Domestic and International Border Effects: State Size Matters

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Abstract
International borders hinder trade flows. Similarly, studies have found that domestic borders between U.S. states also appear to deter trade. We investigate the sensitivity of international and domestic border effects to the economic size of individual states. We consider a unique data set of exports from individual U.S. states to foreign countries and combine it with trade flows between U.S. states. We find that the larger the U.S. state, the smaller its international border effect and the smaller its domestic border effect. In addition, when states are aggregated into larger U.S. Census divisions, both the international and the domestic border effects become smaller. We use a general equilibrium gravity model to show that aggregation systematically leads to smaller estimated border effects such that all else being equal, larger regions are associated with smaller border effects. Our results cast doubt on the interpretation of border effects as typically estimated in the literature.

JEL classification: F10, F15, R12
Keywords: Border Effects, Intranational Home Bias, Gravity, Trade Costs, Aggregation, Modifiable Areal Unit Problem (MAUP)

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1. Introduction

In a seminal paper, McCallum (1995) found that Canadian provinces trade up to 22 times more with each other than with U.S. states. This astounding result, also known as the international border effect, has led to a large literature on the trade impediments associated with international borders. More recently, Anderson and van Wincoop (2003) revisited the U.S.-Canadian border effect with new micro-founded estimates. Although they are able to reduce the border effect considerably, there is widespread consensus that the international border remains a large impediment to trade.¹

A parallel and somewhat smaller literature has explored the existence of border effects within a country, known as the domestic border effect or intranational home bias. For example, Wolf (2000) finds that trade within individual U.S. states is significantly larger than trade between U.S. states even after controlling for economic size, distance and a number of additional determinants. Similar to the case of the United States in which there are no legal restrictions on trade flows between states, Nitsch (2000) finds that domestic trade within the average European Union country is about ten times larger than trade with another EU country.² In response to Wolf’s findings, Hillberry and Hummels (2003) undertake some adjustments based on possible explanations for home bias and generated home bias estimates one-third as large as Wolf’s. In a more recent paper, Hillberry and Hummels (2008) find that spatial frictions matter, but that the frictions have their greatest effects over very short distances. They conclude that home bias at the level of individual states is simply an artifact of aggregation.

A logical extension of the literature is to estimate international and state border effects so that a direct comparison can occur. One such example is provided by Fally, Paillacar, and Terra (2010).³ As part of a study examining wage differences across Brazilian states, they estimate a gravity equation in which bilateral trade flows are explained by a set of trade cost variables that include both domestic and international border effects. Their estimates indicate that the average

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¹ Anderson and van Wincoop (2004) report 74 percent as an estimate of representative international trade costs for industrialized countries (expressed as a tariff equivalent). About two-thirds of these costs can be attributed to border-related trade barriers such as tariffs and non-tariff barriers. The remainder represents transportation costs. Note that whilst McCallum (1995) compares trade between Canadian provinces and U.S. states to inter-provincial trade, Anderson and van Wincoop (2003) add inter-state trade data, thus using an extended sample.
³ Other examples of research using different tiers of trade flows include Poncet (2003) and Hering and Poncet (2010).
Brazilian state border has a relatively larger negative impact on bilateral trade flows than the international border.\textsuperscript{4}

In the present paper, we examine the heterogeneity of domestic and international border effects across U.S. states. We particularly emphasize the connection between border effects and state size. We also focus on how the aggregation of individual states to larger U.S. Census divisions changes the estimates of border effects. Our approach is inspired by Hillberry and Hummels (2008) who find that counterfactual ZIP code border effects within the United States would be enormous, by far eclipsing the magnitude of traditional border effects typically found in the literature. The findings by Hillberry and Hummels (2008) illustrate an issue known in the geography literature as the Modifiable Areal Unit Problem (MAUP). This problem manifests itself in the sensitivity of empirical results to the geographic units used for the analysis. It is related to both the level of aggregation (i.e., the scale problem) and the configuration of the zoning system (i.e., the zoning problem).

Briant, Combes, and Lafourcade (2010) systematically highlight this problem for empirical work in economic geography. Since spatial statistics are ultimately based on spatial units, they depend on both the size and the shape of these units. For example, two possibilities for the unit of observation for a cross-section study of economic growth in the United States would be counties and states, which simply represent different levels of aggregation (the scale problem). Also, in theory the boundaries of the 50 U.S. states could be redrawn so that 50 equally sized geographic units were produced, and then these units could be examined in an economic growth study (the zoning problem). The resulting spatial statistics and econometric insights tend to be sensitive to the underlying unit of observation. In other words, variation in the underlying spatial units often leads to variation in the statistical results.

In the present paper, we explore how the choice of the spatial unit affects the estimation of domestic and international border effects. As is typical in the literature, the domestic border effect indicates how much a U.S. state trades with itself relative to state-to-state trade, while the international border effect indicates how much a U.S. state trades with foreign countries relative to state-to-state trade. Our gravity-based empirical analysis produces four major results. We find: 1) the smaller the state in terms of economic size, the larger is its own state border effect; 2) the smaller the state, the larger is its international border effect; 3) the domestic border effect tends

\textsuperscript{4} See below for details on their particular estimates.
to decline when the U.S. states are aggregated into the nine U.S. Census divisions; and 4) the international border effect tends to decline when the U.S. states are aggregated into the nine U.S. Census divisions. Clearly, size and aggregation are important factors in the calculation of border effects.

The paper is organized as follows. In section 2 we carefully examine the economic theory of trade in general equilibrium with trade barriers and derive our empirical estimation framework. We show that theory does not provide an *a priori* expectation as to the relative size of the domestic and international border effects. We thus affirm that a relatively large domestic border effect—as we find it in the data—is by no means a foregone conclusion. In section 3 we describe our data set. In section 4 we present our estimates of the international and domestic border effects as well as our results on aggregation. In section 5, we discuss reasons for our findings and their significance for the border effect literature. [*To be completed.*] Section 6 concludes.

