subsidy changes are given by:

$$\frac{dU_j}{U_j} = \underbrace{\frac{1}{\eta}\frac{1}{\varepsilon - 1}\sum_{i=1}^{R}\frac{T_{ij}}{E_j}\frac{dM_i}{M_i}}_{\text{home market effect}} + \underbrace{\frac{1}{\eta}\sum_{i=1}^{R}\frac{T_{ij}}{E_j}\left(\frac{dp_j}{p_j} - \frac{dp_i}{p_i}\right)}_{\text{terms-of-trade effect}} \quad (26)$$

The first term captures a home market effect. In particular, Illinois' subsidy induces some

[11] My benchmark value of $\sigma = 1.5$ is a bit higher than what is usually found in the literature. For example, Serrato and Zidar (2014) find $\sigma = 0.72$ using instrumental variable techniques in a model which also features worker heterogeneity. However, they also have housing in their model so that worker heterogeneity is not their only dispersion force. Naturally, if I added housing to my model, I would also no longer need to assume $\sigma \geq 1.5$ in order to rule out multiple equilibria because there would then be another dispersion force. In any case, one can think of σ as being related to the time horizon envisioned for the counterfactual, with low σ and high σ capturing short-run and long-run.

firms to relocate to Illinois from other states. This has two conflicting effects on Illinois' price index since Illinois' consumers now have access to more domestic varieties but fewer foreign varieties. However, Illinois' consumers gain more from the increase in the number of domestic varieties than they lose from the decrease in the number of foreign varieties since they spend more on domestic varieties because of trade costs.

The second term captures a terms-of-trade effect. In particular, the relocation of firms to Illinois increases labor demand in Illinois relative to other states so that Illinois' wage level increases relative to other states. Given that wage changes directly translate into price changes in this constant markup environment, this then increases the prices of goods made in Illinois relative to the goods made in other states which amounts to an improvement in Illinois' terms-of-trade.

While this relative wage effect is the dominant effect on Illinois' terms-of-trade, two additional effects need to be taken into account. In particular, there is an adverse direct subsidy effect which arises because Illinois' subsidies directly reduce the price of goods made in Illinois. Also, there is an adverse input cost effect which arises because production relocations to Illinois reduce the price index of intermediate goods in Illinois. Defining $\frac{dToT_j}{ToT_j} = \frac{1}{\eta}\sum_i \frac{T_{ij}}{E_j}\left(\frac{dp_j}{p_j} - \frac{dp_i}{p_i}\right)$, I show in Appendix 3 that:

$$\frac{dToT_j}{ToT_j} = \underbrace{\theta^L \sum_{i=1}^{R} \frac{T_{ij}}{E_j}\left(\frac{dw_j}{w_j} - \frac{dw_i}{w_i}\right)}_{\text{relative wage effect}} + \underbrace{\frac{1}{\eta}\sum_{i=1}^{R} \frac{T_{ij}}{E_j}\left(\frac{d\rho_j}{\rho_j} - \frac{d\rho_i}{\rho_i}\right)}_{\text{direct subsidy effect}} + \underbrace{\frac{1-\eta}{\eta}\sum_{i=1}^{R} \frac{T_{ij}}{E_j}\left(\frac{dP_j}{P_j} - \frac{dP_i}{P_i}\right)}_{\text{intermediate cost effect}} \tag{27}$$

As an illustration, I have calculated and decomposed the effects of a 5 percent subsidy imposed by Illinois using the equilibrium conditions as well as equations (26) and (27). Illinois' welfare goes up by 4.7 percent of which 3.1 percent are due to home market effects and 1.6 percent are due to terms-of-trade effects. Moreover, the terms-of-trade effects are brought about by positive relative wage effects (6.8 percent), negative direct subsidy effects (-4.6 percent), and negative intermediate cost effects (-0.6 percent), as claimed above.[12]

[12] I have scaled the home market and terms-of-trade effects from decomposition (26) so that they sum to the welfare effects computed using the system of equilibrium conditions. This is necessary because equation (26) is just a linear approximation for discrete subsidy changes which ignores second-order distortions to expenditure shares.

4.2 Optimal subsidies

I now compute the optimal unilateral subsidies of all 48 states, assuming each time that all other states do not deviate from their factual subsidies. The goal is to understand states' incentives for unilateral policy intervention which also underlie the best response equilibrium analyzed later on. As I explain in detail in Appendix 4, I compute optimal subsidies using the Su and Judd (2012) method of mathematical programming with equilibrium constraints and supply all Jacobians analytically. This ensures fast convergence despite the high dimensionality of the analysis.

Figure 12 summarizes the optimal subsidies of all 48 states. As can be seen, they range from 6.6 percent for Montana to 16.5 percent for Oregon and are strongly related to states' own trade shares. The ten largest manufacturing producers of the U.S. are shown in red. As can be seen, they account for most of the outliers from the optimal subsidy-own trade share relationship. The average optimal subsidy is 13.0 percent and the average own trade share is 36.6 percent. Recall that the own trade share is simply the share of purchases a state makes from itself so that it is an inverse measure of trade openness.

The tight optimal subsidy-own trade share relationship can be explained with reference to the home market effect which is the dominant effect throughout the analysis. In particular, recall that consumers gain more from the larger number of domestic firms than they lose from the smaller number of foreign firms because they spend more on domestic varieties than on foreign varieties. The own trade share essentially quantifies how much more they spend on domestic varieties than on foreign varieties and therefore determines how much they gain from attracting firms.[13]

While trade costs are the main reason why consumers spend more on domestic varieties than on foreign varieties, variation in trade costs is not the only source of variation in own trade shares. In particular, larger states also tend to purchase more from themselves because they offer more varieties. Moreover, more productive states also tend to purchase more from themselves because they offer cheaper varieties. This is illustrated further in Figures 13 and

[13] The average own trade share is 36.6 percent while the average import share is 1.4 percent. Recall that all states import from all other states so that the own trade share does not have to be larger than 50 percent for states to spend more on domestic goods than on foreign goods.

14 which plot own trade shares against manufacturing employment shares and measures of manufacturing productivity, respectively.[14]

The reason why the ten largest states impose lower subsidies than their own trade shares suggest is that there are decreasing returns to the variety benefits production relocations bring about. This is immediately obvious in the special case $\tau_{ij} \to \infty$ for all $i \neq j$ because then $\hat{P}_j = \left(\hat{M}_j\right)^{\frac{1}{1-\varepsilon}} \hat{p}_j$ from equation (25). Intuitively, Illinois gains less from attracting additional firms than Arkansas even though they have almost identical own trade shares simply because Illinois' consumers already enjoy more domestic varieties than Arkansas'.

Figures 15 and 16 turn to the welfare effects associated with the optimal subsidies from Figure 12. The difference is that Figure 15 depicts the welfare effects of going from factual subsidies to optimal subsidies while Figure 16 shows the welfare effects of going from zero subsidies to optimal subsidies. As can be seen, states with higher optimal subsidies also reap larger welfare gains, with the welfare gains averaging 12.9 percent in Figure 15 and 13.9 percent in Figure 16. Naturally, the relationship between optimal subsidies and welfare changes is less tight in Figure 15 than in Figure 16 because states start from different baselines in Figure 15.[15]

Table 1 elaborates on the welfare effects from Figure 15. In particular, it lists the welfare effects on the subsidy imposing states ("own") and the average welfare effects on all other states ("other") and decomposes both into home market and terms-of-trade effects along the lines of equation (26).[16] As can be seen, states indeed gain at the expense of other states with the average welfare gains of subsidy imposing states being 12.9 percent and the average welfare loss of other states being -0.77 percent. Home market effects account for close to two-thirds of these welfare effects.

[14] The manufacturing productivity index used in Figure 14 is simply the share of the nation's output contributed by a particular state, $\sum_n T_{in} / \sum_m \sum_n T_{mn}$, relative to the share of the nation's workers working in that state, λ_i^L.

[15] To be clear, these welfare changes refer to changes in the common component of local utility or equivalently to changes in local per-capita real income. When interpreting them it is important to keep in mind that the model has been calibrated to manufacturing only. Without additional data, it is not entirely clear how to best extrapolate from them to the entire economy. The simplest way would be to assume that there is a passive rest of the economy so that the overall welfare change could be approximated by simply multiplying the calculated welfare changes by the local manufacturing shares. However, there might also be scope for welfare enhancing subsidy policy in non-manufacturing sectors in which case this approximation would understate the overall effects.

[16] I have again scaled the production relocation and terms-of-trade effects so that they sum to the welfare effects, just as explained in footnote 12 above.

Table 2 replicates Table 1 with the only difference that governments are now assumed to maximize local employment instead of local welfare. As can be seen, the results are virtually identical in all respects so that one can effectively think of both objective functions interchangeably.[17] Formally, this follows from equation (8) which implies that $d \ln \lambda_i^L \approx (1/\sigma)\, d \ln U_i$ for large R so that maximizing U_i is very similar to maximizing λ_i^L. I find this feature of the model very appealing because it squares well with the central role jobs play in real-world policy debates.

Figure 17 illustrates the geographic propagation of the welfare effects of optimal subsides returning again to the example of Illinois. In particular, it presents a heat map representing the welfare effects of Illinois' optimal subsidy on other states with negative effects shown in blue and positive effects shown in red. As can be seen, the welfare effects vary strongly with distance from Illinois with nearby states gaining and far away states losing. This simply reflects the fact that close states trade more with Illinois allowing them to reap more of the benefits from Illinois' increased product variety.

Figure 18 illustrates the associated migration patterns in a very similar way. In particular, it illustrates the percentage changes in local employment as a heat map with worker inflows shown in red and worker outflows shown in blue. As can be seen, the geographic pattern of employment changes closely mirrors the geographic pattern of welfare changes, as should be expected from the close relationship between employment and welfare discussed above. Figure 19 does exactly the same with respect to capital flows whose response to Illinois' optimal subsidy is similar but more extreme.

Tables 3a and 3b explore the sensitivity of the results to alternative values of the elasticity of substitution, ε, and the shape parameter of the Gumbel distribution of idiosyncratic preference draws, σ. Recall that the baseline ε was chosen to match markups found in the microdata while the baseline σ was chosen to ensure uniqueness given this ε. Since a lower ε implies stronger agglomeration forces and a lower σ implies weaker dispersion forces, Tables 3a and 3b focus on values larger than the baseline values to preserve uniqueness throughout. Recall that the baseline values are $\varepsilon = 4$ and $\sigma = 1.5$.

[17] This can also be seen by comparing the top and bottom panels of Figure 11 which show that Illinois' welfare is closely related to Illinois' employment share.

As one would expect, the optimal subsidies as well as all associated welfare effects and factor flows are strongly decreasing in ε. This is simply because ε parameterizes the marginal benefits of expanding local economic activity, as is particularly clear from the Armington analogy discussed above. While changes in σ barely have any effect on the optimal subsidy, the associated welfare effects and factor flows are strongly decreasing in σ for values close to the baseline $\sigma = 1.5$. However, this is no longer the case once σ becomes sufficiently large in which case further increasing σ hardly matters at all.[18]

4.3 Nash subsidies

I now turn to the best-response equilibrium in which all states retaliate optimally. This is meant to capture fully noncooperative policy making which I will also refer to as a subsidy war. It can be found by iterating over the algorithm used to compute optimal subsidies until all states impose welfare-maximizing subsidies given all other states welfare-maximizing subsidies, as I explain in detail in Appendix 4. To avoid confusion, I call the resulting best-response subsidies Nash subsidies and continue referring to the welfare-maximizing subsidies without retaliation as optimal subsidies throughout.

Figure 20 plots the Nash subsidies against states' own trade shares marking the ten largest manufacturing producers in red. Just like optimal subsidies, Nash subsidies are again strongly increasing in the states' own trade shares with the ten largest states imposing somewhat lower subsidies than the trend suggests. Figure 21 plots the Nash subsidies against optimal subsidies with a 45 degree line added as a reference. As can be seen, Nash subsidies are slightly lower than optimal subsidies with California being the only exception to this rule. Nash subsidies average 11.8 percent whereas optimal subsidies average 13.0 percent.

Optimal subsidies tend to be higher than Nash subsidies because states' own trade shares respond more to optimal subsidies than to Nash subsidies. In particular, states attract more firms if other states do not retaliate so that they are then also induced to spend more on

[18] I consider $\varepsilon \leq 6.5$ in Table 3a to correspond as closely as possible to the range of trade elasticities estimated by Simonovska and Waugh (2014) which represents the state of the art in the trade literature. I focus on $\sigma \leq 9.0$ in Table 3b simply because the results do not vary much after that. For example, the optimal subsidy would be 12.3 percent, the own welfare change would be 6.5 percent, and the average of the other states' welfare changes would be -0.4 percent, for $\sigma = 20$. Notice that the abovementioned approximation $d\ln\lambda_i^L \approx (1/\sigma)\, d\ln U_i$ works very well in both tables, keeping in mind that $\sigma = 1.5$ is assumed for all rows in Table 3a.

domestic goods. This increased own trade share, in turn, magnifies states' incentives to impose further subsidies which explains why optimal subsidies tend to be higher than Nash subsidies. Recall that states gain more from firm relocations if their own trade shares are high because they then benefit more from the increase in domestic variety and lose less from the decrease in foreign variety.

Figure 22 illustrates the welfare effects associated with these Nash subsidies. As can be seen, labor-abundant states tend to gain while capital-abundant states tend to lose from a subsidy war. The reason is that states with higher capital-labor ratios have higher per-capita taxes which makes them less attractive places for workers to live.[19] In particular, states are forced to increase their taxes in order to finance their subsidies which are largely ineffective in a subsidy war. Moreover, the per-capita tax burden is higher in capital-abundant states than in labor-abundant states because subsidies are financed by workers but cover labor and capital costs.[20]

Figure 23 illustrates that Western states tend to gain and Eastern states tend to lose from a subsidy war. As should be clear from the above discussion, this mainly reflects the fact that Western states tend to be labor-abundant and Eastern states tend to be capital-abundant as far as manufacturing production is concerned. Given the close relationship between local welfare and local employment, this geographic pattern also shows up with respect to labor and capital flows. This can be seen in Figures 24 and 25 which show that labor and capital would tend to move westwards if a subsidy war broke out.

Table 4 elaborates on the welfare effects from Figures 22. As can be seen, the subsidy war harms states on average with the mean welfare loss being 2.3 percent. This is because governments distort incentives when imposing subsidies in an attempt to attract firms. Most importantly, the subsidies make intermediate goods too cheap relative to other factors of production which results in there being too many firms. In particular, the subsidies cause P_i to fall relative to w_i and r which then increases M_i, as follows from equation (15). Here, M_i increases by 10.9 percent on average as a result of the subsidy war.[21]

[19] State-level capital-labor ratios are simply computed from λ_i^K/λ_i^L.

[20] Of course, the strong relationship between per-capita subsidy expenditures and capital-labor ratios is a consequence of my assumption that regional governments cover a percentage of all production costs. The more general point is that states with high per-capita subsidy expenditures tend to lose from subsidy wars.

