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Trade, Wages, and Productivity

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Abstract:
We develop a new general equilibrium model of trade with heterogeneous firms, variable demand elasticities and endogenously determined wages. Trade integration favors wage convergence, intensifies competition, and forces the least efficient firms to leave the market, thereby affecting aggregate productivity. Since wage and productivity responses are endogenous, our model is well suited to study the impacts of trade integration on aggregate productivity and factor prices. Using Canada-U.S. interregional trade data, we first estimate a system of theory-based gravity equations under the general equilibrium constraints generated by the model. Doing so allows us to measure "border effects" and to decompose them into a "pure" border effect, relative and absolute wage effects, and a selection effect. Using the estimated parameter values, we then quantify the impacts of removing the Canada-U.S. border on wages, productivity, markups, the share of exporters, the mass of varieties produced and consumed, and welfare. We finally provide a similar quantification with respect to regional population changes.

Keywords: Heterogeneous firms, gravity equations, general equilibrium, monopolistic competition, variable demand elasticities

JEL Classification: F12, F15, F17

1 Introduction

Over the last decade, empirical research in international trade has revealed the existence of substantial firm-level heterogeneity. Only a small share of firms is engaged in foreign trade, and these firms differ along various dimensions from purely domestic ones. Exporters tend, in particular, to be larger and more productive than non-exporters. These firm-level productivity differences act as channels through which trade liberalization brings about aggregate productivity gains, by forcing the least efficient firms to leave the market and by reallocating market shares from low to high productivity firms (e.g., Bernard and Jensen, 1999; Aw *et al.*, 2000; Pavcnik, 2002; Bernard *et at.*, 2007). While these firm-level facts are intrinsically incompatible with the paradigm of the 'representative firm' that has dominated international trade theory for decades, several models with heterogeneous firms have been recently put forward to accomodate them. In his seminal contribution, Melitz (2003) extends Krugman's (1980) model of intra-industry trade to cope with productivity differences across firms and shows that the most productive firms self-select into export markets and that trade liberalization forces the least efficient firms to exit, thus leading to aggregate productivity gains.

Although Melitz's (2003) model has greatly increased our understanding of intra-industry reallocations in a trading world it is fair to say that it relies on two restrictive assumptions: factor price equalization (FPE) and constant elasticity of substitution (CES). First, as is well known, FPE need not hold in models of monopolistic competition with differentiated goods and trade costs (e.g., Helpman and Krugman, 1985). Nevertheless, it does hold in Melitz's model because countries are assumed to be symmetric so that no wage differences can arise in equilibrium. Though analytically convenient, such an assumption masks the fact that different productivity gains across countries map quite naturally into different changes in factor prices and incomes, both of which are bound to affect trade in various ways in general equilibrium. Second, the CES framework generates constant markups over marginal costs, i.e., price-cost margins are unaffected by trade integration, by firms' productivities, and by local market size. These features do not accord with abundant recent empirical evidence.[1]

The recent literature on heterogeneous firms has addressed either one of these restrictive features. First, Bernard *et al.* (2003) relax FPE by imposing exogenous cross-country wage differences within a Ricardian framework. However, their model offers the stark prediction of identical distributions of markups across countries. Second, Melitz and Ottaviano (2008) provide a model where markups decrease with trade integration and can be distributed differently across countries, depending on both market size and accessibility. However, they assume

[1] For example, Badinger (2007) finds solid evidence that the Single Market Programme of the European Union has reduced markups in aggregate manufacturing. Foster *et al.* (2008) show that more productive firms set lower prices and charge higher markups. Finally, Syverson (2004) documents that areas of high economic density and large local market size have higher average productivity and less productivity dispersion.

quasi-linear preferences which channel all income effects towards a homogeneous numeraire good. The quasi-linear specification also implies FPE given identical technologies across countries and free trade in the numeraire good. Last, Bernard *et al.* (2007) embed Melitz's model into a two-country Heckscher-Ohlin framework, which allows for factor price differences across countries. They, however, rely again on the CES specification and therefore obtain constant markups that are invariant to trade liberalization and market size.[2]

We are unaware of a full-fledged general equilibrium model with heterogeneous firms in which wages and markups are endogenous and need not be equalized across countries. Developing such a framework is the first contribution of this paper. To this end, we extend the recent model by Behrens and Murata (2007) to accommodate heterogeneous firms and multiple countries which may differ in size, accessibility, and their underlying productivity distributions. Within this setting, we shed light on the impacts of trade integration and market size on wages, firm selection, and markups. Falling trade barriers increase expected profits in the foreign markets and encourage firms to start exporting. This induces tougher selection, increases average productivity and reduces average markups as in, for instance, Melitz and Ottaviano (2008). Furthermore, higher average productivity maps into wage changes which differ across asymmetric countries. Put differently, trade integration spurs additional effects due to changes in relative and absolute wages. On the one hand, wages in some regions will rise relatively to those in others. Consequently, there is a cost increase for the firms located in regions where relative wages rise, which erodes their competitive position in foreign markets. On the other hand, absolute wages also rise in some regions which are then reflected in higher export prices and larger local demands. These various price and income effects must be taken into consideration to understand how trade liberalization may affect productivity and wages.

Despite the richness of effects and economic mechanisms at work, our model remains highly tractable even when extended to multiple asymmetric countries. This makes it particularly well suited as a basis for applied work. Therefore, turning to our second contribution, we take our model to data and quantify it using a methodology similar to the ones developed in Anderson and van Wincoop (2003) and Bernard *et al.* (2003). To do so, we derive a gravity equation under the general equilibrium constraints generated by the model, and structurally estimate it using a well-known dataset on interregional trade flows between U.S. states and Canadian provinces.[3] This quantified framework is particularly useful, because it allows us to finely assess

[2]Other important contributions to the heterogeneous firms literature with a different focus include Helpman *et al.* (2004), who extend Melitz's (2003) model to include multinational firms; and Antràs and Helpman (2004), who introduce outsourcing into a heterogeneous firms framework. For an overview of recent advances in the literature, see Helpman (2006).