2. Aggregation and border effects in gravity theory

2.1 The basic gravity framework

The seminal contribution of McCallum (1995) has led to a large number of papers that estimate border effects based on a gravity estimation framework. Gravity theory describes how trade flows are determined in general equilibrium with trade barriers. To obtain results that are easily comparable to the previous literature on border effects, we adopt the widely used gravity framework by Anderson and van Wincoop (2003).\(^5\)

Anderson and van Wincoop’s (2003) parsimonious model rests on the Armington assumption that countries produce differentiated goods and trade is driven by consumers’ love of variety. They derive the following gravity equation for exports \(x_{ij}\) from region \(i\) to region \(j\):

\[
x_{ij} = \frac{y_i y_j}{y^W} \left( \frac{I_{ij}}{P_i P_j} \right)^{1-\sigma},
\]

where \(y_i\) and \(y_j\) denote output of regions \(i\) and \(j\) and \(y^W\) denotes world output. The bilateral trade cost factor is given by \(t_{ij}\) (one plus the tariff equivalent), which is also assumed to be symmetric.

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\(^5\) However, our results could also be generated with other frameworks. It is well-known that similar, multiplicative gravity equations can be derived from a variety of trade models. For example, gravity is also consistent with the Ricardian trade model by Eaton and Kortum (2002) and the heterogeneous firms model by Chaney (2008).
for any given country pair (i.e., $t_{ij} = t_{ji}$). $P_i$ and $P_j$ are the multilateral resistance terms which can be interpreted as average trade barriers of regions $i$ and $j$. The parameter $\sigma > 1$ is the elasticity of substitution.

We follow McCallum (1995) and other authors by hypothesizing that trade costs $t_{ij}$ are a log-linear function of bilateral geographic distance, $dist_{ij}$, and an international border dummy, $INTERNATIONAL_{ij}$, which takes on the value 1 whenever regions $i$ and $j$ are located in different countries and 0 otherwise. In addition, we allow domestic trade costs within a region to be systematically different from bilateral trade costs. We therefore include a domestic dummy variable, $OWNSTATE_{ij}$, that takes on the value 1 whenever $i = j$ and 0 otherwise.  

$$
\ln(t_{ij}) = \tilde{\beta} \cdot INTERNATIONAL_{ij} + \tilde{\gamma} \cdot OWNSTATE_{ij} + \tilde{\delta} \ln(dist_{ij}),
$$

where $\tilde{\beta}$ and $\tilde{\gamma}$ are coefficients and $\tilde{\delta}$ is the elasticity of trade costs with respect to distance.

Expression (2) nests the most common trade cost functions from the literature. Wolf (2000) and Hillberry and Hummels (2003) only consider trade flows within the United States so that an international border effect cannot be estimated. This corresponds to $\tilde{\beta} = 0$ in trade cost function (2). Conversely, Anderson and van Wincoop (2003) follow McCallum’s (1995) specification that does not allow for a domestic border effect ($\tilde{\gamma} = 0$).

We log-linearize equation (1) and insert the trade cost function (2):

$$
\ln(x_{ij}) = \ln(y_i) + \ln(y_j) - \ln(y^w) + (\sigma - 1) \ln(P_i) + (\sigma - 1) \ln(P_j) + (1 - \sigma) \tilde{\beta} \cdot INTERNATIONAL_{ij} + (1 - \sigma) \tilde{\gamma} \cdot OWNSTATE_{ij} + (1 - \sigma) \tilde{\delta} \ln(dist_{ij}).
$$

To simplify notation, we define $\beta = (1 - \sigma) \cdot \tilde{\beta}$, $\gamma = (1 - \sigma) \cdot \tilde{\gamma}$ and $\delta = (1 - \sigma) \cdot \tilde{\delta}$ so that the equation becomes

$$
\ln(x_{ij}) = \ln(y_i) + \ln(y_j) - \ln(y^w) + (\sigma - 1) \ln(P_i) + (\sigma - 1) \ln(P_j) + \beta \cdot INTERNATIONAL_{ij} + \gamma \cdot OWNSTATE_{ij} + \delta \ln(dist_{ij}).
$$

In border effect gravity regressions $\beta$ and $\gamma$ are of the coefficients of interest. All else being equal, $\beta$ indicates to what extent the international border impedes bilateral trade ($\beta$ is typically negative), whereas $\gamma$ indicates to what extent domestic trade within a region exceeds non-

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6 The regions for which we estimate domestic border effects in the empirical section are U.S. states. Hence the ‘OWNSTATE’ variable name.
domestic bilateral trade ($\gamma$ is typically positive). We now attempt to explain what happens to these border effect coefficients when individual regions are aggregated.

### 2.2 Aggregation and the domestic border effect

To make our theoretical exposition as simple as possible, we abstract from distance and assume that border effects are the only trade cost determinants (i.e., $\tilde{\delta}=0$). To further simplify the analysis we assume symmetry across regions in terms of region size and trade flows. We first examine the domestic border effect, setting $\tilde{\beta}=0$.

#### 2.2.1 Symmetric regions

As an example, consider the four hypothetical regions in Figure A. These symmetric regions are based in the same country. Each region trades $x_{ii}=20$ units domestically. Trading with another region is assumed to cut trade flows in half, thus resulting in $x_{ij}=10$ units for each region-to-region flow. The total income of each region follows as $y_i=x_{ii}+3^*x_{ij}=50$ units.