[21] The finding that states lose from a subsidy war on average is actually not as obvious as it might seem.

Tables 5a and 5b explore the sensitivity of the results to alternative values of the elasticity of substitution, ε, and the shape parameter of the Gumbel distribution of idiosyncratic preference draws, σ. Just like optimal subsidies, the Nash subsidies and their associated welfare effects are strongly decreasing in ε. Moreover, the Nash subsidies and their associated welfare effects are now very robust to changes in σ. Recall that σ parameterizes how reluctant workers are to move across states. This is now less relevant because workers have less incentives to move anyway since all states try to attract firms at the same time.

4.4 Cooperative subsidies

I now consider cooperative subsidy policy leaving behind the best-response logic from the subsidy war. The goal is to understand what subsidies are Pareto efficient from the perspective of state governments and how much there is to gain relative to Nash subsidies and factual subsidies. I assume that governments follow a bargaining process resembling symmetric Nash bargaining. In particular, they choose subsidies s_i and transfers Ω_i to maximize $\hat{U}_1$ subject to the constraints that $\hat{U}_1 = \hat{U}_i$ for all i and $\sum_i \Omega_i = 0$ relative to a benchmark such as Nash subsidies or factual subsidies. This ensures that all governments gain the same relative to the chosen benchmark and end up on the efficiency frontier.

Using an algorithm which I discuss in detail in Appendix 4, I find that the cooperative subsidies are always zero while the cooperative transfers vary with the particular benchmark governments negotiate from. Essentially, the cooperative subsidies eliminate all distortions while the cooperative transfers ensure that all governments gain the same as required by the bargaining protocol. The result that cooperative subsidies are zero depends critically on the assumption that the federal government subsidizes intermediate goods consumption at a rate $1/\varepsilon$ to correct a markup distortion faced by firms. Otherwise, cooperative subsidies would be equal to $1/\varepsilon$ and neutralize the markup distortion that way.[22]

Here, it depends crucially on the assumption that the federal government subsidizes intermediate consumption in order to counteract a relative price distortion faced by firms. Without federal subsidies, welfare would actually increase by 7.5 percent in the Nash equilibrium on average because state subsidies would then correct this relative price distortion to some extent. This will become clearer in the next section which explains the efficiency enhancing role state subsidies might play. The results would again by very similar if governments were assumed to maximize λ_i^L instead of U_i.

[22] Recall that P_i is too high relative to w_i and r in the laissez-faire equilibrium because firms charge a markup $\frac{\varepsilon}{\varepsilon-1}$ over marginal costs. The federal subsidy on intermediate consumption at a rate $\frac{1}{\varepsilon}$ corrects this directly by reducing the effective P_i paid by firms by a factor $\frac{\varepsilon-1}{\varepsilon}$. Alternatively, a cooperative state subsidy on total

To gain more intuition for this zero-subsidy result, notice that the Krugman (1980) New Trade model is a special case of my New Economic Geography model with only labor and no labor mobility. As is well-known from Dixit and Stiglitz (1977), the equilibrium is constrained efficient in such a model so that no Pareto gains can be achieved by offering subsidies. Allowing for labor mobility does not fundamentally change this result which can be seen most clearly by imposing $\hat{U}_1 = \hat{U}_i$ for all i as part of the bargaining protocol. This is because $\hat{U}_1 = \hat{U}_i$ for all i implies $\hat{\lambda}_i^L = 1$ for all i from equation (18) which reveals that governments can reach the efficiency frontier without inducing any worker flows.

Tables 6 and 7 report the effects of negotiating from Nash subsidies to zero subsidies and factual subsidies to zero subsidies, respectively. As can be seen, a cooperative move from Nash subsidies to zero subsidies increases welfare by 3.9 percent in each state, while a cooperative move from factual subsidies to zero subsidies increases welfare by 0.04 percent in each state. Notice that the number of firms falls by 8.8 percent on average in a cooperative move from Nash subsidies to zero subsidies and by 0.7 percent on average in a cooperative move from factual subsidies to zero subsidies. Again, this reflects the fact that subsidies encourage excessive entry, as I discussed above.

Figures 26 and 27 plot the transfer payments associated with a cooperative move from Nash subsidies to zero subsidies and factual subsidies to zero subsidies, respectively. In particular, they plot the transfer payments made by governments as a percentage of state output against the welfare changes governments would have experienced if they had moved to zero subsidies without making any transfer payments at all. As can be seen, the transfer payments are indeed used to redistribute gains from states who would gain more than average to states who would lose more than average otherwise. To be clear, a positive number implies that a government makes a payment and the other way around.

Figures 28 and 29 show the geographic pattern of capital flows following a cooperative move from Nash subsidies to zero subsidies and factual subsidies to zero subsidies, respectively. These patterns are almost perfectly correlated with the underlying subsidy patterns in the sense that states who reduce their subsidies the most also experience the largest capital outflows. This points to the fact that subsidies also distort the allocation of capital which

costs at a rate $\frac{1}{\varepsilon}$ could correct this indirectly by reducing p_i charged by firms by a factor of $\frac{\varepsilon-1}{\varepsilon}$.

is another inefficiency cooperation undoes. Recall that there is no migration at all following a cooperative move to zero subsidies since $\hat{U}_1 = \hat{U}_i$ for all i implies $\hat{\lambda}_i^L = 1$ for all i from equation (18).

Tables 8a and 8b explore the sensitivity of the results to alternative values of the elasticity of substitution, ε, and the shape parameter of the Gumbel distribution of idiosyncratic preference draws, σ. As can be seen, the gains from cooperation starting at Nash subsidies are strongly decreasing in ε while the gains from cooperation starting at factual subsidies remain virtually unchanged. This reflects the fact that the Nash subsidies are strongly decreasing in ε while the factual subsidies just are what they are. Moreover, the results are quite robust to changes in σ. This is because governments always negotiate such that there is no migration so that migration frictions obviously play less of a role.

Figure 30 compares noncooperative and cooperative subsidies to factual subsidies. The light grey lines represent noncooperative subsidies at various degrees of escalation. In particular, the top grey line shows the fully noncooperative subsidies while the bottom grey line (the x-axis) shows the fully cooperative subsidies and the intermediate grey lines show proportionately scaled versions of the fully noncooperative subsidies with the scalings decreasing in 10 percentage point steps all the way from 90 percent down to 10 percent. The factual subsidies are superimposed onto this using state labels and states are always sorted in increasing order of their noncooperative subsidies.

As can be seen, factual subsidies are much closer to cooperative subsidies than to noncooperative subsidies, with the exception of a few outliers such as Vermont. This is not surprising since one would not expect U.S. states to be in a fully escalated subsidy war. Besides perhaps engaging in tacit cooperation, U.S. states also act in the shadow of the federal government which would probably try to restrict subsidy competition if it became too extreme. For example, the federal government could adopt the argument put forth by some legal scholars that state incentive programs violate the Commerce Clause of the U.S. constitution because they discriminate against out-of-state businesses.[23]

[23] More precisely, the argument refers to the "dormant" Commerce Clause which U.S. courts have inferred from the Commerce Clause of the U.S. constitution. It holds that states are prohibited from passing legislation which interferes with interstate commerce even if Congress does not intervene. The legal debate therefore focuses on the question of whether state incentive programs interfere with interstate commerce. See Rogers (2000) for an interesting overview.

Even though factual subsidies are much lower than Nash subsidies, Figure 30 suggests that states with higher factual subsidies tend to have higher Nash subsidies, as one would expect if factual subsidies are set noncooperatively to some extent. This relationship becomes even more apparent in Figure 31 which considers (log) subsidy costs instead of subsidy rates. While these are encouraging observations, they clearly have to be taken with a large grain of salt. Most importantly, the factual subsidy costs I measure are likely to be incomplete and imprecise proxies for the business incentives state governments actually provide, as I discussed in the data section above.

5 Conclusion

What motivates regional governments to subsidize firm relocations and what are the implications of the subsidy competition among them? In this paper, I addressed these questions using a quantitative economic geography model which I calibrated to U.S. states. I showed that states have strong incentives to subsidize firm relocations in order to gain at the expense of other states. I also showed that subsidy competition creates large distortions so that there is much to gain from a cooperative approach. Overall, I found that manufacturing real income can be up to 3.9 percent higher if states stop competing over firms.

By using the "exact hat algebra" from the international trade literature, I was able to quantify my theory in a meaningful way. In my view, this is a significant advance relative to the earlier New Economic Geography literature which focused mostly on numerical examples to make its points. Having said this, my quantitative results still have to be interpreted with caution since my model includes many simplifications in the interest of transparency. For example, my formulation of subsidies is clearly unrealistic and probably understates the distortions real-world business incentives impose.

6 Appendix

6.1 Appendix 1: Isomorphism with Armington model

Introducing only the modifications described in subsection 2.4, it should be easy to verify that conditions (7) - (12) remain identical while conditions (13), (14), (15), and (16) change. In particular, the Armington analog to equation (13) is

$$p_i = \frac{\left((w_i)^{\theta^L}(r)^{\theta^K}\right)^{\eta}(P_i)^{1-\eta}\rho_i}{\varphi_i I_i^{\phi}}$$

which should be intuitive since firms no longer charge markups but productivity is now $\varphi_i I_i^{\phi}$. Also, the Armington analog to (14) is

$$\eta\theta^L \sum_{j=1}^{R}(p_i\tau_{ij})^{1-\varepsilon}(P_j)^{\varepsilon-1}\left(E_j^F + E_j^I\right) = \rho_i w_i L_i$$

which simply says that a fraction $\eta\theta^L$ of firm revenues is spent on worker compensation. The Armington analog to equation (15) is

$$I_i = \frac{L_i}{\eta\theta^L}\frac{w_i}{\left((w_i)^{\theta^L}(r)^{\theta^K}\right)^{\eta}(P_i)^{1-\eta}}$$

which should make sense since $I_i = M_i i_i$ in the original model and now M_i is exogenous and normalized to one. Finally, equation (16) remains unchanged other than that now $M_i = 1$.

Equations (13), (14), (15), and (16) from the main model can be combined into the two condensed equilibrium conditions

$$\sum_{j=1}^{R}\left(\frac{\tau_{ij}}{\tilde{\varphi}_i}\right)^{1-\varepsilon}(P_j)^{\varepsilon-1}\left(E_j^F + E_j^I\right) = (\rho_i)^{\varepsilon}\left(\left((w_i)^{\theta^L}(r)^{\theta^K}\right)^{\eta}(P_i)^{1-\eta}\right)^{\varepsilon}$$

$$P_j = \left(\sum_{i=1}^{R}\frac{L_i}{\eta\theta^L}\frac{w_i}{\left(\left((w_i)^{\theta^L}(r)^{\theta^K}\right)^{\eta}(P_i)^{1-\eta}\right)^{\varepsilon}}\left(\frac{\rho_i\tau_{ij}}{\tilde{\varphi}_i}\right)^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$$

where I have replaced the original productivity parameter with a rescaled one satisfying $\tilde{\varphi}_i = \left(\frac{\varepsilon^{\varepsilon} f_i}{(\varepsilon-1)^{(\varepsilon-1)}}\right)^{\frac{1}{1-\varepsilon}}\varphi_i$. Similarly, the abovementioned Armington analogs to equations (13), (14), (15), and (16) can be combined into the two condensed equilibrium conditions

$$\sum_{j=1}^{R}\left(\frac{\tau_{ij}}{\varphi_i}\right)^{1-\varepsilon}(P_j)^{\varepsilon-1}\left(E_j^F+E_j^I\right)=\left(\frac{w_iL_i}{\eta\theta^L}\right)^{1-\phi(\varepsilon-1)}(\rho_i)^{\varepsilon}\left(\left(\left((w_i)^{\theta^L}(r)^{\theta^K}\right)^{\eta}(P_i)^{1-\eta}\right)^{1+\phi}\right)^{\varepsilon-1}$$

$$P_j=\left(\sum_{i=1}^{R}\left(\frac{L_i}{\eta\theta^L}\right)^{\phi(\varepsilon-1)}\frac{(w_i)^{\phi(\varepsilon-1)}}{\left(\left((w_i)^{\theta^L}(r)^{\theta^K}\right)^{\eta}(P_i)^{1-\eta}\right)^{(1+\phi)(\varepsilon-1)}}\left(\frac{\rho_i\tau_{ij}}{\varphi_i}\right)^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$$

where I have left the original productivity parameter unchanged. The isomorphism can now be seen by imposing $\phi=\frac{1}{\varepsilon-1}$ on the condensed Armington conditions which reveals that both models are identical up to the scale of φ_i.

6.2 Appendix 2: Equilibrium conditions with federal subsidies

As discussed in subsection 3.2, I introduce a federal subsidy $s^I=1/\varepsilon$ on intermediate consumption to correct a markup distortion faced by firms. The resulting equilibrium conditions in levels are:

$$E_i^F=w_iL_i+\lambda_i^L rK-s_i\left(w_iL_i+rK_i+\rho^IE_i^I\right)-\lambda_i^L s^I\sum_{m=1}^{R}E_m^I-\Omega_i$$

$$\lambda_i^L=\frac{U_i^{\frac{1}{\sigma}}}{\sum_{j=1}^{R}U_j^{\frac{1}{\sigma}}}$$

$$U_i=A_i\frac{E_i^F/L_i}{P_i}$$

$$w_iL_i=\frac{\theta^L}{\theta^K}rK_i$$

$$E_i^I=\frac{1-\eta}{\rho^I\eta\theta^K}rK_i$$

$$p_i=\frac{\varepsilon}{\varepsilon-1}\frac{\left((w_i)^{\theta^L}(r)^{\theta^K}\right)^{\eta}\left(\rho_i^IP_i\right)^{1-\eta}\rho_i}{\varphi_i}$$

$$\frac{1}{\varepsilon}\sum_{j=1}^{R}(p_i\tau_{ij})^{1-\varepsilon}(P_j)^{\varepsilon-1}\left(E_j^F+E_j^I\right)=\left((w_i)^{\theta^L}(r)^{\theta^K}\right)^{\eta}\left(\rho^IP_i\right)^{1-\eta}\rho_if_i$$

$$M_i = \frac{L_i}{\varepsilon f_i \eta \theta^L} \frac{w_i}{\left((w_i)^{\theta^L} (r)^{\theta^K}\right)^{\eta} (\rho^I P_i)^{1-\eta}}$$

$$P_j = \left(\sum_{i=1}^{R} M_i (p_i \tau_{ij})^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$$