[3]Our empirical analysis supplements Anderson and van Wincoop (2003) in that our general equilibrium constraints include both endogenous wages and firm heterogeneity. Several recent contributions have derived gravity equations with heterogeneous firms (e.g., Chaney, 2008; Helpman *et al.*, 2008; Melitz and Ottaviano, 2008). In all these models, wages are either equalized or assumed to differ exogenously via Ricardian differences

how and through which economic channels various exogenous shocks would affect the different Canadian provinces and U.S. states. We provide two such 'counterfactual analyses'. First, we simulate the effects of eliminating the trade distortion generated by the Canada-U.S. border on regional trade flows, which represents a hypothetical scenario where only distance still matters as an impediment to trade. We compute a series of *bilateral border effects* which summarize how trade flows between any two regions (within or across countries) would be affected by the hypothetical border removal. These bilateral border effects can then be decomposed into a 'pure' border effect, relative and absolute wage effects, and a selection effect, thereby providing a detailed account of which factors drive these effects in the first place. We show that both endogenous wage responses and firm selection systematically increase measured U.S. and decrease measured Canadian border effects as compared to previous estimates from the literature. Second, we quantify the impacts of this full removal of the Canada-U.S. border on other key economic variables at the regional level. In particular, we show that all regions would experience welfare gains since average productivity increases and product diversity expands everywhere, but that some regions quite naturally gain more than others. Finally, we investigate how local market size affects the equilibrium via changes in regional populations. To this end, we hold trade frictions fixed at their initial levels and consider how the observed population changes between 1993 and 2007 affect the different provinces and states. We find that the western Canadian provinces and the southern U.S. states gain the most in terms of productivity and wages, whereas small peripheral regions like Newfoundland may experience productivity and welfare losses.

The remainder of the paper is organized as follows. Section 2 deals with the closed economy case. In Section 3 we extend it to a multi-country framework. Section 4 derives the gravity equation system, describes the data, and presents the estimation procedure. In Section 5 we illustrate the counterfactual experiment of removing the border. Section 6 concludes.

2 Closed economy

Consider a closed economy with a final consumption good, provided as a continuum of horizontally differentiated varieties. We denote by Ω the endogenously determined set of available varieties, with measure N. There are L consumers, each of whom supplies inelastically one unit of labor, which is the only factor of production.

in some costlessly tradable numeraire sector. Balistreri and Hillberry (2007) are, to the best of our knowledge, the first to structurally estimate a gravity equation with endogenous wages, but they neglect firm heterogeneity.

2.1 Preferences and demands

All consumers have identical preferences which display 'love of variety' and give rise to demands with variable elasticities. Following Behrens and Murata (2007), the utility maximization problem of a representative consumer is given by:

$$\max_{q(j),\, j\in\Omega} \; U \equiv \int_\Omega \left[1 - \mathrm{e}^{-\alpha q(j)}\right]\mathrm{d}j \qquad \text{s.t.} \quad \int_\Omega p(j)q(j)\mathrm{d}j = E, \tag{1}$$

where E denotes expenditure; $p(j) > 0$ and $q(j) \geq 0$ stand for the price and the per capita consumption of variety j; and $\alpha > 0$ is a parameter. As shown by Behrens and Murata (2007), solving (1) yields the following demand functions:

$$q(i) = \frac{E}{N\overline{p}} - \frac{1}{\alpha}\left\{\ln\left[\frac{p(i)}{N\overline{p}}\right] + h\right\}, \quad \forall i \in \Omega, \tag{2}$$

where

$$\overline{p} \equiv \frac{1}{N}\int_\Omega p(j)\mathrm{d}j \quad \text{and} \quad h \equiv -\int_\Omega \ln\left[\frac{p(j)}{N\overline{p}}\right]\frac{p(j)}{N\overline{p}}\mathrm{d}j$$

denote the average price and the differential entropy of the price distribution, respectively. Since marginal utility at zero consumption is bounded, the demand for a variety need not be positive. Indeed, as can be seen from (2), the demand for variety i is positive if and only if its price is lower than the reservation price p^d. Formally,

$$q(i) > 0 \quad \Longleftrightarrow \quad p(i) < p^d \equiv N\overline{p}\,\mathrm{e}^{\frac{\alpha E}{N\overline{p}} - h}. \tag{3}$$

Note that the reservation price p^d is a function of the price aggregates $\overline{p}$ and h. Combining expressions (2) and (3) allows us to express the demand for variety i concisely as follows:

$$q(i) = \frac{1}{\alpha}\ln\left[\frac{p^d}{p(i)}\right]. \tag{4}$$

2.2 Technology and market structure

The labor market is assumed to be perfectly competitive so that all firms take the wage rate w as given. Prior to production, each firm engages in research and development, which requires a fixed amount F of labor paid at the market wage. Each entrant discovers its marginal labor requirement $m(i) \geq 0$ only after making this irreversible investment. We assume that $m(i)$ is drawn from a common and known, continuously differentiable distribution G. Since research and development costs are sunk, a firm will remain active in the market provided it can charge a price $p(i)$ above marginal cost $m(i)w$.