What is the implied domestic border effect for the regions in Figure A? The coefficient of interest is $\gamma$ in equation (3) since its exponential, $\exp(\gamma)$, indicates by how much domestic trade exceeds bilateral trade. Given $\tilde{\delta} = \tilde{\beta}=0$ and $\gamma = (1-\sigma)\tilde{\gamma}$, trade cost function (2) implies:

$$
t_{ii}^{1-\sigma} = \exp(\gamma \text{OWNSTATE}_{ii}) = \exp(\gamma), \quad \text{and}
$$
$$
t_{ij}^{1-\sigma} = \exp(\gamma \text{OWNSTATE}_{ij}) = 1 \quad \forall \ i \neq j.
$$

It turns out that the ratio $t_{ii}^{1-\sigma} / t_{ij}^{1-\sigma}$ is convenient if we want to express $\exp(\gamma)$ in terms of observable variables. First we solve gravity equation (1) for $t_{ij}^{1-\sigma}$. We also consider the corresponding gravity equation for domestic trade flows $x_{ii}$ and solve it for $t_{ii}^{1-\sigma}$. Then we take the ratio and obtain:

$$
(4) \quad \frac{t_{ii}^{1-\sigma}}{t_{ij}^{1-\sigma}} = \exp(\gamma) = \frac{x_{ii}}{x_{ij}} \frac{y_i}{y_j} \left( \frac{P_i}{P_j} \right)^{1-\sigma}.
$$

Due to the symmetry assumption, the output and multilateral resistance terms in equation (4) cancel (i.e., $y_i=y_j$ and $P_i=P_j$). It follows $\exp(\gamma) = x_{ii}/x_{ij}=20/10=2$. Estimating a gravity equation for regions that are like those in Figure A would therefore indicate that domestic trade is twice as large as bilateral trade.
It is also possible to derive a solution of the multilateral resistance term \( P_i \). Following the approach of Novy (2010), we consider the gravity equation (4) for domestic trade \( x_{ii} \) and solve for the multilateral resistance term:

\[
P_i^{2(1-\sigma)} = \frac{y_i / y^w}{x_{ii} / y_i} t_i^{1-\sigma}.
\]

Using \( t_i^{1-\sigma} = x_{ii}/x_{ij} \) from above, we obtain

\[
(5) \quad P_i^{1-\sigma} = \left( \frac{y_i / y^w}{x_{ij} / y_i} \right)^{\frac{1}{2}}.
\]

The numerical example of Figure A implies \( P_i^{1-\sigma} = (1.25)^{1/2} \).

Now suppose that the four regions of Figure A are aggregated into two larger regions, as illustrated in Figure B. Each region now trades \( x_{ii} = 60 \) units domestically, consisting of twice the domestic and twice the bilateral trade flows in Figure A. The bilateral flows between the large regions now become \( x_{ij} = 40 \), consisting of four times the bilateral flows from Figure A. The total income of each region is given by \( y_i = x_{ii} + x_{ij} = 100 \) units.

What is the new implied domestic border effect? We can use the same expression as in equation (4). Due to symmetry it follows \( \exp(\gamma) = \frac{x_{ii}}{x_{ij}} = \frac{60}{40} = 1.5 \). Thus, once regions have been aggregated, domestic trade no longer exceeds bilateral trade by as much as in Figure A. This insight can be generalized as follows:

**Implication 1:** Aggregation reduces the domestic border effect. Conversely, disaggregation increases the domestic border effect.

The underlying reason is that aggregation affects bilateral trade flows disproportionately strongly. Comparing the particular examples in Figures A and B, one can see that the size of bilateral trade quadruples while domestic trade only triples. Since the \( \text{OWNSTATE} \) indicator variable now refers to trade flows whose relative size has changed, it appears that domestic trade is no longer as large relative to bilateral trade.

It is important to note that Implication 1 depends on the fact that the initial domestic trade flow in Figure A is larger than the initial bilateral trade flow (i.e., \( 20 > 10 \)), which is generally the case in standard data sets. In contrast, suppose that the initial domestic trade flows were also
equal to $x_i=10$. In that case, aggregation would not alter the ratio $x_i/x_{ij}$. Or suppose that the initial domestic trade flows were in fact smaller, say, $x_i=5$. Then aggregation would have the opposite effect and increase the domestic border effect.

Finally, we can use equation (5) to compute the multilateral resistance term for the regions in Figure B. It follows as $P_i^{L-S}=(1.25)^{1/2}$ and is thus the same as for the regions in Figure A. Intuitively, multilateral resistance is an average of bilateral trade barriers weighted by region size (see Anderson and van Wincoop, 2003). But aggregation does not change the underlying bilateral trade barriers. It merely reshuffles the weights of regions. In this case, it doubles the weight of small symmetric regions. Thus, aggregation does not affect overall multilateral resistance.

### 2.2.2 Asymmetric regions and individual domestic border effects

As the next step, we want to depart from the symmetry assumption and instead consider the more realistic scenario with regions of different size. To remain as close as possible to the previous analysis, we still work with Figure A as the initial scenario but now consider Figure C as the outcome of aggregation. We first compute the domestic border effects associated individually with the large and small regions. That is, we adopt the trade cost function:

\[
\begin{align*}
\gamma_{L}^i &= \exp(\gamma_k \ \text{OWNSTATE}_{ij}) = \exp(\gamma_k), \text{ and} \\
\gamma_{S}^j &= \exp(\gamma_k \ \text{OWNSTATE}_{ij}) = 1 \ \forall \ i \neq j,
\end{align*}
\]

where the domestic border dummy coefficient is allowed to vary across regions $k$ with $k\in\{L,S\}$. $L$ denotes the large region and $S$ denotes the small regions of Figure C.

The individual border effects can be computed based on equation (4). Since the multilateral resistance terms are equal for small and large regions, the last term of equation (4) can be dropped. As $x_{ij}$ could denote trade either from a large to a small region or from a small to a large region, we add $L$ and $S$ superscripts to avoid ambiguous notation. For example, $x_{ij}^{LS}$ means trade from the large to a small region, and $y_i^L$ denotes the output of the large region.

Starting with the large region of Figure C, we obtain

\[
\begin{align*}
\exp(\gamma_L) &= \frac{x_{ij}^{LL}/y_i^L}{x_{ij}^{LS}/y_j^S} = \frac{60/100}{20/50} = 1.5.
\end{align*}
\]
Thus, the individual domestic border effect for the large region in Figure C is the same as the border effect in Figure B.