Defining $S_i^I \equiv \lambda_i^L s^I \sum_m E_m^I$, their equivalents in changes are:

$$\hat{E}_i^F = \frac{w_i L_i}{E_i^F} \hat{w}_i \hat{\lambda}_i^L + \frac{\lambda_i^L r K}{E_i^F} \hat{\lambda}_i^L - \frac{S_i}{E_i^F} s_i' \left(\frac{w_i L_i}{S_i} \hat{w}_i \hat{\lambda}_i^L + \frac{r K_i}{S_i} \hat{\lambda}_i^K + \frac{\rho^I E_i'^I}{S_i} \hat{E}_i^I\right) - \frac{S_i^I}{E_i^F} \hat{\lambda}_i^L \sum_{m=1}^{R} \lambda_m^K \hat{E}_m^I - \frac{\Omega_i'}{E_i^F}$$

$$\hat{\lambda}_i^L = \frac{\left(\hat{U}_i\right)^{\frac{1}{\sigma}}}{\sum_{j=1}^{R} \lambda_j^L \left(\hat{U}_j\right)^{\frac{1}{\sigma}}}$$

$$\hat{U}_i = \frac{\hat{E}_i^F / \hat{\lambda}_i^L}{\hat{P}_i}$$

$$\hat{w}_i \hat{\lambda}_i^L = \hat{\lambda}_i^K$$

$$\hat{E}_i^I = \hat{\lambda}_i^K$$

$$\hat{p}_i = (\hat{w}_i)^{\theta^L \eta} \left(\hat{P}_i\right)^{1-\eta} \hat{\rho}_i$$

$$\sum_{j=1}^{R} \frac{T_{ij}}{\sum_n T_{in}} \left(\hat{P}_j\right)^{\varepsilon-1} \left(\frac{E_j^F}{E_j} \hat{E}_j^F + \frac{E_j^I}{E_j} \hat{E}_j^I\right) = (\hat{p}_i)^{\varepsilon}$$

$$M_i = \frac{L_i}{\varepsilon f_i \eta \theta^L} \frac{w_i}{\left((w_i)^{\theta^L} (r)^{\theta^K}\right)^{\eta} (\rho^I P_i)^{1-\eta}}$$

$$\hat{P}_j = \left(\sum_{i=1}^{R} \frac{T_{ij}}{\sum_m T_{mj}} \hat{M}_i (\hat{p}_i)^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$$

All coefficients can again be expressed as functions of the observables T_{ij} and λ_i^L, namely $w_i L_i = \frac{\eta \theta^L}{\rho_i} \sum_n T_{in}$, $r K_i = \frac{\eta \theta^K}{\rho_i} \sum_n T_{in}$, $E_i^I = \frac{1-\eta}{\rho_i \rho^I} \sum_n T_{in}$, $rK = \sum_i \sum_n \frac{\eta \theta^K}{\rho_i} T_{in}$, $E_i^F = \sum_m T_{mi} - \frac{1-\eta}{\rho_i \rho^I} \sum_n T_{in}$, $\lambda_i^K = \frac{r K_i}{r K}$, and $\Omega_i = N X_i - \left(1 - \frac{s^I}{\rho^I} \frac{1-\eta}{\eta \theta^K}\right) \left(\lambda_i^K - \lambda_i^L\right) r K$.

6.3 Appendix 3: Decomposition of welfare effects

Differentiating equation (9) yields:

$$\frac{dU_j}{U_j}=\frac{dE_j^F}{E_j^F}-\frac{d\lambda_j^L}{\lambda_j^L}-\frac{dP_j}{P_j}$$

Equations (13) and (14) imply $\sum_j T_{ij}=M_i\left(\varepsilon-1\right)p_i\varphi_i f_i$. Since $E_j=\sum_i T_{ij}$, one can write $E_j=M_j\left(\varepsilon-1\right)p_j\varphi_j f_j-NX_j$. Around $NX_j=0$, one therefore obtains:

$$\frac{dE_j}{E_j}=\frac{dM_j}{M_j}+\frac{dp_j}{p_j}-\frac{dNX_j}{E_j}$$

Recall from the discussion preceding equation (15) in the main text that the number of firms can be expressed as $M_i=\frac{1}{\varepsilon f_i}\left(\frac{1}{\eta}\left(\frac{L_i}{\theta^L}\right)^{\theta^L}\left(\frac{K_i}{\theta^K}\right)^{\theta^K}\right)^{\eta}\left(\frac{C_i^I}{1-\eta}\right)^{1-\eta}$. Making use of equation (9), this implies:

$$\frac{dM_j}{M_j}=\eta\left(\theta^L\frac{d\lambda_j^L}{\lambda_j^L}+\theta^K\frac{d\lambda_j^K}{\lambda_j^K}\right)+\left(1-\eta\right)\left(\frac{dE_j^I}{E_j^I}-\frac{dP_j}{P_j}\right)$$

Differentiating equation (16) yields:

$$\frac{dP_j}{P_j}=\sum_{i=1}^{R}\frac{T_{ij}}{E_j}\left(\frac{dp_i}{p_i}-\frac{1}{\varepsilon-1}\frac{dM_i}{M_i}\right)$$

These four equations can be combined to:

$$\begin{aligned}\eta\frac{dU_j}{U_j} \quad &= \quad \sum_{i=1}^{R}\frac{T_{ij}}{E_j}\left(\frac{1}{\varepsilon-1}\frac{dM_i}{M_i}+\frac{dp_j}{p_j}-\frac{dp_i}{p_i}\right)\\ &\quad +\left(1-\eta\right)\frac{dE_j^I}{E_j^I}+\eta\frac{dE_j^F}{E_j^F}-\frac{dE_j}{E_j}\\ &\quad +\eta\theta^K\left(\frac{d\lambda_j^K}{\lambda_j^K}-\frac{d\lambda_j^L}{\lambda_j^L}\right)-\frac{dNX_j}{E_j}\end{aligned}$$

This equation simplifies to equation (26) in the main text because the last two terms are equal to zero around $s_i=\Omega_i=NX_i=0$. To see why the second term is zero, notice that $E_i^F/E_i=\eta$ and $E_i^I/E_i=1-\eta$ if $s_i=\Omega_i=NX_i=0$ since then $E_i^F=\frac{rK_i}{\theta^K}$, $E_i^I=\frac{1-\eta}{\eta}\frac{rK_i}{\theta^K}$, and $E_i=\frac{rK_i}{\eta\theta^K}$ as follows from combining equations (7), (11), and (12) and the relationship

$NX_i = \left(\lambda_i^K - \lambda_i^L\right) rK + \Omega_i$ discussed in the main text. To see why the third term is zero, make use of some of the same relationships, namely $NX_i = \left(\lambda_i^K - \lambda_i^L\right) rK + \Omega_i$ and $E_i = \frac{rK_i}{\eta\theta^K}$.

Given the definition $\frac{dToT_j}{ToT_j} = \frac{1}{\eta} \sum_i \frac{T_{ij}}{E_j} \left(\frac{dp_j}{p_j} - \frac{dp_i}{p_i}\right)$, equation (27) follows straightforwardly from differentiating equation (13) which yields:

$$\frac{dp_j}{p_j} = \eta\theta^L \frac{dw_j}{w_j} + \frac{d\rho_j}{\rho_j} + (1-\eta)\frac{dP_j}{P_j}$$

6.4 Appendix 4: Algorithm

I compute optimal subsidies by maximizing the government's objective function (19) subject to the equilibrium conditions in Appendix 2 corresponding to equations (17), (18), (20), (21), (22), (23), (24), and (25) in the main text using the algorithm suggested by Su and Judd (2012) which builds on the idea of mathematical programming with equilibrium constraints. To accelerate convergence, I provide analytic derivatives of the objective functions and the equilibrium constraints which I do not reproduce here in the interest of brevity.

I compute Nash subsidies following the same method I applied in Ossa (2014). Starting at factual subsidies, I compute each state's optimal subsidies, then impose these optimal subsidies, and let all states reoptimize given all other states' optimal subsidies, and so on, until the solution converges in the sense that no state has an incentive to deviate from its subsidies. I have experimented with many different starting values without finding any differences in the results which makes me believe that the identified Nash equilibrium is unique. This is, however, subject to the restriction that $\lambda_i^L > 0$ for all i which I impose throughout my analysis. As can be seen from equations (8) and (9), the model would also be consistent with corner solutions since $\lambda_i^L = 0$ implies $U_i = 0$ and vice versa.

I compute cooperative subsidies and transfers by maximizing $\hat{U}_1$ subject to the condition that $\hat{U}_1 = \hat{U}_i$ for all i and all abovementioned equilibrium constraints again using the algorithm proposed by Su and Judd (2012). When I calculate the outcome of cooperation starting at Nash subsidies, I first simulate the Nash equilibrium and then impose the corresponding Nash equilibrium values wherever observables are required in the equilibrium constraints. To accelerate convergence, I again provide analytic derivatives of the objective functions and the equilibrium constraints which I do not reproduce here in the interest of brevity.

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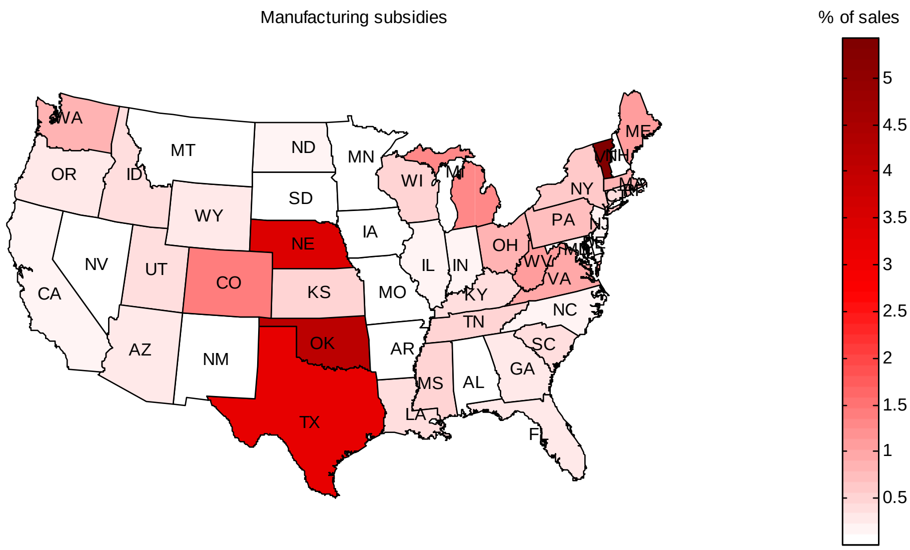