Each surviving firm sets its price to maximize operating profit

$$\pi(i) = L\big[p(i) - m(i)w\big]q(i), \tag{5}$$

where $q(i)$ is given by (4). Since there is a continuum of firms, no individual firm has any impact on p^d so that the first-order conditions for (operating) profit maximization are given by:

$$\ln\left[\frac{p^d}{p(i)}\right] = \frac{p(i) - m(i)w}{p(i)}, \quad \forall i \in \Omega. \tag{6}$$

A price distribution satisfying (6) is called a *price equilibrium*. Multiplying both sides of (6) by $p(i)$, integrating over Ω, and using (4) yield the average price as follows:

$$\overline{p} = \overline{m}w + \frac{\alpha E}{N}, \tag{7}$$

where $\overline{m} \equiv (1/N)\int_\Omega m(j)\mathrm{d}j$ denotes the average marginal labor requirement of the surviving firms. Observe that expression (7) displays pro-competitive effects, i.e., the average price is decreasing in the mass of surviving firms N.

Equations (4) and (6) imply that $q(i) = (1/\alpha)[1 - m(i)w/p(i)]$, which allows us to derive the upper and lower bounds for the marginal labor requirement. The maximum output is given by $q(i) = 1/\alpha$ at $m(i) = 0$. The minimum output is given by $q(i) = 0$ at $p(i) = m(i)w$, which by (6) implies that $p(i) = p^d$. Therefore, the cutoff marginal labor requirement is defined as $m^d \equiv p^d/w$. A firm that draws m^d is indifferent between producing and not producing, whereas all firms with a draw below (resp., above) m^d remain in (resp., exit from) the market.

Since firms differ only by their marginal labor requirement, we can express all firm-level variables in terms of m. Solving (6) by using the Lambert W function, defined as $\varphi = W(\varphi)\mathrm{e}^{W(\varphi)}$, the profit-maximizing prices and quantities as well as operating profits can be expressed as follows:

$$p(m) = \frac{mw}{W}, \quad q(m) = \frac{1}{\alpha}(1 - W), \quad \pi(m) = \frac{Lmw}{\alpha}\left(W^{-1} + W - 2\right), \tag{8}$$

where we suppress the argument $\mathrm{e}m/m^d$ of W to alleviate notation (see Appendix A.1 for the derivations). It is readily verified that $W' > 0$ for all non-negative arguments and that $W(0) = 0$ and $W(\mathrm{e}) = 1$. Hence, $0 \leq W \leq 1$ if $0 \leq m \leq m^d$.[4] The expressions in (8) then show that a firm with draw m^d charges a price equal to marginal cost, faces zero demand, and earns zero profit. Since $W' > 0$, we readily obtain $\partial p(m)/\partial m > 0$, $\partial q(m)/\partial m < 0$ and $\partial \pi(m)/\partial m < 0$. In words, firms with better draws charge lower prices, sell larger quantities, and earn higher operating profits than firms with worse draws.

2.3 Equilibrium

We now state the equilibrium conditions for the closed economy, which consist of zero expected profits and labor market clearing. First, given the mass of entrants N^E, the mass of surviving

[4] Clearly, $\varphi = W(\varphi)\mathrm{e}^{W(\varphi)}$ implies that $W(\varphi) \geq 0$ for all $\varphi \geq 0$. Taking logarithms on both sides and differentiating yield $W'(\varphi) = W(\varphi)/\{\varphi[W(\varphi)+1]\} > 0$ for all $\varphi > 0$. Finally, we have $0 = W(0)\mathrm{e}^{W(0)}$, which implies $W(0) = 0$, and $\mathrm{e} = W(\mathrm{e})\mathrm{e}^{W(\mathrm{e})}$, which implies $W(\mathrm{e}) = 1$.

firms can be written as $N = N^E G(m^d)$. Using (5), the zero expected profit condition for each firm is given by

$$L \int_0^{m^d} \left[p(m) - mw\right] q(m) \mathrm{d}G(m) = Fw, \tag{9}$$

which, combined with (8), can be rewritten as

$$\frac{L}{\alpha} \int_0^{m^d} m \left(W^{-1} + W - 2\right) \mathrm{d}G(m) = F. \tag{10}$$

As the left-hand side of (10) is strictly increasing in m^d from 0 to ∞, there always exists a unique equilibrium cutoff (see Appendix A.2). Furthermore, the labor market clearing condition is given by:[5]

$$N^E \left[L \int_0^{m^d} mq(m) \mathrm{d}G(m) + F\right] = L, \tag{11}$$

which combined with (8) can be rewritten as

$$N^E \left[\frac{L}{\alpha} \int_0^{m^d} m \left(1 - W\right) \mathrm{d}G(m) + F\right] = L. \tag{12}$$

Given the equilibrium cutoff m^d, equation (12) can be uniquely solved for N^E.

How does population size affect firms' entry and survival probabilities? Using the equilibrium conditions (10) and (12), we can show that a larger L leads to more entrants N^E and a smaller cutoff m^d, respectively (see Appendix A.3). The effect of population size on the mass of surviving firms N is in general ambiguous. However, under the commonly made assumption that firms' productivity draws $1/m$ follow a Pareto distribution

$$G(m) = \left(\frac{m}{m^{\max}}\right)^k,$$

with upper bound $m^{\max} > 0$ and shape parameter $k \geq 1$, we can show that N is increasing in L.[6] Using this distributional assumption, we readily obtain closed-form solutions for the equilibrium cutoff and mass of entrants:

$$m^d = \left[\frac{\alpha F \left(m^{\max}\right)^k}{\kappa_2 L}\right]^{\frac{1}{k+1}} \quad \text{and} \quad N^E = \frac{\kappa_2}{\kappa_1 + \kappa_2} \frac{L}{F},$$

[5]Note that using (9) and the budget constraint $N^E \int_0^{m^d} p(m)q(m)\mathrm{d}G(m) = E$, we obtain $EL/(wN^E) = L \int_0^{m^d} mq(m)\mathrm{d}G(m) + F$ which, together with (11), yields $E = w$ in equilibrium.