For each small region in Figure C, there are two different bilateral trade flows: one to the large region ($x_{ij}^{SL}$) and one to the other small region ($x_{ij}^{SS}$). As a result, there are two different cases of relating domestic to bilateral trade. It turns out, however, that equation (4) implies the same overall result. For the case of $x_{ij}^{SL}$ as the bilateral trade flow, we have:

$$\exp(\gamma_S) = \frac{x_{ii}^{SS} / y_i^s}{x_{ij}^{SL} / y_j^L} = \frac{20/50}{20/100} = 2.$$ 

For the case of $x_{ij}^{SS}$ as the bilateral trade flow, we have:

$$\exp(\gamma_S) = \frac{x_{ii}^{SS} / y_i^s}{x_{ij}^{SS} / y_j^S} = \frac{20/50}{10/50} = 2.$$ 

Thus, the individual domestic border effect for the small regions in Figure C is the same as in Figure A. In summary, we therefore conclude:

**Implication 2:** Smaller regions are associated with larger domestic border effects, and vice versa.

Finally, we examine the standard common domestic border effect associated with regions of asymmetric size in Figure C (i.e., $\gamma_L = \gamma_S = \gamma$). In that case, OLS estimation of gravity equation (3) would yield the simple average of the individual border effects of the three regions in Figure C.\(^7\) That is, OLS would give a third of the weight to each individual border effect:

$$\gamma = \frac{1}{3} \gamma_L + \frac{2}{3} \gamma_S = \frac{1}{3} \ln(1.5) + \frac{2}{3} \ln(2)$$

such that $\exp(\gamma) = 1.82$. Thus, the common domestic border effect lies in between the individual domestic border effects (1.5<1.82<2). But it is closer to the small regions’ border effects as those carry a larger weight. This result can be generalized as follows:

**Implication 3:** All else being equal, samples that contain a relatively big number of small regions are associated with a relatively large domestic border effect, and vice versa.

\(^7\) OLS is the most common estimation technique in the border effects literature
2.3 Aggregation and the international border effect

We continue to abstract from distance, setting $\delta = 0$ in the trade cost function (2). We now consider the international border effect, setting $\gamma = 0$. [To be completed.]

2.3.1 Symmetric regions

Consider the four hypothetical regions in Figure D. [To be completed.]

3. Data

To obtain comparable results, we use the same data sets as Wolf (2000) and Anderson and van Wincoop (2003) for domestic trade flows within the United States. The novelty of our approach is to combine these domestic trade flows with international trade flows from individual U.S. states to the 50 largest U.S. export destinations. Thus, our data set comprises, for instance, trade flows within Minnesota, exports from Minnesota to Texas as well as exports from Minnesota to Canada. We also employ trade data between foreign countries in our sample. We take data quality seriously, and below we describe in detail the data sources, potential concerns with the state-based data and how we address these concerns.

3.1 Domestic exports: Commodity Flow Survey

For our measures of the shipments of goods within and across U.S. states, we use aggregate trade data from the Commodity Flow Survey, which is a joint effort of the Bureau of Transportation Statistics and the Bureau of the Census. We use survey results from 1993, 1997, 2002, and 2007. The survey covers the origin and destination of shipments of manufacturing, mining, wholesale trade, and selected retail establishments. The survey excludes shipments in the following sectors: services, crude petroleum and natural gas extraction, farm, forestry, fishery, construction, government, and most retail. Shipments from foreign establishments are also excluded; import shipments are excluded until they reach a domestic shipper. U.S. export (i.e., trans-border) shipments are also excluded. 

8 Erlbaum and Holguin-Veras (2006) note that sample size has been a major issue. The 1993 survey collected data from 200,000 establishments and the size was subsequently reduced to 100,000 in 1997 and 50,000 in 2002. In response to complaints from the freight data users community, the sample size was increased to 100,000 in 2007.
3.2 International exports from U.S. states: Origin of Movement

Our data on exports by U.S. states to foreign destinations are from the Origin of Movement series. These data are compiled by the Foreign Trade Division of the U.S. Bureau of the Census. The data in this series identify the state from which an export begins its journey to a foreign country. However, we would like to know the state in which the export was produced. Below we provide details on the Origin of Movement series and its suitability as a measure of the origin of production.

Beginning in 1987, the Origin of Movement series provides the current-year export sales, or free-alongside-ship (f.a.s.) costs if not sold, for 54 ‘states’ to 242 foreign destinations. These export sales are for merchandise sales only and do not include services exports. The 54 ‘states’ include the 50 U.S. states plus the District of Columbia, Puerto Rico, U.S. Virgin Islands, and unknown. Following Wolf (2000), we use the 48 contiguous U.S. states. Rather than all 242 destinations, we use the 50 leading export destinations for U.S. exports for 2005. We use the annual data from 1993, 1997, 2002, and 2007 for total merchandise exports.

Concerns about using the Origin of Movement series to identify the location of production are especially pertinent for agricultural and mining exports. We, however, focus on manufactured goods. Cassey (2009) has examined the issue of the coincidence of the state origin of movement and the state of production for manufactured goods. The reason for restricting the focus to manufacturing is that the best source for location-based data on export production, “Exports from Manufacturing Establishments,” covers only manufacturing.