Figure 1: Geographic variation of subsidy rates

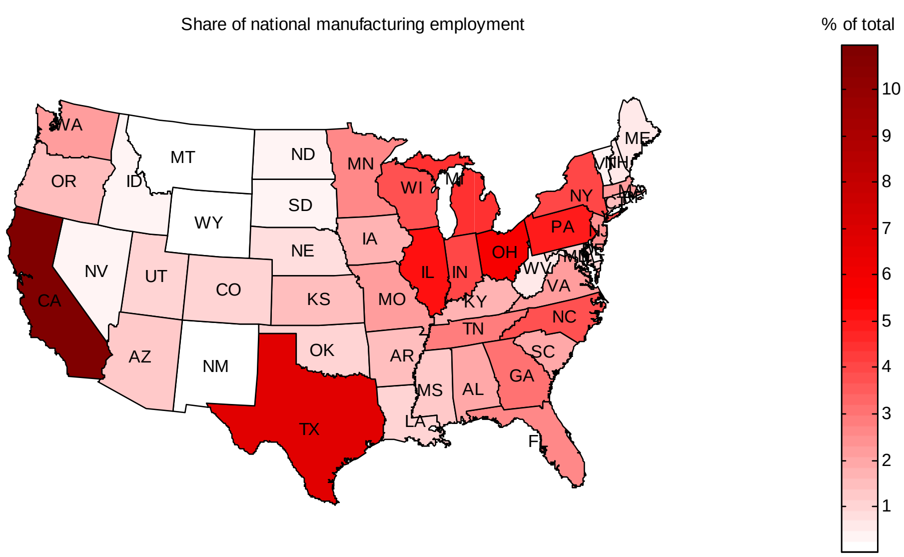

Figure 2: Geographic variation of manufacturing employment

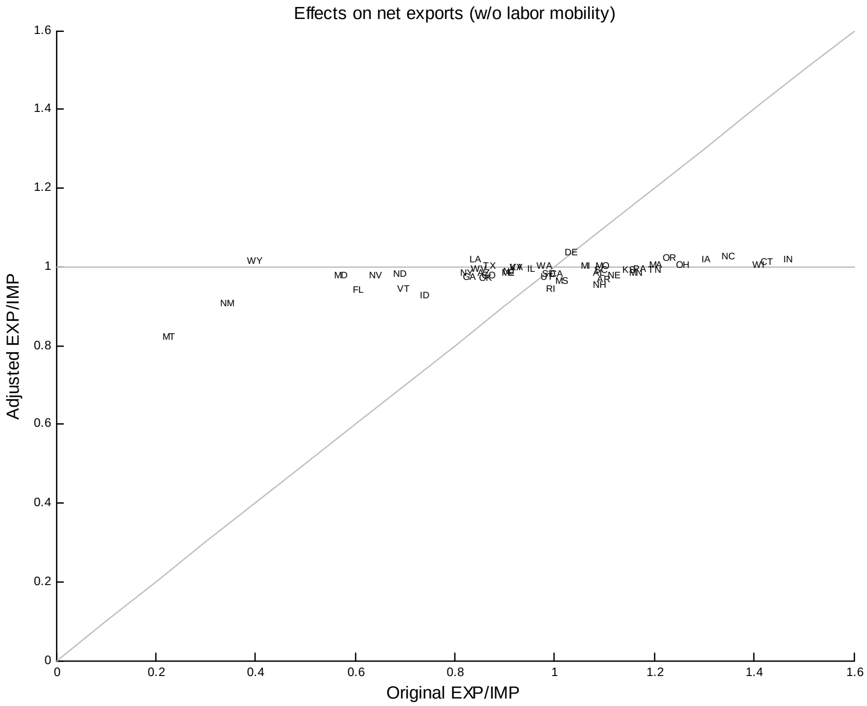

Figure 3: Change in net exports resulting from setting $\Omega_i = 0$

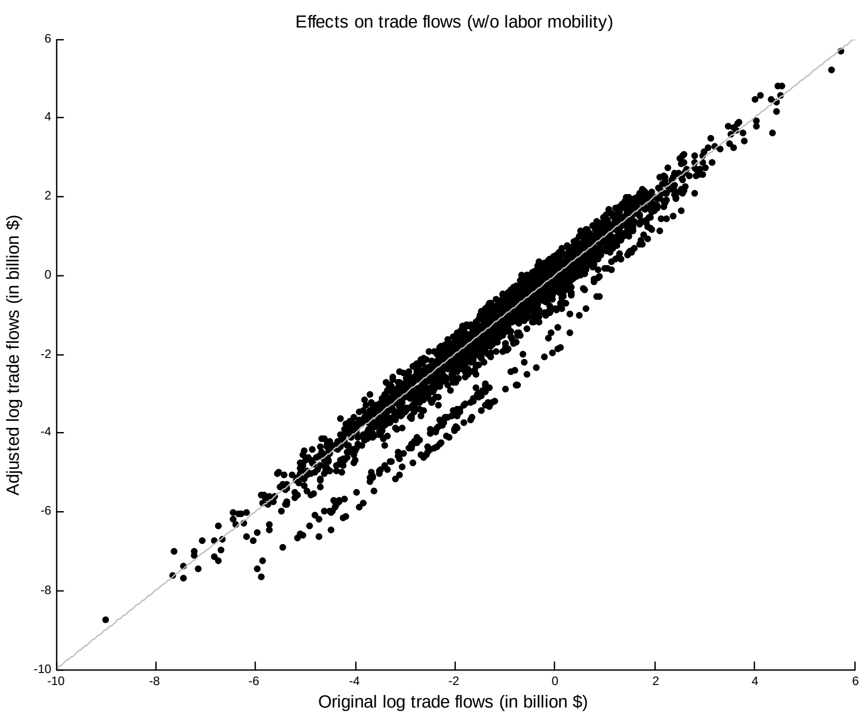

Figure 4: Change in trade flows resulting from setting $\Omega_i = 0$

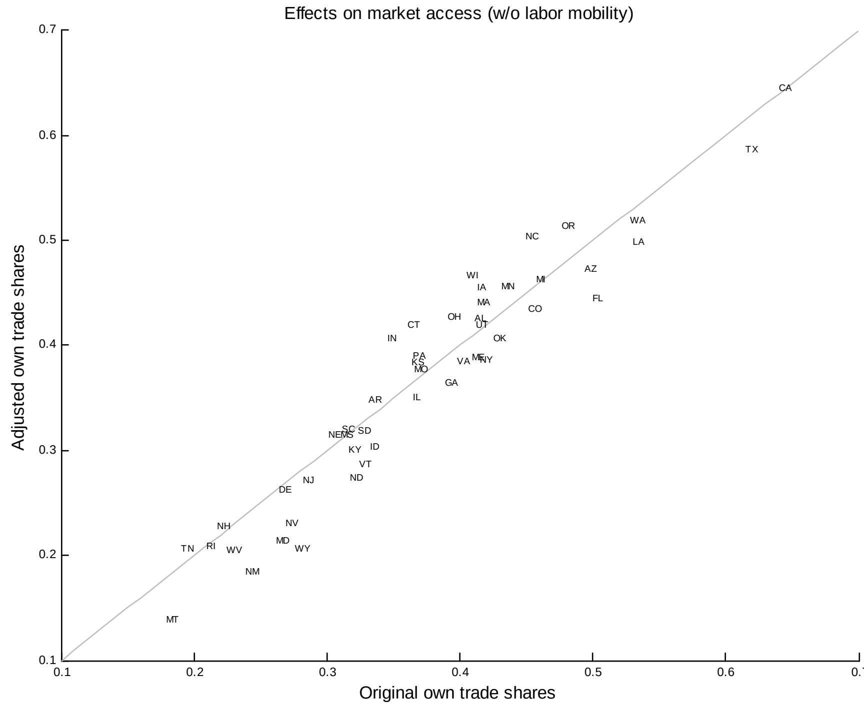

Figure 5: Change in own trade shares resulting from setting $\Omega_i = 0$

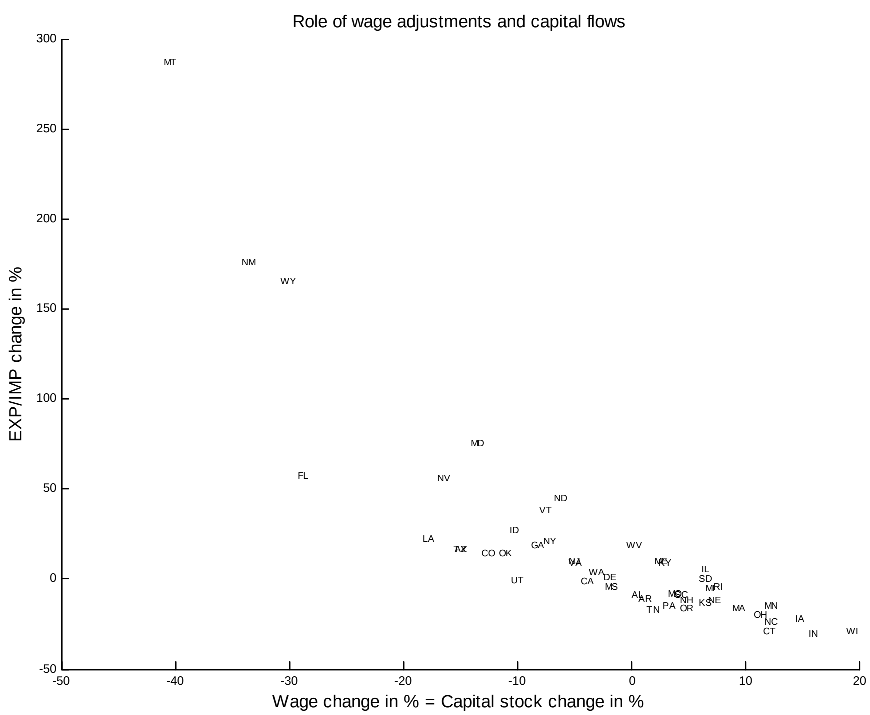

Figure 6: Change in wages and capital stocks resulting from setting $\Omega_i = 0$