[6]The Pareto distribution has been extensively used in the previous literature on heterogeneous firms (Bernard *et al.*, 2007; Helpman *et al.*, 2008; Melitz and Ottaviano, 2008). Such a distribution is also consistent with the U.S. firm size distribution (see Axtell, 2001).

where κ_1 and κ_2 are positive constants that solely depend on k (see Appendices B.1 and B.2).[7] The mass of surviving firms is then given as follows:

$$N = \frac{\kappa_2^{\frac{1}{k+1}}}{\kappa_1 + \kappa_2} \left(\frac{\alpha}{m^{\max}} \right)^{\frac{k}{k+1}} \left(\frac{L}{F} \right)^{\frac{1}{k+1}},$$

which is increasing in population size. One can further check that N is decreasing in the fixed labor requirement F and in the upper bound $m^{\max}$. Finally, since $\overline{m} = [k/(k+1)]m^d$ holds when productivity follows a Pareto distribution, a larger population also maps into higher average productivity.

3 Open economy

We now turn to the open economy case. As dealing with two regions only marginally alleviates the notational burden, we first derive the equilibrium conditions for the general case with K asymmetric regions that we use when taking our model to the data. We then present some clear-cut analytical results for the special case of two asymmetric regions in order to guide the intuition for the general case.

3.1 Preferences and demands

Preferences are analogous to the ones described in the previous section. Let $p_{sr}(i)$ and $q_{sr}(i)$ denote the price and the per capita consumption of variety i when it is produced in region s and consumed in region r. It is readily verified that the demand functions in the open economy case are given as follows:

$$q_{sr}(i) = \frac{E_r}{N_r^c \overline{p}_r} - \frac{1}{\alpha} \left\{ \ln \left[\frac{p_{sr}(i)}{N_r^c \overline{p}_r} \right] + h_r \right\}, \quad \forall i \in \Omega_{sr},$$

where N_r^c is the mass of varieties consumed in region r; Ω_{sr} denotes the set of varieties produced in region s and consumed in region r; and

$$\overline{p}_r \equiv \frac{1}{N_r^c} \sum_s \int_{\Omega_{sr}} p_{sr}(j) \mathrm{d}j \quad \text{and} \quad h_r \equiv - \sum_s \int_{\Omega_{sr}} \ln \left[\frac{p_{sr}(j)}{N_r^c \overline{p}_r} \right] \frac{p_{sr}(j)}{N_r^c \overline{p}_r} \mathrm{d}j$$

denote the average price and the differential entropy of the price distribution of all varieties consumed in region r. As in the closed economy case, the demand for domestic variety i (resp., foreign variety j) is positive if and only if the price of variety i (resp., variety j) is lower than the reservation price p_r^d. Formally,

$$q_{rr}(i) > 0 \iff p_{rr}(i) < p_r^d \quad \text{and} \quad q_{sr}(j) > 0 \iff p_{sr}(j) < p_r^d,$$

[7] For this solution to be consistent, we must ensure that $m^d \leq m^{\max}$, i.e., $m^{\max} \geq (\alpha F/L)^{1/k}$.

where $p_r^d \equiv N_r^c \overline{p}_r e^{\alpha E_r/(N_r^c \overline{p}_r) - h_r}$ is a function of the price aggregates $\overline{p}_r$ and h_r. The demands for domestic and foreign varieties can then be concisely expressed as follows:

$$q_{rr}(i) = \frac{1}{\alpha} \ln \left[\frac{p_r^d}{p_{rr}(i)} \right] \quad \text{and} \quad q_{sr}(j) = \frac{1}{\alpha} \ln \left[\frac{p_r^d}{p_{sr}(j)} \right]. \tag{13}$$

3.2 Technology and market structure

Technology and the entry process are identical to the ones described in Section 2. We assume that shipments from r to s are subject to trade costs $\tau_{rs} > 1$ for all r and s, that markets are segmented, and that firms are free to price discriminate.

Firms in region r independently draw their productivities from a region-specific distribution G_r. Assuming that firms incur trade costs in terms of labor, the operating profit of firm i in r is given by:

$$\pi_r(i) = \sum_s \pi_{rs}(i) = \sum_s L_s q_{rs}(i) \left[p_{rs}(i) - \tau_{rs} m_r(i) w_r \right]. \tag{14}$$

Each firm maximizes (14) with respect to its prices $p_{rs}(i)$ separately. Since it has no impact on the price aggregates and on the wages, the first-order conditions are given by:

$$\ln \left[\frac{p_s^d}{p_{rs}(i)} \right] = \frac{p_{rs}(i) - \tau_{rs} m_r(i) w_r}{p_{rs}(i)}, \quad \forall i \in \Omega_{rs}. \tag{15}$$

We first solve for the average price in region r. To do so, multiply (15) by $p_{rs}(i)$, use (13), integrate over Ω_{rs}, and finally sum the resulting expressions to obtain

$$\overline{p}_r \equiv \frac{1}{N_r^c} \sum_s \int_{\Omega_{sr}} p_{sr}(j) \mathrm{d}j = \frac{1}{N_r^c} \sum_s \tau_{sr} w_s \int_{\Omega_{sr}} m_s(j) \mathrm{d}j + \frac{\alpha E_r}{N_r^c}, \tag{16}$$

where the first term is the average of marginal delivered costs in region r. Expression (16) shows that $\overline{p}_r$ is decreasing in the mass N_r^c of firms competing in region r, which is similar to the result on pro-competitive effects established in the closed economy case.