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9 Other studies that have used the Origin of Movement series include Smith (1999), Coughlin and Wall (2003), Coughlin (2004) and Cassey (2007).
10 The highlighted details as well as much additional information can be found in Cassey (2009).
11 In alphabetical order, these countries are Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, China, Colombia, Costa Rica, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Finland, France, Germany, Guatemala, Honduras, Hong Kong, India, Indonesia, Ireland, Israel, Italy, Japan, Kuwait, Malaysia, Mexico, Netherlands, New Zealand, Norway, Panama, Peru, Philippines, Russia, Saudi Arabia, Singapore, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, Thailand, Turkey, United Arab Emirates, United Kingdom, and Venezuela.
12 We have also tried the data for manufacturing only (as opposed to total merchandise). The two series are very highly correlated (99 percent). The regression results are almost identical and we therefore do not report them.
14 For the initial work on this issue, see Coughlin and Mandelbaum (1991) and Cronovich and Gazel (1999). As Cassey’s (2009) analysis refers to manufactured goods, we note that we have also tried the Origin of Movement manufacturing data (as opposed to total merchandise) with virtually identical results.
15 The data in the “Exports from Manufacturing Establishments” is available at http://www.census.gov/mcd/exports/ but does not contain destination information, so it cannot be used for the current research project.
Cassey’s key finding relevant to our analysis is that, overall, the Origin of Movement data is of sufficient quality to be used as the origin of the production of exports. Nonetheless, the data for specific states may not be of sufficient quality as the origin of production. These states are: Alaska, Arkansas, Delaware, Florida, Hawaii, New Mexico, South Dakota, Texas, Vermont, and Wyoming. He recommends the removal of Alaska and Hawaii in particular. As we use the 48 contiguous U.S. states, our data set is consistent with this recommendation. The next two candidates for removal would be Delaware and Vermont. Cassey further highlights that the consolidation of export shipments might systematically affect the Origin of Movement estimates (relative to the origin of production). Specifically, consolidation tends to bias upward the estimates for Florida and Texas and to bias downward the estimates for Arkansas and New Mexico. As a robustness check, we drop these states from the sample (see section 4.3).

3.3 Adjustments to the state trade data

Our simultaneous use of the intra-state and inter-state shipments data from the Commodity Flow Survey and the merchandise international trade data from the Origin of Movement series requires an adjustment to increase the comparability of these data sets. Such an adjustment arises because of three important differences between the data sources. First, the merchandise international trade data measures a shipment from the source to the port of exit just once, whereas the commodity flow data likely measures a good in a shipment more than once. For example, a good may be shipped from a plant to a warehouse and, later, to a retailer. Second, goods destined for foreign countries, when they are shipped to a port of exit, are included in domestic shipments. Third, the coverage of sectors differs between the data sources. The Commodity Flow Survey includes shipments of manufactured goods, but it excludes agriculture and part of mining. Meanwhile, the merchandise trade data includes all goods.

Identical to Anderson and van Wincoop (2003), we scale down the data in the Commodity Flow Survey by the ratio of total domestic merchandise trade to total domestic shipments from the Commodity Flow Survey. Total domestic merchandise trade is approximated by gross output in the goods-producing sectors (i.e., agriculture, mining, and manufacturing).

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16 The problems for Wyoming and South Dakota are primarily in individual sectors—chemicals for Wyoming and computers in South Dakota.
minus international merchandise exports. This calculation yields an adjustment factor of 0.495 for 1993, 0.508 for 1997, 0.430 for 2002, and 0.405 for 2007. Similar to Anderson and van Wincoop (2003), our adjustment to the commodity flow data does not solve all the measurement problems, but it is the best feasible option.

3.4 Other data

The rest of the data used in our estimations can be characterized as well-known. We take export data between the 50 foreign countries in our sample from the IMF Direction of Trade Statistics. For individual U.S. states we use state gross domestic product data from the U.S. Bureau of Economic Analysis. For foreign countries, we use data on gross domestic product taken from the IMF World Economic Outlook Database (October 2007 edition).

We use the standard great circle distance formula to measure inter-state and international distances between capital cities in kilometers. As intra-state distance, we use the distance between the two largest cities in a state. As alternatives for intra-state distance, we also try the measure used by Wolf (2000) that weights the distance between a state’s two largest cities by their population, as well as the measure suggested by Nitsch (2000) that is based on land area. Finally, we also use a distance measure that is related to actual shipping distances, based on data for individual shipments used by Hillberry and Hummels (2003), see section 4.2 for details.

4. Empirical results

We form a balanced sample over the years 1993, 1997, 2002 and 2007. Due to the data quality concerns for Alaska, Hawaii and Washington, D.C., we drop these states so that we are left with 48 contiguous states. This yields 1,726 trade observations per cross-section within the U.S, including 48 ownstate observations and 1,678 state-to-state observations per cross-section. The observations that involve the 50 foreign countries are made up of 2,338 export flows from U.S. states to foreign countries as well as 2,233 exports flows amongst foreign countries per

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18 The difference between our adjustment factor for 1993 and that of Anderson and van Wincoop, 0.495 vs. 0.517, is due to data revision.
19 The maximum possible number of U.S. observations would be 48*48 = 2,304 per cross-section. The missing observations are due to the fact that a number of Commodity Flow Survey estimates did not meet publication standards because of high sampling variability or poor response quality. To generate a balanced sample pairs are dropped once at least one year is missing.
cross-section. Our entire sample thus comprises 6,297 observations per cross-section, or 25,188 in total.\footnote{The maximum possible number of international exports from U.S. states would be 48*50 = 2,400 per year. Sixty-two observations are missing mainly because exports to Malaysia were generally not reported in 1993. Only 18 of these observations not included in our sample are most likely zeros (as opposed to missing). The maximum possible number of exports between foreign countries would be 49*50 = 2,450 per cross-section. To generate a balanced sample pairs are dropped once at least one year is missing.}

We first show that our data exhibit a substantial domestic border effect, as established by Wolf (2000). We also show that the data exhibit a significant international border effect, as established by McCallum (1995). In a second step, we move away from border effects that are common across states, as typically imposed in the literature. Instead, we estimate individual border effects that are allowed to vary across states, thus uncovering a large degree of underlying heterogeneity. Finally, we aggregate the 48 U.S. states in our sample to larger units in the form of nine U.S. Census divisions and re-estimate domestic and international border effects at this higher level of aggregation.