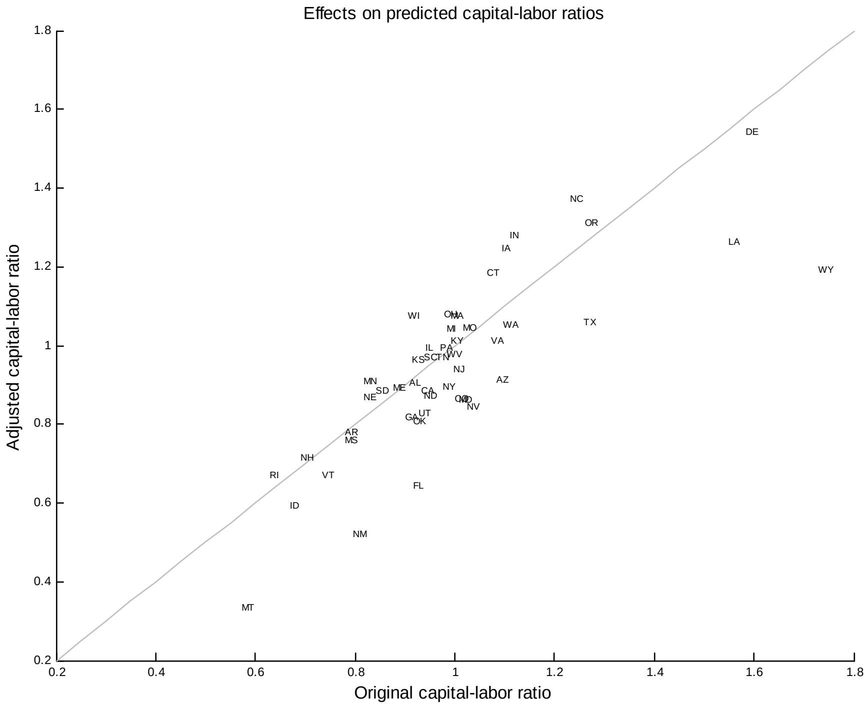

Figure 7: Change in capital-labor ratios from setting $\Omega_i = 0$

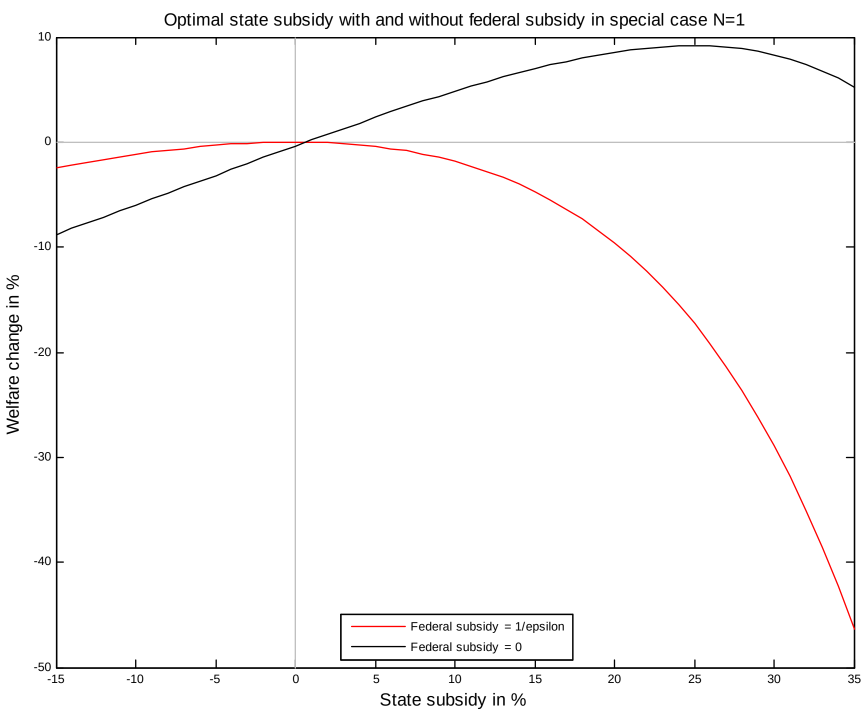

Figure 8: Illustration of role played by federal subsidy

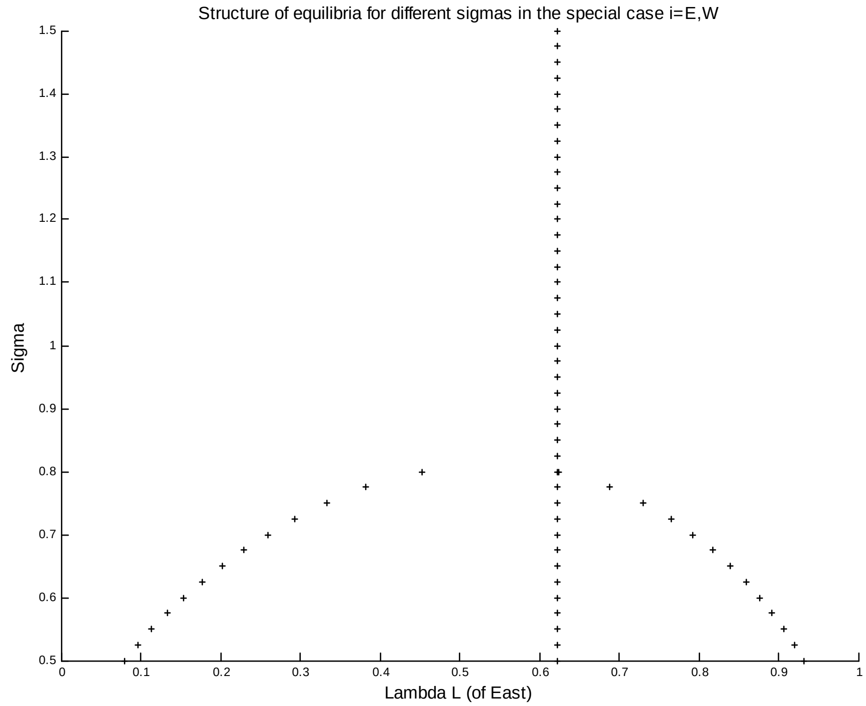

Figure 9: Multiple equilibria in the two-region case

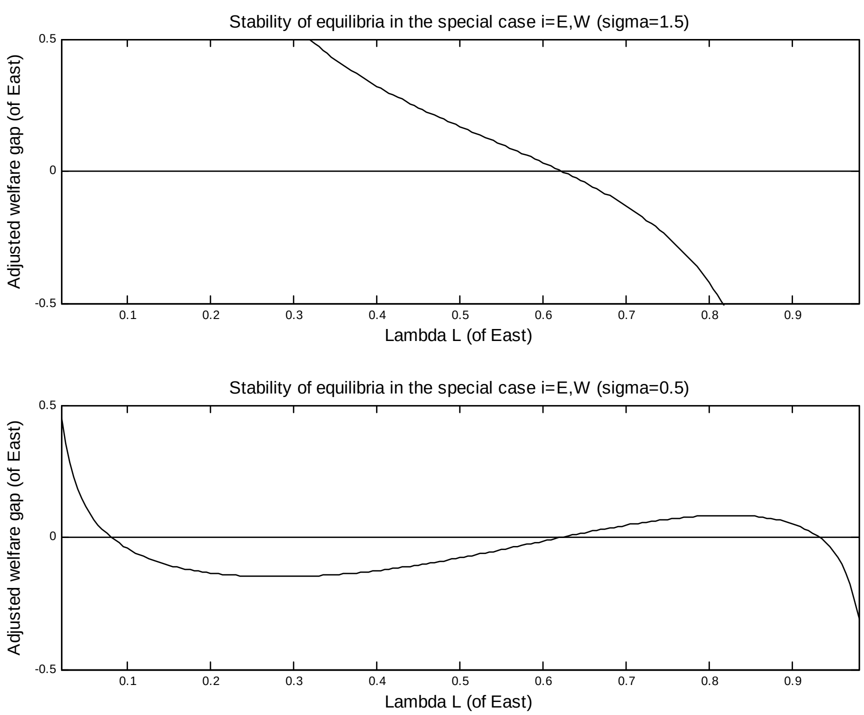

Figure 10: Stability of equilibria in the two-region case

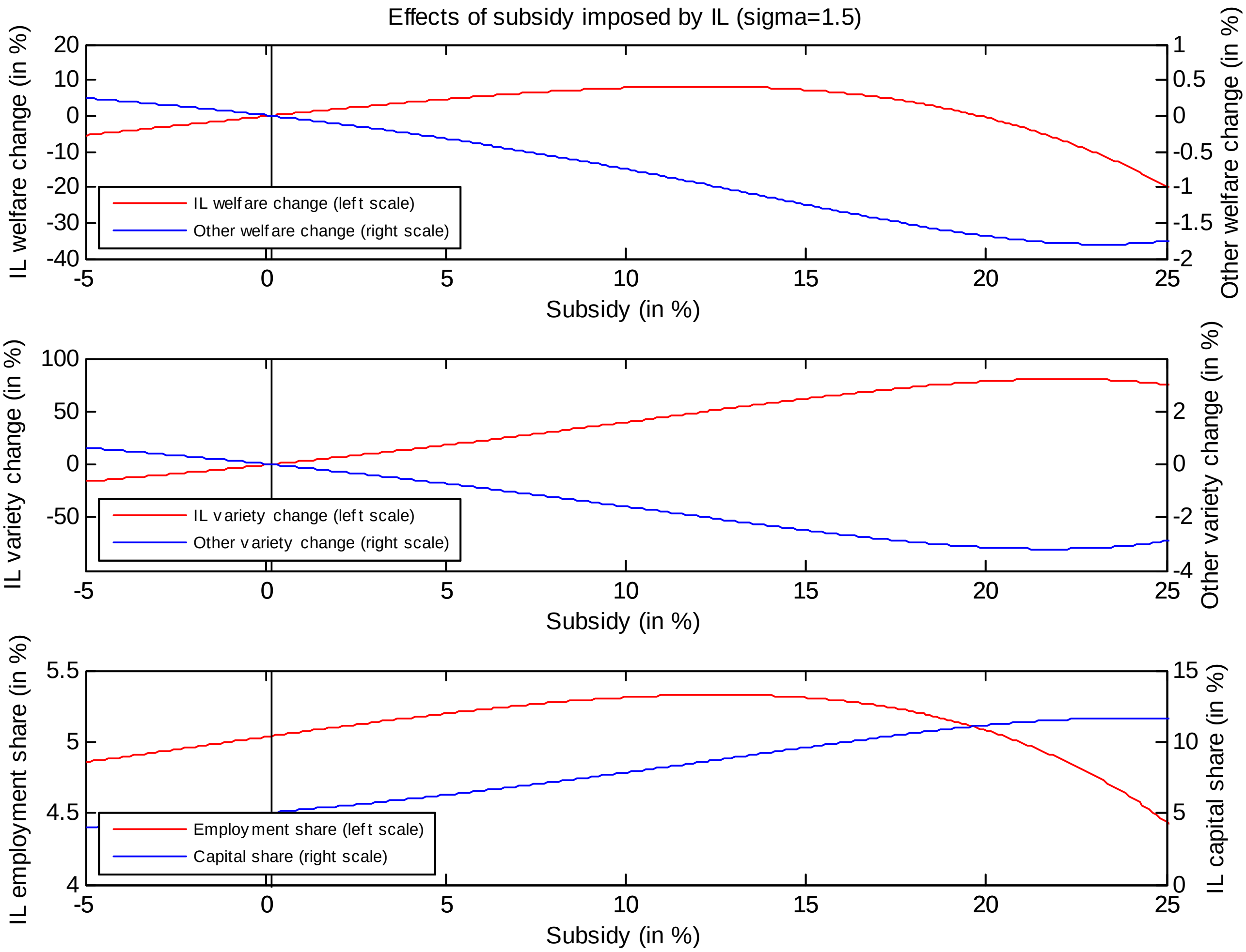

Figure 11: Effects of Illinois' subsidy change

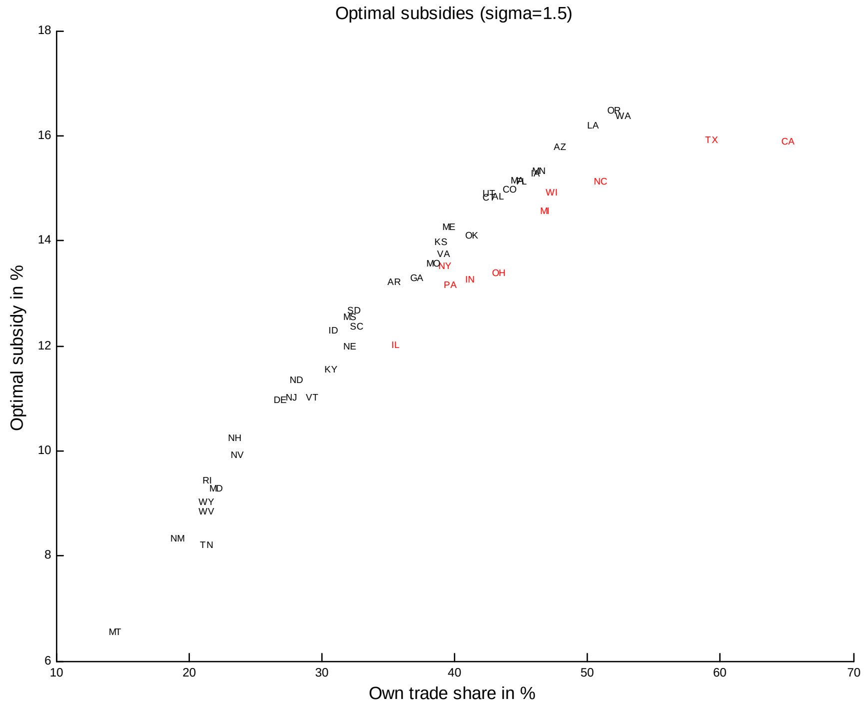

Figure 12: Optimal subsidies

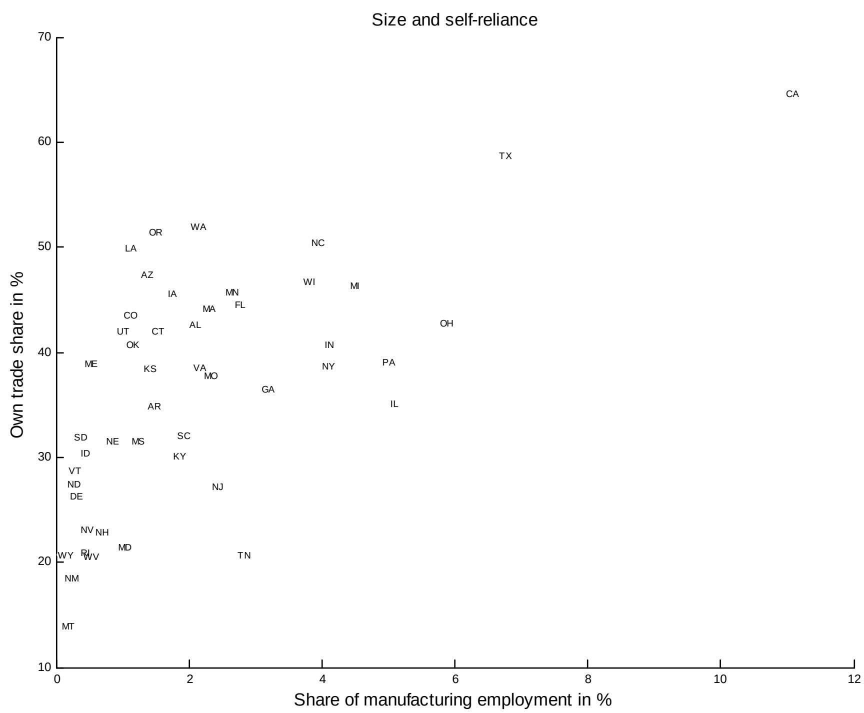

Figure 13: Size and own trade shares

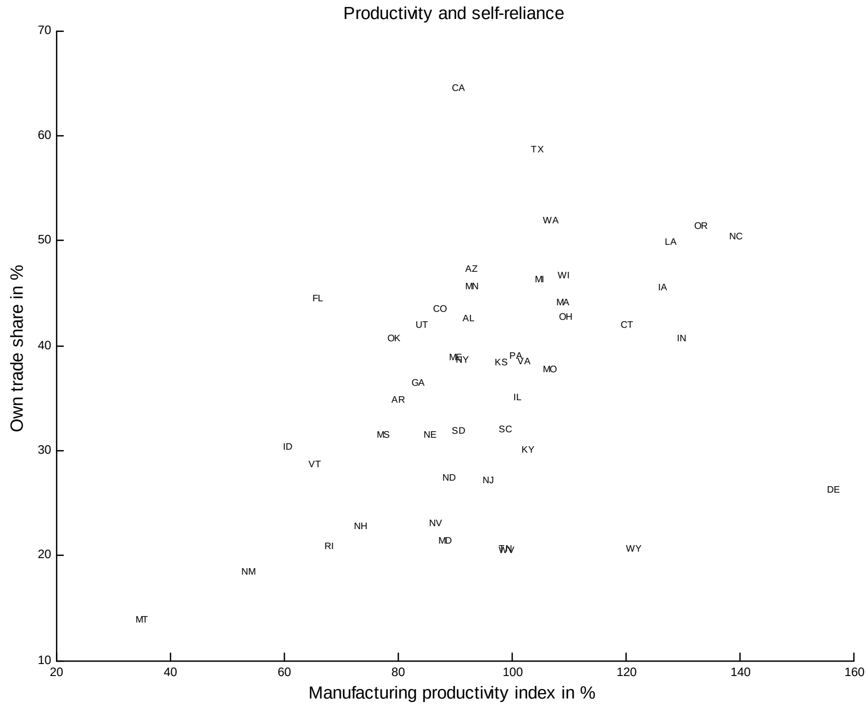

Figure 14: Productivity and own trade share

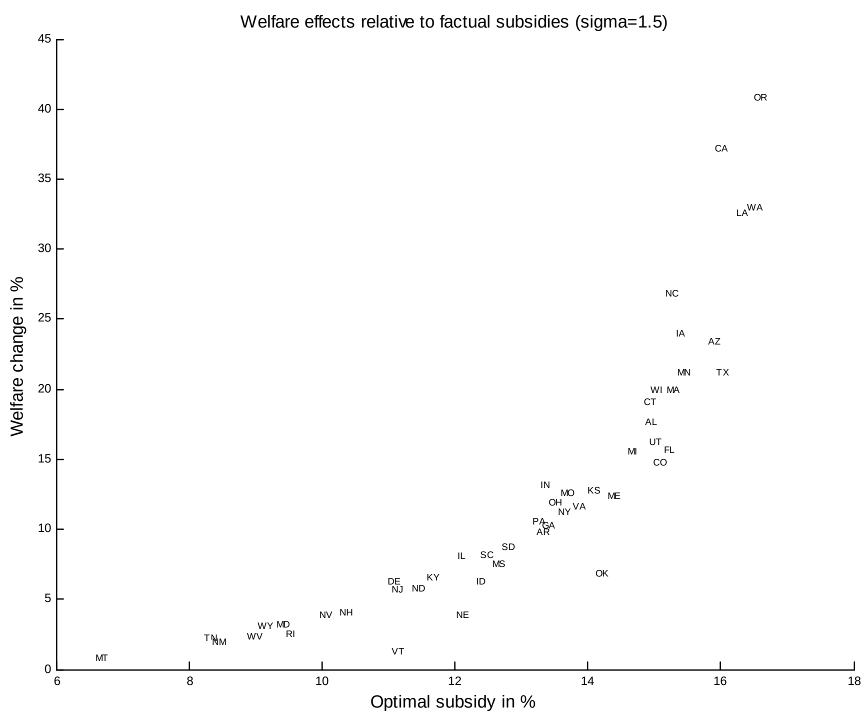

Figure 15: Welfare effects of optimal subsidies relative to factual subsidies

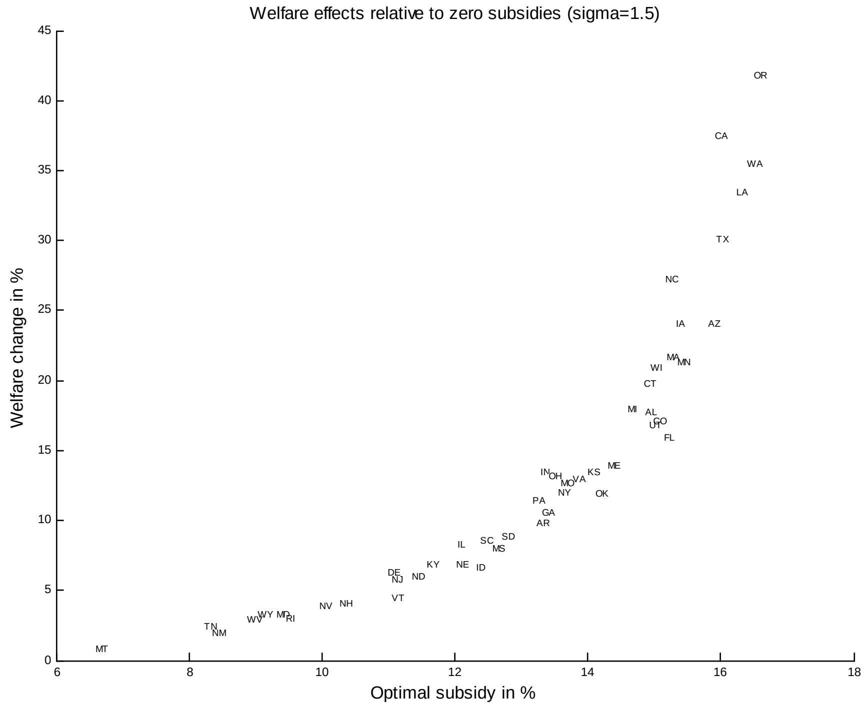

Figure 16: Welfare effects of optimal subsidies relative to zero subsidies