Equations (13) and (15) imply that $q_{rs}(i) = (1/\alpha)[1 - \tau_{rs} m_r(i) w_r / p_{rs}(i)]$, which shows that $q_{rs}(i) = 0$ at $p_{rs}(i) = \tau_{rs} m_r(i) w_r$. It then follows from (15) that $p_{rs}(i) = p_s^d$. Hence, a firm located in r with draw $m_{rs}^x \equiv p_s^d / (\tau_{rs} w_r)$ is just indifferent between selling and not selling in region s. All firms with draws below m_{rs}^x are productive enough to sell to region s. In what follows, we refer to $m_{ss}^x \equiv m_s^d$ as the *domestic cutoff* in region s, whereas m_{rs}^x with $r \neq s$ is the *export cutoff*. Export and domestic cutoffs are linked as follows:

$$m_{rs}^x = \frac{\tau_{ss}}{\tau_{rs}} \frac{w_s}{w_r} m_s^d. \tag{17}$$

Expression (17) reveals how trade costs and wage differentials affect firms' ability to break into foreign markets. When wages are equalized ($w_r = w_s$) and internal trade is costless ($\tau_{ss} = 1$), all export cutoffs must fall short of the domestic cutoffs since $\tau_{rs} > 1$. In that case, breaking into any foreign market is always harder than selling domestically. However, in the presence of wage differentials and internal trade costs, the domestic and the foreign cutoffs can no longer be clearly ranked. The usual ranking, namely that exporting to s is more difficult than selling domestically in s, prevails only when $\tau_{ss} w_s < \tau_{rs} w_r$.

The first-order conditions (15) can be solved as in the closed economy case. Switching to notation in terms of m, the profit-maximizing prices and quantities as well as operating profits are given by:

$$p_{rs}(m) = \frac{\tau_{rs} m w_r}{W}, \quad q_{rs}(m) = \frac{1}{\alpha}\left(1 - W\right), \quad \pi_{rs} = \frac{L \tau_{rs} m w_r}{\alpha}(W^{-1} + W - 2), \tag{18}$$

where W denotes the Lambert W function with argument $\mathrm{e}\tau_{rs} m w_r / p_s^d$. It is readily verified that more productive firms again charge lower prices, sell larger quantities, and earn higher operating profits.

Observe that in an open economy, the masses of varieties consumed and produced in each region need not be the same. Given a mass of entrants N_r^E, only $N_r^p = N_r^E G_r\left(\max_s \{m_{rs}^x\}\right)$ firms survive, namely those which are productive enough to sell at least in one market. Finally, the mass of varieties consumed in region r is given by

$$N_r^c = \sum_s N_s^E G_s(m_{sr}^x), \tag{19}$$

which, contrary to N_r^p, depends on the distributions G_s of all its trading partners.

3.3 Equilibrium

The zero expected profit condition for each firm in region r is given by

$$\sum_s L_s \int_0^{m_{rs}^x} \left[p_{rs}(m) - \tau_{rs} m w_r\right] q_{rs}(m) \mathrm{d}G_r(m) = F_r w_r, \tag{20}$$

where F_r is the region-specific fixed labor requirement. Furthermore, each labor market clears in equilibrium, which yields

$$N_r^E \left[\sum_s L_s \tau_{rs} \int_0^{m_{rs}^x} m q_{rs}(m) \mathrm{d}G_r(m) + F_r\right] = L_r. \tag{21}$$

Last, trade is balanced for each region:

$$N_r^E \sum_{s \neq r} L_s \int_0^{m_{rs}^x} p_{rs}(m) q_{rs}(m) \mathrm{d}G_r(m) = L_r \sum_{s \neq r} N_s^E \int_0^{m_{sr}^x} p_{sr}(m) q_{sr}(m) \mathrm{d}G_s(m).$$

As in the foregoing section, we can restate the equilibrium conditions using the Lambert W function (see Appendix C for details).

In what follows, we assume that productivity draws $1/m$ follow a Pareto distribution with identical shape parameters $k \geq 1$. However, to capture local technological possibilities, we allow the upper bounds to differ across regions, i.e., $G_r(m) = (m/m_r^{\max})^k$. A lower $m_r^{\max}$ implies that firms in region r have a higher probability of drawing a better productivity. Under the Pareto distribution, the equilibrium conditions can be greatly simplified. First, using the expressions in Appendices B.1 and C.1, labor market clearing requires that

$$N_r^E \left[\frac{\kappa_1}{\alpha \left(m_r^{\max}\right)^k} \sum_s L_s \tau_{rs} \left(\frac{\tau_{ss}}{\tau_{rs}} \frac{w_s}{w_r} m_s^d \right)^{k+1} + F_r \right] = L_r. \tag{22}$$

Second, using Appendices B.2 and C.2, zero expected profits imply that

$$\mu_r^{\max} \equiv \frac{\alpha F_r \left(m_r^{\max}\right)^k}{\kappa_2} = \sum_s L_s \tau_{rs} \left(\frac{\tau_{ss}}{\tau_{rs}} \frac{w_s}{w_r} m_s^d \right)^{k+1}, \tag{23}$$

where μ_r is a simple monotonic transformation of the upper bounds. Last, using Appendices B.3 and C.3, balanced trade requires that

$$\frac{N_r^E w_r}{\left(m_r^{\max}\right)^k} \sum_{s \neq r} L_s \tau_{rs} \left(\frac{\tau_{ss}}{\tau_{rs}} \frac{w_s}{w_r} m_s^d \right)^{k+1} = L_r \sum_{s \neq r} \tau_{sr} \frac{N_s^E w_s}{\left(m_s^{\max}\right)^k} \left(\frac{\tau_{rr}}{\tau_{sr}} \frac{w_r}{w_s} m_r^d \right)^{k+1}. \tag{24}$$

The $3K$ conditions (22)–(24) depend on $3K$ unknowns: the wages w_r, the masses of entrants N_r^E, and the domestic cutoffs m_r^d. The export cutoffs m_{rs}^x can then be computed using (17). Combining (22) and (23) immediately shows that

$$N_r^E = \frac{\kappa_2}{\kappa_1 + \kappa_2} \frac{L_r}{F_r}. \tag{25}$$

The mass of entrants in region r therefore positively depends on that region's size L_r and negatively on its fixed labor requirement F_r.