4.1 Estimating common domestic and international border effects

In columns 1 and 2 of Table 1, we show results that replicate the intranational home bias. We use the log-linear estimation equation (4) that is standard in the literature. Like Hillberry and Hummels (2003) we use exporter and importer fixed effects to control for multilateral resistance; the output regressors thus drop out. Identical to Wolf (2000), in column 1 we only use data for 1993. In column 2 we add the data for 1997, 2002 and 2007. International observations are not included. Our estimates are virtually identical to Wolf’s baseline coefficient of 1.48 for the ownstate indicator variable. The interpretation of this coefficient is that given distance and economic size, ownstate trade is 4.4 times higher than state-to-state trade (exp(1.48) = 4.4).

Hillberry and Hummels (2003) reduce the ownstate coefficient by about a third when excluding wholesale shipments from the Commodity Flow Survey data. The reason is that wholesale shipments are predominantly local so that their removal disproportionately reduces the extent of ownstate trade.\footnote{We do not have access to the private-use coding of wholesale shipments and thus cannot replicate their finding with our data. However, our main result on the relative size of the domestic and international border effects would seem robust to a reduction by a third in the ownstate coefficient magnitudes (see Tables 2-4). Hillberry and Hummels (2003) further reduce the ownstate coefficient by using an alternative distance measure that is based on actual shipping distances. We refer to section 4.3 where we employ such a measure, but our main result is unchanged.} However, Nitsch (2000) reports higher home bias coefficients by
comparing trade within European Union countries to trade between EU countries. He finds home bias coefficients in the range of 1.8 to 2.9.

In columns 3 and 4 we do not consider ownstate trade and instead focus on the international border effect. To be able to identify the international border effect we follow Anderson and van Wincoop (2003) and others by using state and country fixed effects instead of exporter and importer fixed effects. As the output regressors are collinear with these fixed effects, we drop them from the estimation. In column 3 we estimate an international border coefficient of -1.25 for the year 1993, implying that after we control for distance and economic size, exports from U.S. states to foreign countries are about 71 percent lower than state-to-state trade (\(\exp(-1.25) = 0.29\)). This estimate is not as pronounced and significantly different from the estimate of -1.59 obtained by Anderson and van Wincoop (2003, Table 2) in their multi-country model, but it roughly falls in the same ballpark range. When we pool the data over the years 1993, 1997, 2002 and 2007 in column 4, the magnitude of the border effect hardly changes at -1.21.

Overall, we have replicated domestic and international border effects as they are typically found in the literature. We note that in absolute value, the domestic and international border effects are rather similar. In fact, our domestic border effect point estimate exceeds the international border effect, a finding which is consistent with Fally, Paillacar and Terra (2010) in their study of Brazilian trade data. We will now revisit these findings by allowing border effects to vary across individual states.

### 4.2 Estimating individual domestic and international border effects

We now run the same types of regression specifications with panel data as in columns 2 and 4 of Table 1, but now allowing the domestic and international border effects to vary across states. That is, we estimate individual, state-specific border effects.

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22 An alternative would be to use the logarithm of \(x_{ij}/(y_{i}y_{j})\) as the dependent variable as in Anderson and van Wincoop (2003), thus imposing unitary income elasticities. This yields very similar results.

23 For example, in the first column of Table 2 Fally, Paillacar and Terra (2010) report an estimate of -2.594 for their internal border dummy and an estimate of -4.326 for their international border dummy in a log-linear regression that includes exporter and importer fixed effects and that controls for distance and other bilateral trade cost proxies. Their border dummies are not defined in the same way as ours but are directly comparable due to the Frisch-Waugh theorem. Their estimates imply that trade within Brazilian states is on average \(\exp(2.594)=13.4\) times larger than trade between Brazilian states, whereas trade between Brazilian states trade is only \(\exp(4.326-2.594)=5.7\) times larger than trade with foreign countries.
Figure 1 illustrates the point estimates of domestic border effects for the 48 U.S. states in our sample. They are plotted against the economic size of the states, measured as the log of state output. Two main observations can be made. First, there is a large degree of heterogeneity across the individual border effects. Although the mean of the individual border effects at 1.32 is close to the point estimates reported in columns 1 and 2 of Table 1, some states display individual border effects with magnitudes around 4, whereas others display negative values. Second, the individual border effects are systematically related to the economic size of states. The larger the state, the smaller the corresponding domestic border effects tends to be. For example, the five states with the smallest state outputs (Wyoming, Vermont, North Dakota, Montana, South Dakota) have border effects with magnitudes 3 or higher. A simple regression of the individual estimates on a constant and the log of state output yields an R-squared of 0.23.

Figure 2 plots the individual international border effects against the log of state output. The relationship is even tighter. As with the domestic border effects, the individual estimates display a large degree of heterogeneity with a range of -2.7 to 0.9. The mean estimate is -0.64. The larger the state, the smaller is the individual international border effect. For example, Wyoming as the smallest state is associated with a border effect of -1.53, whereas California as the largest state has a border effect of -0.34. A simple regression of the individual estimates on a constant and the log of state output yields an R-squared of 0.46.

4.3 Aggregating U.S. states to U.S. Census divisions

The individual border effects illustrated in Figures 1 and 2 demonstrate that larger states tend to exhibit smaller border effects. We now trace this relationship between economic size and the magnitude of the border effects in a different way by aggregating states and thus enlarging the economic sizes of the underlying exporting and importing units.

To be specific, we aggregate the 48 contiguous U.S. states into the nine U.S. Census divisions. Figure 3 provides a map of the Census divisions. Trade flows within a division are taken to equal the sum of the internal trade flows of its states plus the flows between the states. Trade flows between divisions are given by the sum of trade flows between their respective states. Likewise, trade flows from a division to a foreign country are given by the sum of exports from the states in the division to the foreign country.
Tables 2a and 2b report the results of regressions that correspond to those in Table 1. In Table 2a we use the simple average of distances associated with the underlying individual trade flows. In Table 2b we weight the distances by the individual trade flows.