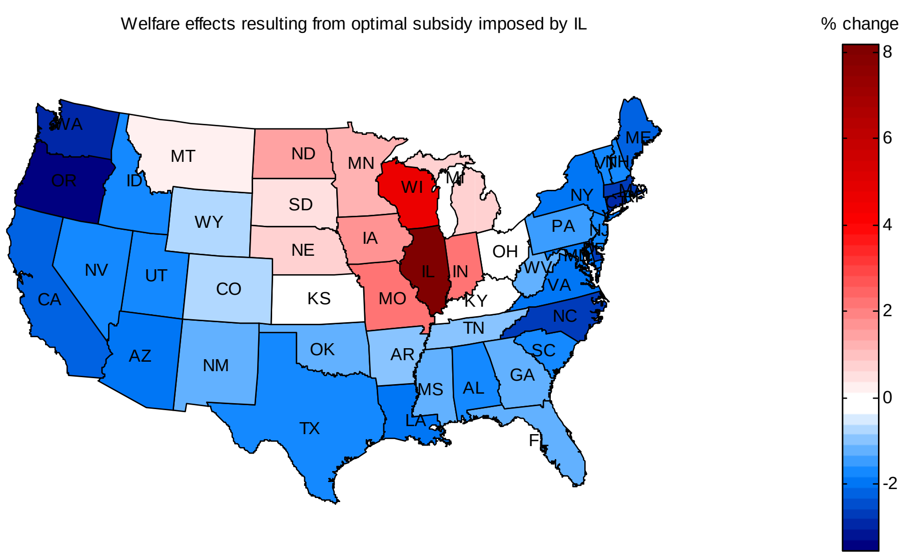

Figure 17: Geographic propagation of welfare effects

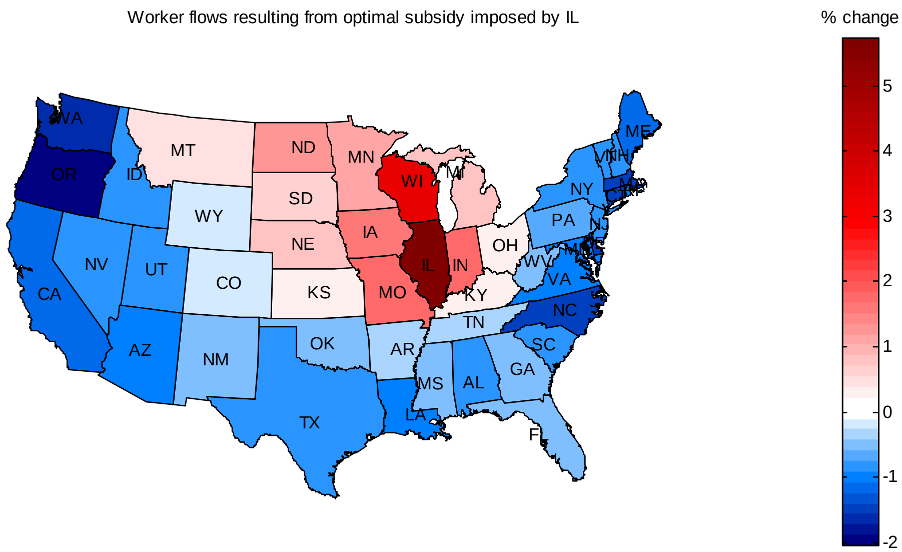

Figure 18: Geographic variation of migration flows

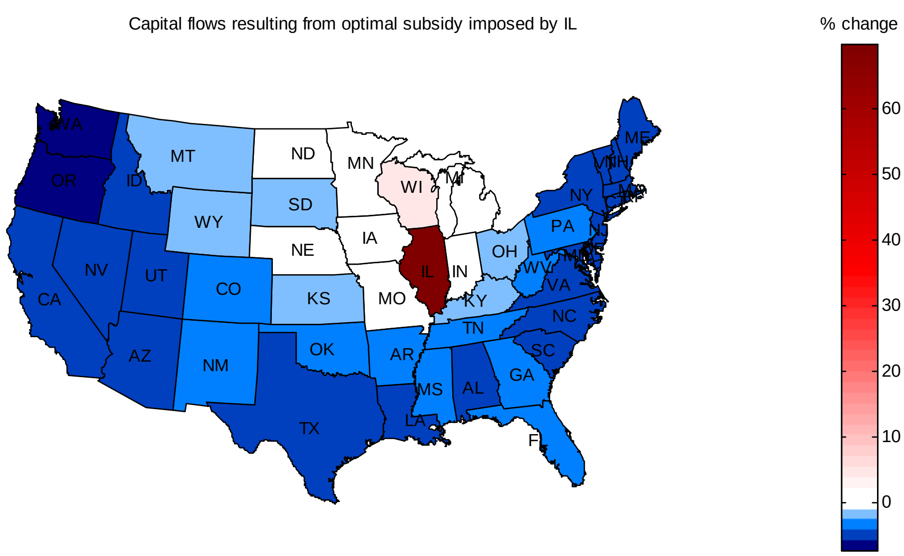

Figure 19: Geographic variation of capital flows

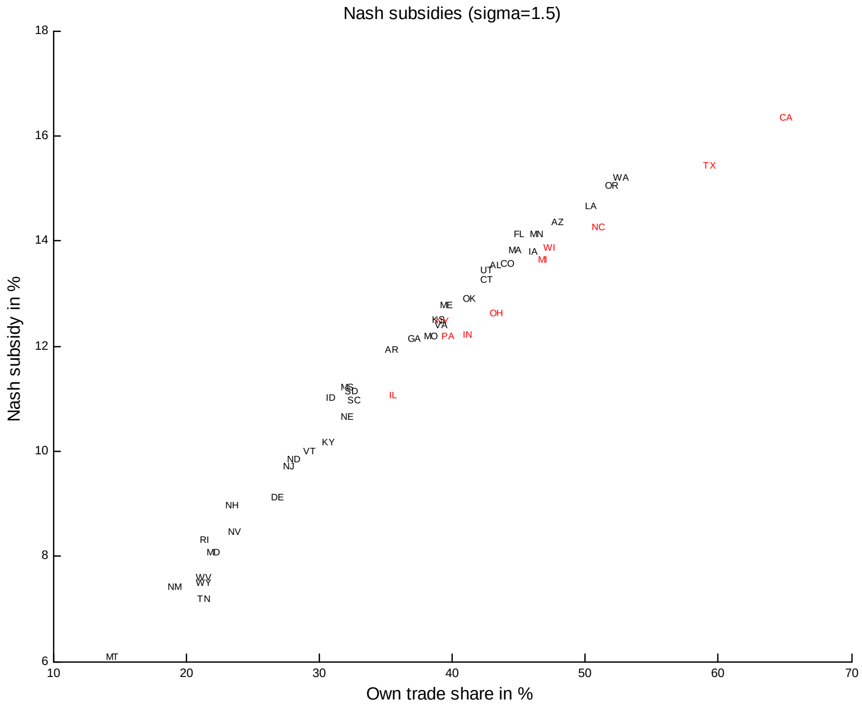

Figure 20: Nash subsidies

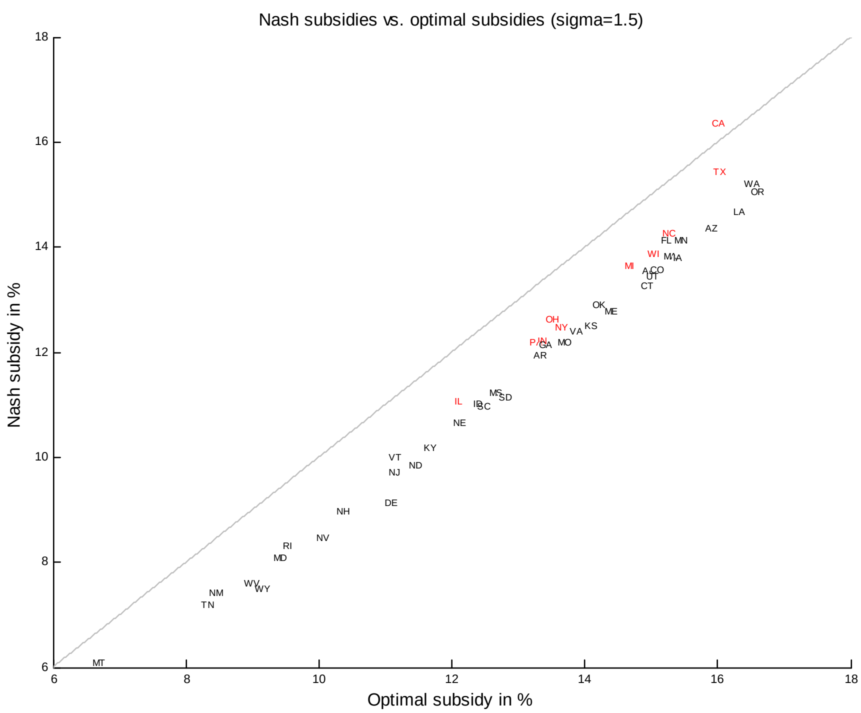

Figure 21: Nash subsidies vs. optimal subsidies

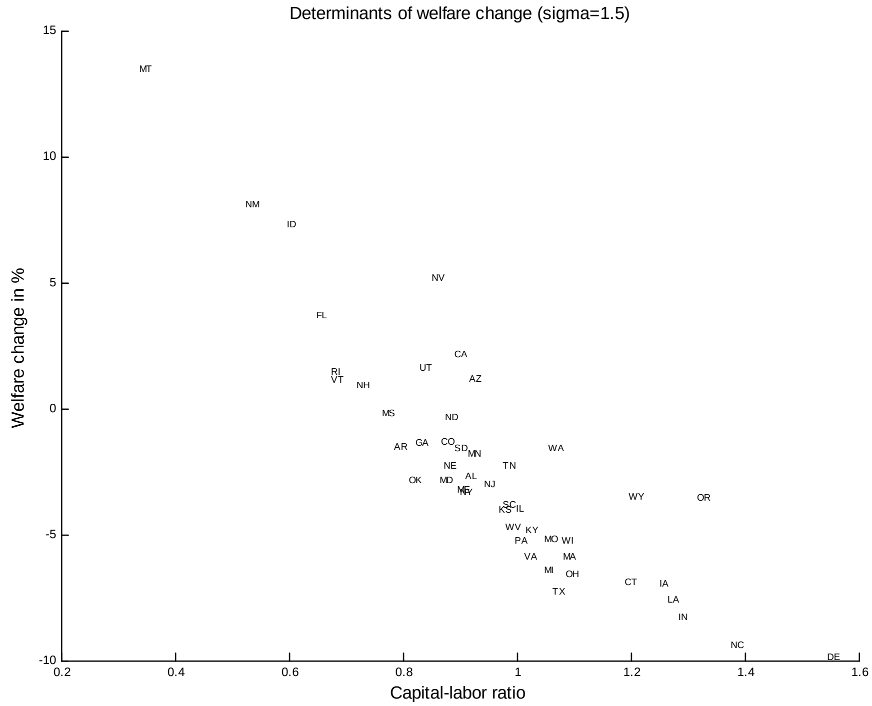

Figure 22: Welfare effects of Nash subsidies

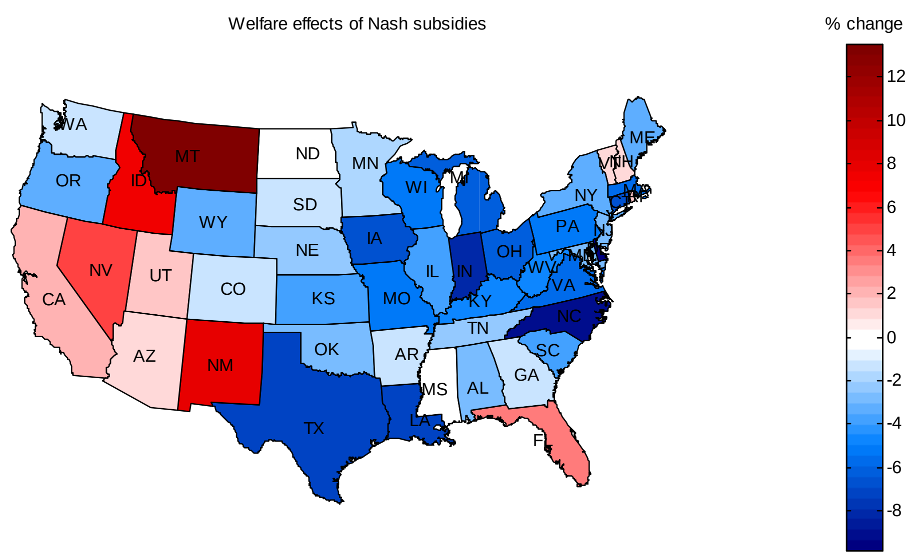

Figure 23: Geographic propagation of welfare effects

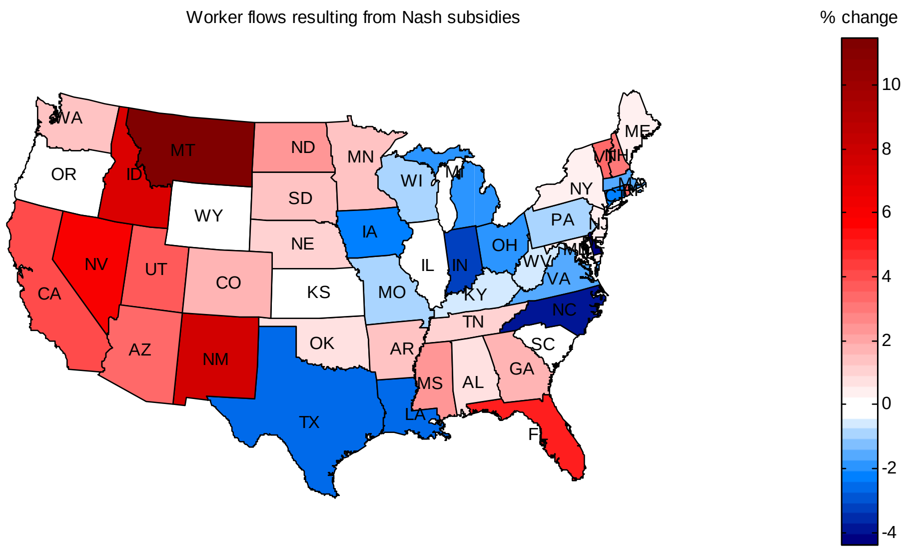

Figure 24: Geographic variaton of migration flows

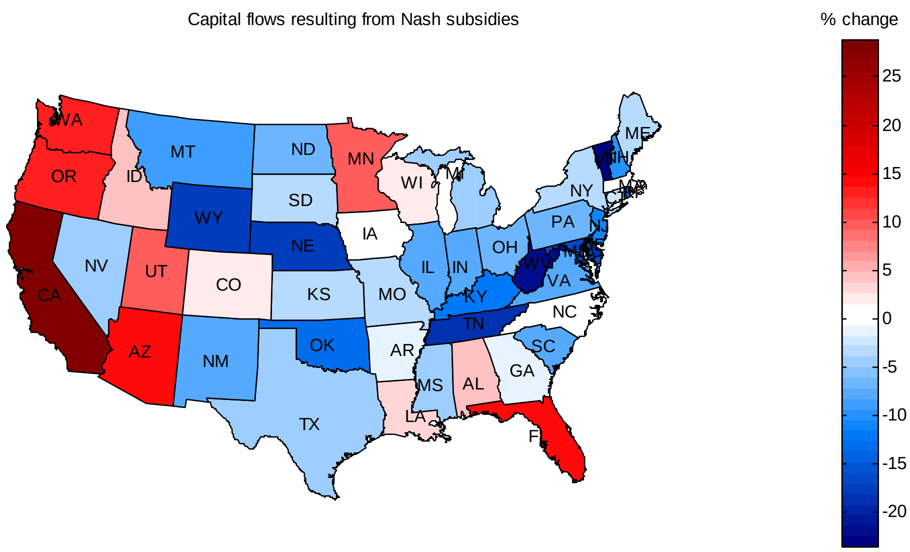

Figure 25: Geographic variation of capital flows

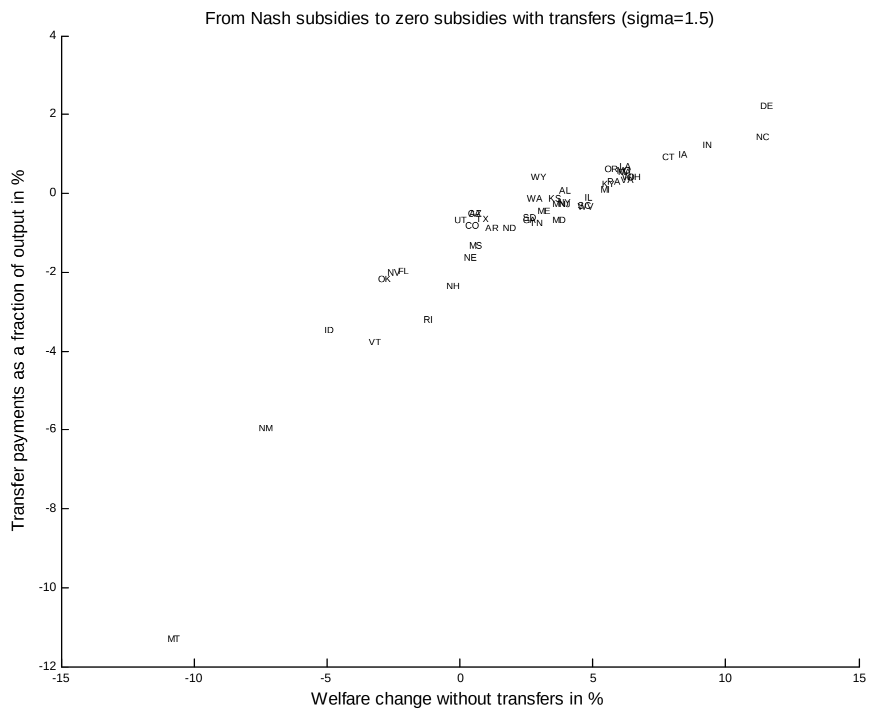

Figure 26: Transfers paid in a cooperative move from Nash subsidies to zero subsidies