Adding the term in r that is missing on both sides of (24), and using (23) and (25), we obtain the following equilibrium relationship:

$$\frac{1}{\left(m_r^d\right)^{k+1}} = \sum_s L_s \tau_{rr} \left(\frac{\tau_{rr}}{\tau_{sr}} \frac{w_r}{w_s} \right)^k \frac{1}{\mu_s^{\max}}. \tag{26}$$

Expressions (23) and (26) summarize how wages, upper bounds, cutoffs, trade costs and population sizes are related in general equilibrium.

3.4 Two-region case

Our model allows for clear-cut comparative static results with two asymmetric regions. Using (23)–(25), an equilibrium can be characterized by a system of three equations with three unknowns $\omega \equiv w_1/w_2$, m_1^d and m_2^d as follows:

$$\left(\frac{w_1}{w_2}\right)^{2k+1} = \left(\frac{\tau_{21}}{\tau_{12}}\right)^k \left(\frac{\tau_{22}}{\tau_{11}}\right)^{k+1} \left(\frac{m_2^d}{m_1^d}\right)^{k+1} \left(\frac{\mu_2^{\max}}{\mu_1^{\max}}\right) \quad (27)$$

$$\mu_r^{\max} = L_r \tau_{rr} \left(m_r^d\right)^{k+1} + L_s \tau_{rs} \left(\frac{\tau_{ss}}{\tau_{rs}} \frac{w_s}{w_r} m_s^d\right)^{k+1}, \quad (28)$$

for $r = 1, 2$ and $s \neq r$. Equation (28) for regions 1 and 2 can readily be solved for the cutoffs as a function of ω:

$$(m_1^d)^{k+1} = \frac{\mu_1^{\max}}{L_1 \tau_{11}} \frac{1 - \rho \left(\frac{\tau_{22}}{\tau_{12}}\right)^k \omega^{-(k+1)}}{1 - \left(\frac{\tau_{11}\tau_{22}}{\tau_{12}\tau_{21}}\right)^k} \quad \text{and} \quad (m_2^d)^{k+1} = \frac{\mu_2^{\max}}{L_2 \tau_{22}} \frac{1 - \rho^{-1} \left(\frac{\tau_{11}}{\tau_{21}}\right)^k \omega^{k+1}}{1 - \left(\frac{\tau_{22}\tau_{11}}{\tau_{21}\tau_{12}}\right)^k}, \quad (29)$$

where $\rho \equiv \mu_2^{\max}/\mu_1^{\max}$ captures relative technological possibilities. A larger ρ implies, ceteris paribus, that firms in region 2 face a higher probability of drawing a worse productivity than those in region 1. Substituting the cutoffs (29) into (27) and simplifying then yields

$$\text{LHS} \equiv \omega^k = \rho \frac{L_1}{L_2} \left(\frac{\tau_{21}}{\tau_{12}}\right)^k \frac{\rho \tau_{11}^{-k} - \tau_{21}^{-k} \omega^{k+1}}{\tau_{22}^{-k} \omega^{k+1} - \rho \tau_{12}^{-k}} \equiv \text{RHS}. \quad (30)$$

Assume that intraregional trade is less costly than interregional trade, i.e., $\tau_{11} < \tau_{21}$ and $\tau_{22} < \tau_{12}$. Then, the RHS of (30) is decreasing in ω on its relevant domain, whereas the LHS is increasing in ω. Hence, there exists a unique equilibrium such that the equilibrium relative wage ω^* is bounded by relative trade costs τ_{22}/τ_{12} and τ_{21}/τ_{11}, relative technological possibilities ρ, and the shape parameter k (see Appendix A.4).

Since the RHS of (30) is decreasing, the comparative static results are straightforward to derive. In Appendix A.5 we show that, everything else equal: (i) the larger region has the higher wage; (ii) the region with better technological possibilities has the higher wage; (iii) higher internal trade costs in one region reduce its relative wage; (iv) better access for one region to the other market raises its relative wage; and (v) wages converge as bilateral trade barriers fall.

4 Estimation

In this section we take the model with K asymmetric regions to the data. To this end, we first derive a theory-based gravity equation with general equilibrium constraints. Using Canada-U.S. regional trade flow data, we then structurally estimate trade friction parameters as well as other parameters of the model.[8] In the next section we turn to counterfactual analyses,

[8]Since our model is one of intra-industry trade, it is better suited to analyze trade among similar regions where factor proportions are less likely to matter. Furthermore, the Canada-U.S. regional trade data has been widely used in the literature, which makes it possible to compare our results to existing ones.

where we consider the impacts of a decrease in trade frictions as well as changes in population sizes on various economic variables.