The division-based domestic border effect estimates in Table 2a are 1.17 and 1.25 and thus smaller than the corresponding point estimates of 1.47 and 1.48 from Table 1. The estimates based on weighted distances in Table 2b are even lower at 0.92 and 0.98 and significantly different from the values in Table 1. The reason is that weighted distances tend to be shorter than average distances, thus making the extent of internal trade seem less extreme (see Hillberry and Hummels, 2003). The division-based international border effect estimates in Table 2a are -0.36 and -0.39 and thus considerably smaller in absolute magnitude than the corresponding point estimates of -1.25 and -1.21 in Table 1. The estimates are even slightly smaller in Table 2b at -0.31 and -0.34.

Overall, when the border effects estimated in Tables 2a and 2b are compared to those in Table 1, a common pattern arises. That is, the border effects are more extreme for states as the smaller underlying economic units, whereas border effects are more muted for divisions as the larger underlying units. This pattern mirrors the cross-sectional heterogeneity apparent in the individual border effects depicted in Figures 1 and 2. There it is also the case that larger economic units (i.e., larger states) are associated with smaller border effects.

We also estimate individual domestic and international border coefficients for the nine Census divisions.\(^{24}\) We plot the individual estimates against logarithmic GDP in Figures 4 and 5, respectively. As in Figure 1, the domestic border effects are negatively related to GDP. For example, East South Central as the smallest Census division is associated with one of the highest domestic border coefficient (equal to 1.29). As in Figure 2, the international border effects are positively related to GDP. For example, the coefficient for East South Central is equal to -0.17.

Considering the vertical scales of Figures 4 and 5, we note that the absolute magnitudes of the individual border effects are generally smaller than in Figures 1 and 2. For instance, the individual domestic coefficients for states in Figure 1 fall into the range [-2.5, 4.3], whereas the corresponding coefficients for divisions in Figure 4 fall into the narrower range [-0.5, 1.5].

\(^{24}\) These estimates are based on the weighted distance measure as in Table 2b. The results are very similar for the unweighted distance measure as in Table 2a.
Similarly, the ranges for the individual international coefficients are [-2.7, 0.9] for states and [-0.6, 0.4] for divisions.

4.4 Aggregating a subset of U.S. states

As an additional check for the results on aggregation, we conduct an alternative aggregation exercise. Whilst maintaining the size and trade flows of all other states, we assume that the six New England states of Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont form a union into a single entity that corresponds to the New England Census division. The trade flows of the individual states are aggregated as described previously. We then rerun the regressions that correspond to Table 1 combining the New England Census division and the remaining U.S. states. To be clear about our approach, other Census divisions could equally be chosen to conduct this alternative aggregation experiment. But we focus on New England as it is the smallest Census division by land area with a strong regional identity and can arguably most closely be regarded as an economic entity.

The individual regression results can be found in Table 3 where we employ the weighted distance measure as in Table 2b.\textsuperscript{25} Compared to Table 1, the border and distance coefficients are broadly similar. Perhaps the most noticeable change is the lower magnitude of the international border effect in columns 3 and 4. The coefficients are -1.17 and -1.12 and thus slightly lower in absolute value than in Table 1 (-1.25 and -1.21). These lower magnitudes are consistent with the strong effect of aggregation on the international border effect as demonstrated in Tables 2a and 2b.

We also estimate individual border effects for the New England division and the other states in the sample. They are plotted in the upper panels of Figures 6 and 7. As a reference point, the bottom panels depict the individual border effects of the six New England states based on Figures 1 and 2 before they were aggregated into a division. The New England domestic border effect in Figure 6 (equal to 0.78) is essentially an average of the six corresponding border effects in the lower panel (their average is 0.70). However, the New England international border effect in Figure 7 (equal to 0.32) is pushed up considerably compared to the six corresponding border effects (whose average is equal to -0.60). This latter finding confirms the previous result on aggregation. Again, we find that aggregating states into a larger entity increases the relative

\textsuperscript{25} The unweighted distance measure yields almost identical results.
size of international trade flows and thus reduces the estimated negative impact of the international border.

4.5 Robustness

Before explaining our above findings, we provide a number of robustness checks. [To be completed.]

5. Explaining the relationship between border effects and economic size

We discuss a number of explanations for our results from a statistical as well as economic perspective. Combining these explanations provides a foundation for understanding our results.

5.1 An overview of our data and the effect of aggregation

We start by providing some quantitative intuition. This intuition is suggestive rather than conclusive because our discussion examines only the impact of aggregation on trade flows. Because aggregation also changes some of the key explanatory variables in our regression analysis, such changes likely also affect our empirical results.

Restricting the focus to trade flows involving a U.S. state and assuming no deleted values because of a zero trade flow or questionable data quality, for a given year the data set would contain 4704 trade flows – 48 intra-state flows, 2256 inter-state flows (48*47), and 2400 international flows. Given that we have four years of data, the maximum number of trade flows would be 18,816 – consisting of 192 intra-state flows, 9024 inter-regional flows, and 9600 international flows. Via aggregation of the 48 states into 9 Census divisions, two changes occur. First, the potential number of observations changes as the number of intra-division flows would be 36, inter-division flows would be 288, and international flows would be 1800. Thus, the percentage reduction in the number of flows would be 81 percent for those within a region, 97 percent for those between (U.S.) regions, and 81 percent for those between a region and a foreign country. Second, the aggregation redefines some trade flows as internal to a division that were previously between states.

In terms of average trade flows, relative to intra-state and inter-state trade flows, the first change by itself would increase both average intra-division and inter-division flows, but the former would increase less than the latter. However, the second change by itself would increase
average intra-division flows and reduce inter-division flows. Consequently, relative to intra-state and inter-state trade flows, it is unclear how the ratio of intra-division to inter-division trade flows would change.

In our data set, using only non-zero values for the four years, the average intra-state trade flow based on 192 observations is 32,362 (millions of dollars) and the average inter-state trade flow based on 6712 observations is 1173. Thus, average intra-state flows exceed inter-state flows by a factor of over 27. Via aggregation, the average intra-division trade flow based on 36 observations is 232,078 and the average inter-division trade flow is 19,904. Thus, average intra-division trade flows exceed inter-division trade flows by a factor slightly less than 12. The impact of the aggregation is to reduce “intra” flows relative to “inter” flows. Such a change is crucial for understanding why the estimated domestic border effect declines as one aggregates the state-level data into Census divisions.