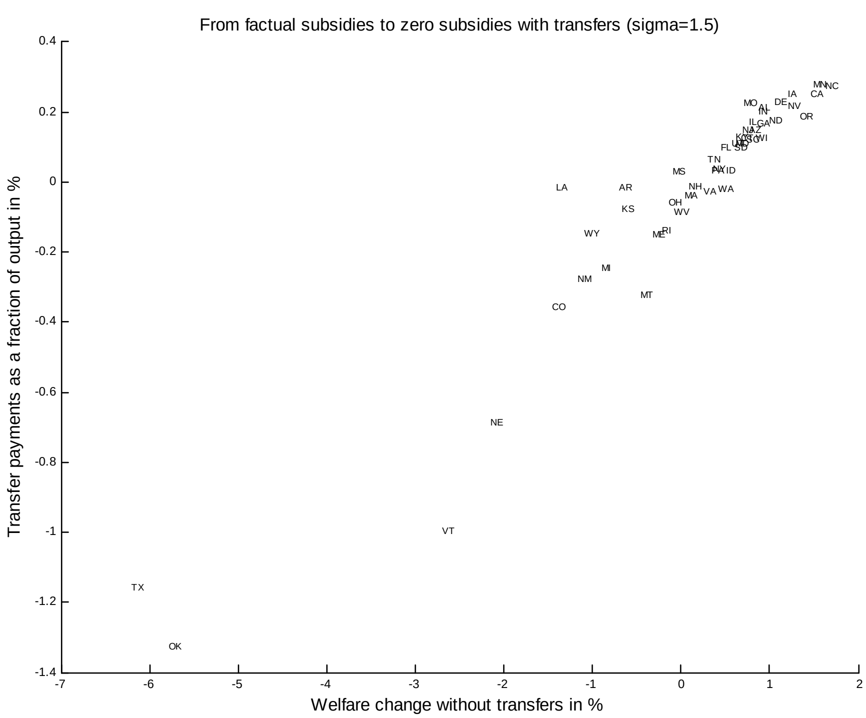

Figure 27: Transfers paid in a cooperative move from factual subsidies to zero subsidies

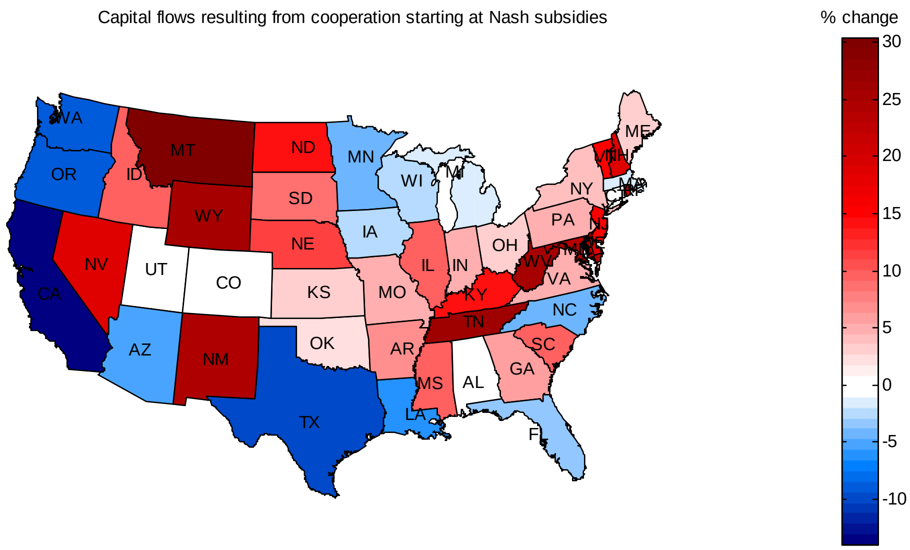

Figure 28: Geographic variation of capital flows

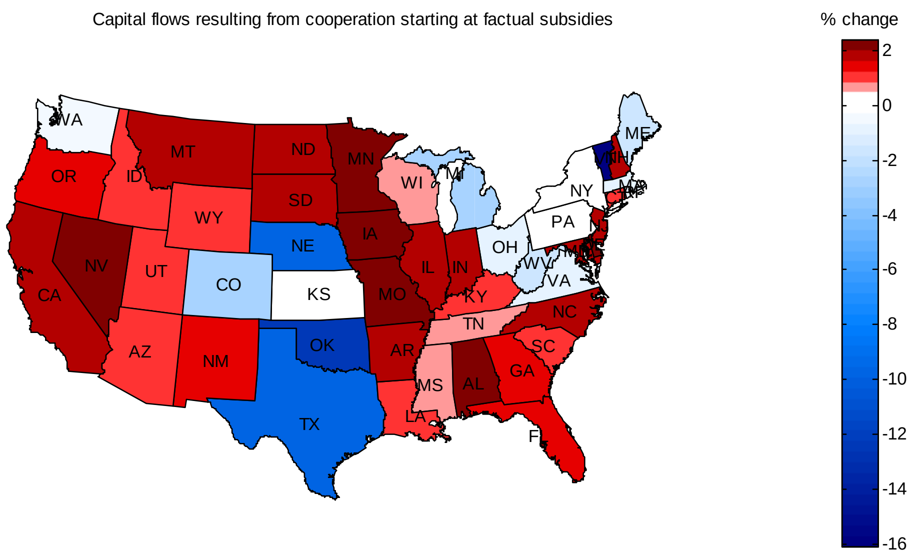

Figure 29: Geographic variation of capital flows

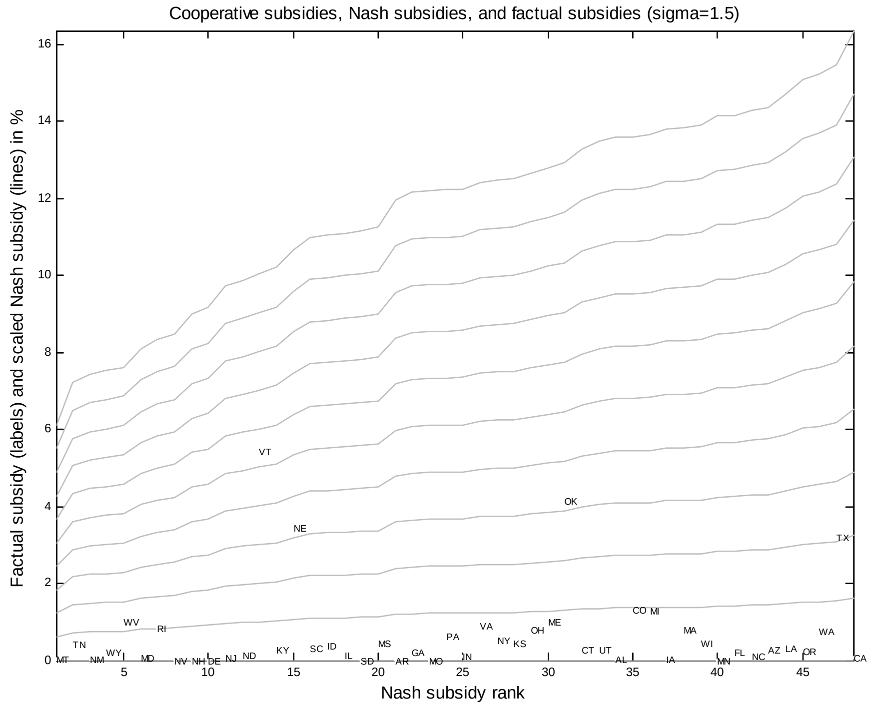

Figure 30: Comparing factual subsidies to cooperative subsidies and Nash subsidies

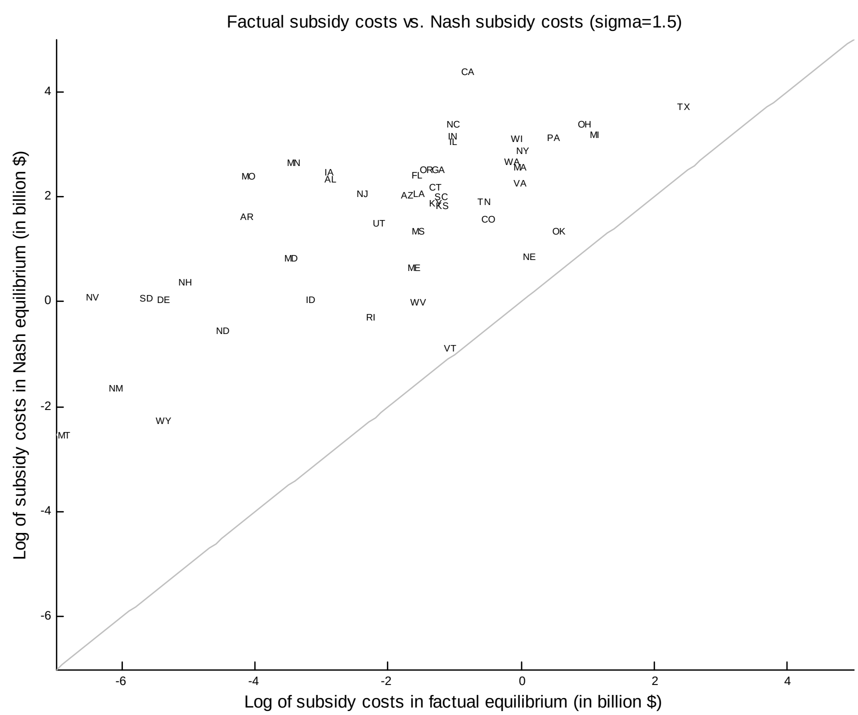

Figure 31: Comparing factual subsidy costs to Nash subsidy costs

TABLE 1: Optimal subsidies

	Δ welfare		home market		terms-of-trade		
	own	other	own	other	own	other	subsidy
AL	17.7	-0.68	10.3	-0.25	7.5	-0.43	14.9
AZ	23.5	-0.58	14.4	-0.29	9.2	-0.29	15.8
AR	9.9	-0.25	5.1	-0.08	4.8	-0.17	13.2
CA	37.3	-7.62	29.0	-5.63	8.2	-1.98	15.9
CO	14.9	-0.29	8.69	-0.16	6.2	-0.13	15.0
CT	19.2	-0.64	11.4	-0.27	7.8	-0.37	14.8
DE	6.4	-0.04	3.0	-0.02	3.4	-0.02	11.0
FL	15.7	-0.69	9.0	-0.27	6.7	-0.42	15.1
GA	10.4	-0.62	5.6	-0.23	4.8	-0.38	13.3
ID	6.4	-0.04	3.1	-0.01	3.3	-0.02	12.3
IL	8.2	-0.95	4.5	-0.52	3.7	-0.42	12.0
IN	13.3	-1.38	7.9	-0.52	5.4	-0.87	13.3
IA	24.1	-0.98	14.8	-0.46	9.3	-0.52	15.3
KS	12.9	-0.36	7.1	-0.13	5.8	-0.24	14.0
KY	6.6	-0.27	3.3	-0.09	3.4	-0.19	11.6
LA	32.6	-0.82	21.1	-1.53	11.5	0.72	16.2
ME	12.5	-0.11	6.9	-0.06	5.6	-0.05	14.3
MD	3.3	-0.06	1.4	-0.01	1.9	-0.05	9.3
MA	20.0	-0.96	12.4	-0.51	7.6	-0.45	15.2
MI	15.6	-1.61	9.8	-0.76	5.8	-0.85	14.6
MN	21.3	-1.09	13.0	-0.55	8.4	-0.54	15.3
MS	7.6	-0.16	3.8	-0.05	3.8	-0.11	12.6
MO	12.7	-0.62	7.0	-0.25	5.7	-0.37	13.6
MT	0.9	0.00	0.3	0.00	0.6	0.00	6.6
NE	3.9	-0.07	2.1	-0.03	1.8	-0.05	12.0
NV	4.0	-0.02	1.8	0.00	2.3	-0.03	10.0
NH	4.1	-0.04	1.9	-0.01	2.3	-0.04	10.3
NJ	5.8	-0.28	2.8	-0.05	3.0	-0.23	11.1
NM	2.0	0.00	0.8	0.00	1.2	0.00	8.4
NY	11.3	-0.93	6.5	-0.30	4.9	-0.63	13.6
NC	27.0	-2.60	18.2	-1.63	8.8	-0.97	15.2
ND	5.9	-0.02	2.7	0.00	3.2	-0.02	11.4
OH	12.0	-1.65	7.3	-2.89	4.7	1.24	13.4
OK	6.9	-0.16	4.2	-0.08	2.8	-0.08	14.1
OR	41.0	-1.38	28.1	-0.83	12.9	-0.55	16.5
PA	10.6	-1.15	6.2	-0.51	4.5	-0.64	13.2
RI	2.7	-0.02	1.2	0.00	1.5	-0.02	9.5
SC	8.3	-0.34	4.3	-0.11	4.0	-0.24	12.4
SD	8.9	-0.05	4.4	-0.02	4.5	-0.03	12.7
TN	2.3	-0.14	1.1	0.01	1.2	-0.15	8.2
TX	21.3	-3.21	15.8	-2.00	5.5	-1.21	15.9
UT	16.4	-0.27	9.3	-0.11	7.1	-0.16	14.9
VT	1.4	-0.01	0.8	0.00	0.6	0.00	11.0
VA	11.8	-0.55	6.6	-0.28	5.1	-0.28	13.8
WA	33.1	-1.45	22.6	-1.01	10.5	-0.43	16.4
WV	2.4	-0.03	1.1	-0.01	1.3	-0.02	8.9
WI	20.0	-1.66	12.6	-0.76	7.4	-0.90	14.9
WY	3.2	0.00	1.4	0.00	1.8	0.00	9.0
Average	12.9	-0.77	7.8	-0.48	5.1	-0.28	13.0

Notes: The entries under "welfare" are the percentage changes in U, the entries under "home-market" are the percentage changes in U due to home-market effects, the entries under "terms-of-trade" are the percentage changes in U due to terms-of-trade effects, and the entries under "subsidy" are the optimal subsidies. The entries under "own" are the effects on the subsidy-imposing state while the entries under "other" are the averages of the effects on all other states. Changes in U refer to changes in the common component of utility which is equivalent to changes in real per-capita income. Home-market and terms-of-trade effects are computed using decomposition (26) and then scaled to add up to the overall welfare effects.