4.1 Gravity equation system

Using the results established in the previous section, the value of exports from region r to region s is given by

$$X_{rs} = N_r^E L_s \int_0^{m_{sr}^x} p_{rs}(m) q_{rs}(m) \mathrm{d}G_r(m).$$

Using (18), (25), and the Pareto distribution for $G_r(m)$, we obtain the following gravity equation:[9]

$$\frac{X_{rs}}{L_r L_s} = \tau_{rs}^{-k} \tau_{ss}^{k+1} (w_s/w_r)^{k+1} w_r \left(m_s^d\right)^{k+1} (\mu_r^{\max})^{-1}. \tag{31}$$

As can be seen from (31), exports depend on bilateral trade costs τ_{rs}, internal trade costs in the destination τ_{ss}, origin and destination wages w_r and w_s, destination productivity m_s^d, and origin technological possibilities $\mu_r^{\max}$. A higher relative wage w_s/w_r raises the value of exports as firms in r face relatively lower production costs, whereas a higher absolute wage w_r raises the value of exports by increasing export prices p_{rs}. Furthermore, a larger m_s^d raises the value of exports since firms located in the destination are on average less productive. Last, a lower $\mu_r^{\max}$ implies that firms in region r have higher expected productivity, which quite naturally raises the value of their exports.

From conditions (23) and (26) we obtain the following general equilibrium constraints:

$$\frac{1}{\left(m_s^d\right)^{k+1}} = \sum_v L_v \tau_{vs}^{-k} \tau_{ss}^{k+1} \left(\frac{w_s}{w_v}\right)^k \frac{1}{\mu_v^{\max}} \qquad s = 1, 2, \ldots K \tag{32}$$

$$\mu_r^{\max} = \sum_v L_v \tau_{rv}^{-k} \tau_{vv}^{k+1} \left(\frac{w_v}{w_r}\right)^{k+1} \left(m_v^d\right)^{k+1} \qquad r = 1, 2. \ldots K \tag{33}$$

The *gravity equation system* consists of the gravity equation (31) and the $2K$ general equilibrium constraints (32) and (33) that summarize the interactions between the $2K$ endogenous variables, wages and cutoffs. Expressions (32) and (33) are reminiscent of the constraints in Anderson and van Wincoop (2003), who argue that general equilibrium interdependencies need to be taken into account when conducting counterfactual analysis based on the gravity equation.[10] One of our contributions is to go a step further by extending their approach to

[9] Contrary to the standard gravity literature, we do not move the GDPs but instead the population sizes to the left-hand side. Applying the former approach to our model would amount to assuming that wages are exogenous in the gravity estimation, which is not the case in general equilibrium (see Bergstrand, 1985, for an early contribution on this issue).

[10] It might be tempting to treat w_r, w_s, m_s^d and $\mu_r^{\max}$ as fixed effects in equation (31), as has been frequently done before. However, although fixed effect estimation yields consistent estimates for trade friction parameters,

include firm heterogeneity and endogenous wages. Note that expression (31) is similar to gravity equations that have been derived in previous models with heterogeneous firms. These models rely, however, on exogenous wages (Chaney, 2008; Melitz and Ottaviano, 2008) and also often disregard general equilibrium constraints when being estimated (Helpman *et al.*, 2008). Furthermore, models with endogenous wages such as Balistreri and Hillberry (2007) do not consider firm heterogeneity.

4.2 Estimation procedure

To estimate the gravity equation system (31)–(33) requires data for trade flows and population sizes. We also need to specify trade costs τ_{rs}. In what follows, we stick to standard practice by assuming that $\tau_{rs} \equiv d_{rs}^{\gamma} \mathrm{e}^{\theta b_{rs}}$, where d_{rs} stands for distance between r and s and where b_{rs} is a border dummy valued 1 if r and s are not in the same country and 0 otherwise. This specification, which assumes that regional trade is not only affected by physical distance but also by the presence of the Canada-U.S. border, allows us to relate our first counterfactual to the vast literature on border effects following McCallum (1995).

There are three key issues for the estimation. First, we need to recover a value for the shape parameter k, which requires statistics computed from micro-level data. Such figures for the U.S. are provided by Bernard *et al.* (2003) and Bernard *et al.* (2005) from 1992 Census data. The precise choice for k is discussed in the next subsection.

Second, there exists no data for $\mu_r^{\max}$ since it depends on the unobservables α, F_r and $m_r^{\max}$. To address this issue, we use the general equilibrium constraints (32)–(33). Ideally, we would plug data for $\mu_r^{\max}$ into these $2K$ constraints to solve for the $2K$ endogenous variables w_r and m_s^d. However, as the $\mu_r^{\max}$ are unobservable, we rely instead on data for the K endogenous cutoffs m_s^d. This allows us to solve the $2K$ equilibrium constraints (32) and (33) for theoretically consistent values of the $2K$ variables w_r and $\mu_r^{\max}$.

Last, the estimates of the trade friction parameters γ and θ depend on w_r, $\mu_r^{\max}$ and m_r^d, which depend themselves on the estimates of γ and θ. Put differently, the constraints (32) and (33) include the trade friction parameters, but to estimate the parameters of the gravity equation we need the solution to these constraints. We tackle this problem by estimating the gravity equation system iteratively.