Now let us turn to the impact of the aggregation on the international border effect. Recall that moving from state-level data to Census division-level data causes a 97 percent reduction in the number of flows between (U.S.) regions and an 81 percent reduction in the number of international trade flows. Since the aggregation has no effect on what is defined as an international flow, it is clear that the average international trade flow must increase as one aggregates states into Census divisions. As we saw above, average trade flows between Census divisions relative to between states, which increased, could have either increased or decreased. Thus, similar to the preceding discussion of flows within the United States, it is unclear, relative to inter-state and (state) international trade flows, how the ratio of inter-division to international trade flows changes.

Recall that the average inter-state trade flow in our data set based on 6712 observations is 1173. Meanwhile, the average international trade flow by state based on 9352 observations is 265. Thus, average inter-state trade flows are more than average international trade flows by a factor of slightly more than 4. Recall that after aggregation the average inter-division trade flow based on 288 observations is 19,904. Meanwhile, the average international trade flow by division using 1764 observations 1404. Thus, average inter-division flows are more than the international flows by a factor of more than 14. This rise in “inter” flows relative to international flows suggests that the estimated international border effect should tend to increase as one aggregates
the state-level data into Census divisions. Clearly, something must be happening on the right-hand-side of our equation, a point that has been made previously in the MAUP literature.

For example, Briant, Combes, and Lafourcade (2010) conclude that changing the size of already small economic units even slightly affects empirical estimates (this issue becomes more important the larger the geographic unit), and changing the shape matters less. Compared to econometric specification issues, both of these issues are of secondary importance. They also note that MAUP is likely to be more prominent when variables are not computed under the same aggregation process. In gravity equations for example, the dependent variable might be a summation of trade flows on the left-hand side, while an independent variable such as distance is averaged. Moreover, Fotheringham and Wong (1991) show that the intensity and effects of MAUP in a multivariate analysis are virtually unpredictable.

5.2 The concentration of economic activity

[To be completed.]

6. Conclusion

We collect a data set of U.S. exports that combines three types of trade flows: trade within an individual state (Minnesota-Minnesota), trade between U.S. states (Minnesota-Texas) as well as trade flows from an individual U.S. state to a foreign country (Minnesota-Canada) or between foreign countries (Canada-Japan). This data set allows us to estimate the effect on trade of crossing the domestic state border and the effect of crossing the international border. Moreover, it allows us to estimate state border and international borders effects by state.

We find that the larger the state, the smaller its international border effect and the smaller its own border effect. In addition, both the international border effect and the domestic border effect decline when states are aggregated into larger U.S. Census divisions. Clearly, size and aggregation matter. Our results cast doubt on the interpretation of border effects as typically estimated in the literature. Instead, we argue that border effects have to be interpreted taking into account the economic size of the underlying regions.
References


Figure A:

\[ x_{ii} = 20, \quad x_{ij} = 10, \quad y_i = y_j = 50 \]

Figure B:

\[ x_{ii} = 60, \quad x_{ij} = 40, \quad y_i = y_j = 100 \]

Figure C:
Figure 1: Individual domestic border effects for 48 U.S. states plotted against ln(GDP).

Figure 2: Individual international border effects for 48 U.S. states plotted against ln(GDP).
Figure 3: The nine U.S. Census divisions (source: U.S. Department of Energy).
Figure 4: Individual domestic border effects for nine U.S. Census divisions plotted against GDP.

Figure 5: Individual international border effects for nine U.S. Census divisions plotted against GDP.
Figure 6: Individual domestic border effects for 43 U.S. states and the New England division (upper panel) and for 48 U.S. states as in Figure 1 (lower panel), plotted against GDP.
Figure 7: Individual international border effects for 43 U.S. states and the New England division (upper panel) and for 48 U.S. states as in Figure 1 (lower panel), plotted against GDP.
Figure 8: Domestic border effects (upper panel) and international border effects (lower panel) based on subsamples for the year 1993. Black scatter points indicate the subsequent dropping of the largest states so that the smallest states remain. Grey scatter points indicate the opposite. The horizontal axis indicates the number of states dropped. When no states are dropped, the estimates are the same as for the full sample in Table 1 (1.47 for the upper panel as in Table 1, column 1 and -1.25 for the lower panel as in Table 1, column 3).
Table 1: Domestic and international border effects, based on U.S. states

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Notes: The dependent variable is ln(x<sub>ij</sub>). OLS estimation. Robust standard errors are reported in parentheses, clustered around country pairs i,j in columns 2 and 4. Exporter and importer fixed effects in columns 1 and 2; state and country fixed effects in columns 3 and 4; time-varying in columns 2 and 4. Constants and year dummies are not reported. *** significant at 1% level.
Table 2a: Domestic and international border effects, based on Census divisions

<table>
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Notes: The dependent variable is ln(x<sub>ij</sub>). OLS estimation. Robust standard errors are reported in parentheses, clustered around country pairs i j in columns 2 and 4. Exporter and importer fixed effects in columns 1 and 2; state and country fixed effects in columns 3 and 4; time-varying in columns 2 and 4. Constants and year dummies are not reported. *** significant at 1% level.
Table 2b: Domestic and international border effects, based on Census divisions and weighted distance

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Table 3: Domestic and international border effects, based on U.S. states and New England Census division

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Notes: The dependent variable is ln(x<sub>ij</sub>). OLS estimation. Robust standard errors are reported in parentheses, clustered around country pairs i j in columns 2 and 4. Exporter and importer fixed effects in columns 1 and 2; state and country fixed effects in columns 3 and 4; time-varying in columns 2 and 4. Constants and year dummies are not reported. *** significant at 1% level.