TABLE 2: Employment maximizing subsidies

	Δ welfare		home market		terms-of-trade		
	own	other	own	other	own	other	subsidy
AL	17.7	-0.69	10.2	-0.25	7.5	-0.44	15.1
AZ	23.5	-0.58	14.3	-0.29	9.2	-0.29	15.9
AR	9.9	-0.25	5.0	-0.08	4.9	-0.17	13.4
CA	36.9	-8.09	28.6	-5.94	8.3	-2.15	16.9
CO	14.9	-0.29	8.7	-0.16	6.2	-0.13	15.1
CT	19.2	-0.65	11.3	-0.27	7.9	-0.38	15.0
DE	6.4	-0.04	3.0	-0.02	3.4	-0.02	11.0
FL	15.7	-0.70	9.0	-0.29	6.7	-0.41	15.4
GA	10.4	-0.63	5.5	-0.24	4.8	-0.39	13.6
ID	6.4	-0.04	3.1	-0.01	3.3	-0.02	12.4
IL	8.2	-1.00	4.4	-0.60	3.8	-0.40	12.6
IN	13.3	-1.45	7.8	-0.54	5.5	-0.91	13.8
IA	24.1	-1.00	14.7	-0.46	9.4	-0.54	15.5
KS	12.9	-0.37	7.0	-0.13	5.8	-0.24	14.1
KY	6.6	-0.28	3.2	-0.09	3.4	-0.19	11.8
LA	32.6	-0.82	21.1	-0.80	11.6	-0.02	16.4
ME	12.5	-0.11	6.9	-0.06	5.6	-0.05	14.3
MD	3.3	-0.06	1.4	-0.01	1.9	-0.05	9.4
MA	20.0	-0.98	12.4	-0.52	7.6	-0.46	15.4
MI	15.6	-1.68	9.7	-0.82	5.8	-0.86	15.1
MN	21.3	-1.12	12.9	-0.56	8.4	-0.56	15.6
MS	7.6	-0.16	3.8	-0.05	3.8	-0.11	12.7
MO	12.7	-0.64	6.9	-0.27	5.8	-0.37	13.8
MT	0.9	0.00	0.3	0.00	0.6	0.00	6.6
NE	3.9	-0.08	2.1	-0.03	1.8	-0.05	12.1
NV	4.0	-0.02	1.8	0.00	2.3	-0.03	10.0
NH	4.1	-0.04	1.9	-0.01	2.3	-0.04	10.3
NJ	5.8	-0.28	2.8	-0.05	3.0	-0.24	11.3
NM	2.0	0.00	0.8	0.00	1.2	0.00	8.4
NY	11.3	-0.96	6.4	-0.33	4.9	-0.63	14.0
NC	26.9	-2.71	18.0	-0.12	8.9	-2.59	15.7
ND	5.9	-0.02	2.7	0.00	3.2	-0.02	11.4
OH	11.9	-1.76	7.2	-0.47	4.8	-1.29	14.1
OK	6.9	-0.16	4.1	-0.08	2.8	-0.08	14.2
OR	40.9	-1.40	28.0	-0.84	12.9	-0.56	16.7
PA	10.6	-1.21	6.1	-0.52	4.5	-0.69	13.7
RI	2.7	-0.02	1.2	0.00	1.5	-0.02	9.5
SC	8.3	-0.35	4.2	-0.11	4.0	-0.24	12.6
SD	8.9	-0.05	4.4	-0.02	4.5	-0.03	12.7
TN	2.3	-0.14	1.1	0.01	1.3	-0.15	8.5
TX	21.2	-3.38	15.6	-2.18	5.6	-1.20	16.5
UT	16.4	-0.27	9.3	-0.11	7.1	-0.16	15.0
VT	1.4	-0.01	0.8	0.00	0.6	0.00	11.1
VA	11.8	-0.57	6.6	-0.29	5.2	-0.28	14.0
WA	33.1	-1.47	22.5	-0.02	10.6	-1.45	16.6
WV	2.4	-0.03	1.1	-0.01	1.3	-0.02	8.9
WI	20.0	-1.72	12.5	-0.79	7.5	-0.93	15.4
WY	3.2	0.00	1.4	0.00	1.8	0.00	9.0
Average	12.9	-0.80	7.8	-0.38	5.1	-0.41	13.2

Notes: The entries under "welfare" are the percentage changes in U, the entries under "home-market" are the percentage changes in U due to home-market effects, the entries under "terms-of-trade" are the percentage changes in U due to terms-of-trade effects, and the entries under "subsidy" are the employment-maximizing subsidies. The entries under "own" are the effects on the subsidy-imposing state while the entries under "other" are the averages of the effects on all other states. Changes in U refer to changes in the common component of utility which is equivalent to changes in real per-capita income. Home-market and terms-of-trade effects are computed using decomposition (26) and then scaled to add up to the overall welfare effects.

TABLE 3a: Sensitivity of optimal subsidies wrt ε

ε	subsidy	Δ welfare		$\Delta\lambda^L$
	avg.	own	other	avg.
4.0	13.0	12.9	-0.8	8.6
4.5	11.0	6.2	-0.4	4.2
5.0	9.6	3.8	-0.2	2.6
5.5	8.6	2.6	-0.1	1.8
6.0	7.7	1.9	-0.1	1.3
6.5	7.1	1.4	-0.1	1.0

TABLE 3b: Sensitivity of optimal subsidies wrt σ

σ	subsidy	Δ welfare		$\Delta\lambda^L$
	avg.	own	other	avg.
1.5	13.0	12.9	-0.8	8.6
3.0	12.6	8.3	-0.5	2.8
4.5	12.5	7.5	-0.5	1.7
6.0	12.4	7.1	-0.4	1.2
7.5	12.4	6.9	-0.4	0.9
9.0	12.4	6.8	-0.4	0.8

Notes: The entries under "subsidy" are the averages of the optimal subsidies, the entries under "welfare" are the averages of the percentage changes in U in the subsidy-imposing state ("own") and in the other states ("other"), and the entries under "λ^L" are the averages of the percentage changes in the share of workers employed in the subsidy-imposing state. Changes in U refer to changes in the common component of utility which is equivalent to changes in real per-capita income.

TABLE 4: Nash subsidies

	Δ welfare	Δ firms	subsidy
AL	-2.7	17.7	13.6
AZ	1.2	27.2	14.4
AR	-1.5	12.7	12.0
CA	2.2	38.6	16.4
CO	-1.3	16.2	13.6
CT	-6.8	11.0	13.3
DE	-9.8	-3.8	9.2
FL	3.7	27.6	14.2
GA	-1.3	13.5	12.2
ID	7.4	20.8	11.1
IL	-3.9	7.6	11.1
IN	-8.2	6.2	12.2
IA	-6.9	13.9	13.8
KS	-3.9	11.1	12.5
KY	-4.7	3.2	10.2
LA	-7.5	15.6	14.7
ME	-3.2	11.2	12.8
MD	-2.8	-0.2	8.1
MA	-5.8	12.6	13.8
MI	-6.4	9.5	13.7
MN	-1.7	21.7	14.2
MS	-0.1	11.1	11.3
MO	-5.1	9.9	12.2
MT	13.5	11.2	6.1
NE	-2.2	-0.5	10.7
NV	5.3	13.5	8.5
NH	1.0	6.6	9.0
NJ	-2.9	4.8	9.7
NM	8.1	10.5	7.4
NY	-3.2	11.3	12.5
NC	-9.3	11.9	14.3
ND	-0.3	8.8	9.9
OH	-6.5	7.3	12.7
OK	-2.8	2.9	12.9
OR	-3.5	24.9	15.1
PA	-5.2	7.8	12.2
RI	1.5	3.1	8.3
SC	-3.7	6.9	11.0
SD	-1.5	11.1	11.2
TN	-2.2	-1.4	7.2
TX	-7.2	9.4	15.5
UT	1.7	23.5	13.5
VT	1.2	-4.6	10.0
VA	-5.8	6.9	12.4
WA	-1.5	25.7	15.2
WV	-4.6	-5.3	7.6
WI	-5.2	14.9	13.9
WY	-3.4	-0.6	7.5
Average	-2.3	10.9	11.8

Notes: The entries under "welfare" are the percentage changes in U, the entries under "firms" are the percentage changes in M, and the entries under "subsidy" are the Nash subsidies. Changes in U refer to changes in the common component of utility which is equivalent to changes in real per-capita income.

TABLE 5a: Sensitivity of Nash subsidies wrt ε

ε	subsidy	Δ welfare	$\Delta\lambda^L$
4.0	11.8	-2.3	0.9
4.5	10.3	-1.3	0.6
5.0	9.1	-0.8	0.5
5.5	8.2	-0.5	0.4
6.0	7.5	-0.3	0.3
6.5	6.9	-0.2	0.3

TABLE 5b: Sensitivity of Nash subsidies wrt σ

σ	subsidy	Δ welfare	$\Delta\lambda^L$
1.5	11.8	-2.3	0.9
3.0	11.6	-2.3	0.4
4.5	11.5	-2.3	0.2
6.0	11.5	-2.3	0.2
7.5	11.5	-2.3	0.1
9.0	11.5	-2.3	0.1

Notes: The entries under "welfare" are the percentage changes in U, the entries under "firms" are the percentage changes in M, and the entries under "subsidy" are the Nash subsidies. Changes in U refer to changes in the common component of utility which is equivalent to changes in real per-capita income.

TABLE 6: Cooperation starting at Nash subsidies

	Δ welfare	Δ firms	subsidy
AL	3.9	-13.0	0
AZ	3.9	-16.2	0
AR	3.9	-8.6	0
CA	3.9	-21.7	0
CO	3.9	-13.5	0
CT	3.9	-12.6	0
DE	3.9	-1.2	0
FL	3.9	-14.9	0
GA	3.9	-9.3	0
ID	3.9	-7.3	0
IL	3.9	-7.0	0
IN	3.9	-9.7	0
IA	3.9	-14.3	0
KS	3.9	-10.6	0
KY	3.9	-4.1	0
LA	3.9	-17.0	0
ME	3.9	-11.0	0
MD	3.9	1.3	0
MA	3.9	-13.9	0
MI	3.9	-13.6	0
MN	3.9	-15.2	0
MS	3.9	-6.9	0
MO	3.9	-9.4	0
MT	3.9	4.4	0
NE	3.9	-5.9	0
NV	3.9	-1.9	0
NH	3.9	-1.8	0
NJ	3.9	-3.2	0
NM	3.9	1.0	0
NY	3.9	-10.1	0
NC	3.9	-15.4	0
ND	3.9	-4.1	0
OH	3.9	-10.8	0
OK	3.9	-11.6	0
OR	3.9	-18.7	0
PA	3.9	-9.3	0
RI	3.9	-0.2	0
SC	3.9	-6.7	0
SD	3.9	-7.2	0
TN	3.9	2.6	0
TX	3.9	-19.0	0
UT	3.9	-13.2	0
VT	3.9	-3.5	0
VA	3.9	-9.8	0
WA	3.9	-18.7	0
WV	3.9	2.3	0
WI	3.9	-14.4	0
WY	3.9	1.9	0
Average	3.9	-8.8	0

Notes: The entries under "welfare" are the percentage changes in U, the entries under "firms" are the percentage changes in M, and the entries under "subsidy" are the cooperative subsidies. Changes in U refer to changes in the common component of utility which is equivalent to changes in real per-capita income.

TABLE 7: Cooperation starting at factual subsidies

	Δ welfare	Δ firms	subsidy
AL	0.04	1.0	0
AZ	0.04	0.4	0
AR	0.04	0.8	0
CA	0.04	1.0	0
CO	0.04	-2.6	0
CT	0.04	0.2	0
DE	0.04	0.9	0
FL	0.04	0.5	0
GA	0.04	0.6	0
ID	0.04	0.1	0
IL	0.04	0.7	0
IN	0.04	0.7	0
IA	0.04	1.0	0
KS	0.04	-0.3	0
KY	0.04	0.3	0
LA	0.04	0.1	0
ME	0.04	-1.6	0
MD	0.04	0.8	0
MA	0.04	-1.0	0
MI	0.04	-2.4	0
MN	0.04	1.1	0
MS	0.04	-0.1	0
MO	0.04	1.1	0
MT	0.04	0.6	0
NE	0.04	-7.5	0
NV	0.04	1.1	0
NH	0.04	0.7	0
NJ	0.04	0.8	0
NM	0.04	0.4	0
NY	0.04	-0.3	0
NC	0.04	0.8	0
ND	0.04	0.7	0
OH	0.04	-1.0	0
OK	0.04	-9.8	0
OR	0.04	0.4	0
PA	0.04	-0.6	0
RI	0.04	-1.1	0
SC	0.04	0.3	0
SD	0.04	0.9	0
TN	0.04	0.0	0
TX	0.04	-7.7	0
UT	0.04	0.3	0
VT	0.04	-12.0	0
VA	0.04	-1.2	0
WA	0.04	-0.9	0
WV	0.04	-1.5	0
WI	0.04	0.0	0
WY	0.04	0.0	0
Average	0.04	-0.7	0

Notes: The entries under "welfare" are the percentage changes in U, the entries under "firms" are the percentage changes in M, and the entries under "subsidy" are the cooperative subsidies. Changes in U refer to changes in the common component of utility which is equivalent to changes in real per-capita income.

TABLE 8a: Sensitivity of cooperative subsidies wrt ε

Starting at Nash subsidies			
ε	s	Δ welfare	$\Delta\lambda^L$
4.00	0	3.9	0
4.50	0	2.4	0
5.00	0	1.7	0
5.50	0	1.2	0
6.00	0	0.9	0
6.50	0	0.7	0
Starting at factual subsidies			
ε	s	Δ welfare	$\Delta\lambda^L$
4.00	0	0.04	0
4.50	0	0.04	0
5.00	0	0.03	0
5.50	0	0.03	0
6.00	0	0.03	0
6.50	0	0.03	0

TABLE 8b: Sensitivity of cooperative subsidies wrt to σ

Starting at Nash subsidies			
σ	s	Δ welfare	$\Delta\lambda^L$
1.50	0	3.9	0
3.00	0	3.8	0
4.50	0	3.7	0
6.00	0	3.7	0
7.50	0	3.7	0
9.00	0	3.7	0
Starting at factual subsidies			
σ	s	Δ welfare	$\Delta\lambda^L$
1.50	0	0.04	0
3.00	0	0.04	0
4.50	0	0.04	0
6.00	0	0.04	0
7.50	0	0.04	0
9.00	0	0.04	0

Notes: The entries under "subsidy" are the averages of the cooperative subsidies, the entries under "welfare" are the averages of the percentage changes in U, and the entries under "λ^L" are the averages of the percentage changes in the share of workers employed in each state. Changes in U refer to changes in the common component of utility which is equivalent to changes in real per-capita income.