In sum, our estimation procedure consists of the following four steps:

1. Given our specification of τ_{rs}, the gravity equation (31) can be rewritten in log-linear

this approach cannot be used for counterfactual analysis since the effect of the counterfactual on the estimated fixed effects is not known. In our approach, the endogenous responses of wages and cutoffs are crucial when evaluating the counterfactual scenarios.

stochastic form as follows:

$$\ln\left(\frac{X_{rs}}{L_r L_s}\right) = -k\gamma \ln d_{rs} - k\theta b_{rs} + \zeta_r^1 + \zeta_s^2 + \varepsilon_{rs}, \tag{34}$$

where all terms specific to the origin and the destination are collapsed into exporter and importer fixed effects ζ_r^1 and ζ_s^2; and where ε_{rs} is an error term with the usual properties. From (34), we obtain initial unconstrained estimates of the parameters $(\widehat{\gamma}', \widehat{\theta}')$.[11]

2. Using the initial estimates $(\widehat{\gamma}', \widehat{\theta}')$ and the observed cutoffs m_s^d in (32) and (33), we solve simultaneously for the equilibrium wages and the upper bounds $(\widehat{w}_r', \widehat{\mu_r^{\max}}')$.

3. We use the computed values $(\widehat{w}_r', \widehat{\mu_r^{\max}}')$ to estimate the gravity equation (31) as follows:

$$\ln\left(\frac{X_{rs}}{L_r L_s}\right) + k \ln \widehat{w_r}' - (k+1) \ln \widehat{w_s}' - \ln m_s^d + \ln \widehat{\mu_r^{\max}}'$$
$$= -\gamma k \ln d_{rs} + \gamma(k+1) \ln d_{rr} - k\theta b_{rs} + \varepsilon_{rs},$$

which yields constrained estimates $(\widehat{\gamma}'', \widehat{\theta}'')$.

4. We iterate through steps 2 to 3 until convergence to obtain $(\widehat{\gamma}, \widehat{\theta})$ and $(\widehat{w}_r, \widehat{\mu_r^{\max}})$.

The estimates of trade frictions $(\widehat{\gamma}, \widehat{\theta})$ and of wages and upper bounds $(\widehat{w}_r, \widehat{\mu_r^{\max}})$ are consistent with theory as they take into account all the equilibrium information of the model. We then have all the elements needed to conduct counterfactual analyses and we can retrieve the fitted (predicted) value of trade flows $\widehat{X_{rs}}$ for all regions.

4.3 Data

We use the same regional trade data as Anderson and van Wincoop (2003) and Feenstra (2004). The dataset contains detailed information for 51 U.S. regions (50 states plus the District of Columbia) and 10 Canadian provinces.[12] The variables consist of bilateral trade flows X_{rs} and internal absorption X_{rr} for the year 1993, and geographical distances between regional capitals d_{rs}. We augment this dataset by adding regional population sizes L_r in 1993, which are obtained from Statistics Canada and the U.S. Census Bureau. Internal distances are measured as $d_{rr} = (1/4)\min_{s \neq r}\{d_{rs}\}$ like in Anderson and van Wincoop (2003). As a robustness check we also consider the alternative measure $d_{rr} = (2/3)\sqrt{\text{surface}_r/\pi}$ as in Redding and Venables (2004).

[11] It is worth emphasizing that our estimates do not depend on the starting values used for γ and θ. However, the fixed effects estimates provide a reasonable 'guess' for the starting values and allow for faster convergence of the iterative procedure.

[12] Because of their very small population sizes and predominant reliance on natural resources, we exclude Yukon and Northwest Territories in what follows.

Under the Pareto distribution, the domestic cutoff in each region is proportional to the inverse of the average productivity, i.e., $m_r^d = [(k+1)/k]\overline{m}_r$. We measure $\overline{m}_r$ by using the GDP per employee in Canadian dollars for each state and province in 1993 obtained from Statistics Canada and the U.S. Census Bureau. We choose the shape parameter k as follows. First, if productivity $1/m$ is distributed Pareto with parameter k, then $\log(1/m)$ follows an exponential distribution with parameter k and standard deviation $1/k$ (see Norman *et al.*, 1994). Therefore, one can estimate k by computing the standard deviation of log productivity across plants. The standard deviation of log U.S. plant-level labor productivity in 1992, provided by Bernard *et al.* (2003, Table 2), suggests that k is around 1.4. However, as pointed out by these authors, productivity is likely to be measured with error, thus delivering a downward biased estimate of k. To cope with this problem, Bernard *et al.* (2003) calibrate the parameter governing the variance of productivity in order to match the size and productivity advantage of exporters. Since they work with a Fréchet distribution, we can retrieve the relevant value of $k = 3.6$ for our Pareto distribution.[13] In what follows, we consider $k = 3.6$ as our baseline value. As robustness checks, we also consider $k = 1.4$ and $k = 6.5$. As will become clear, our key results are little sensitive to the choice of k.

To estimate the gravity equation system, we restrict ourselves to the same subset of 40 regions used by both Anderson and van Wincoop (2003) and Feenstra (2004). Doing so allows for better comparability of results. In addition, it circumvents the problem of missing and zero flows which are mainly concentrated on the 21 remaining regions in the sample. Note, however, that once we obtain initial unconstrained estimates for the structural parameters $(\widehat{\gamma}', \widehat{\theta}')$, we can solve (32) and (33) for the wages and upper bounds $(\widehat{w_r}', \widehat{\mu_r^{\max}}')$ even when we have no data on the trade flows between regions r and s. We can hence use a maximum amount of information, namely the full set of 61 regions, in the general equilibrium constraints.[14] Furthermore, we can retrieve the predicted value of trade flows $\widehat{X_{rs}}$ for all regions (even those not in the sample), once we have estimated the gravity equation system. Even when focusing on the 40 regions, we still have to deal with 49 zero trade flows out of 1600 observations. Since there is no generally agreed-upon methodology to deal with this problem (see, e.g., Anderson and van Wincoop, 2004; Disdier and Head, 2008), we include a dummy variable for zero flows in the regressions.[15] As a robustness check, we estimate the system by dropping the 49 zero

[13] In Bernard *et al.* (2003), the lowest cost exporter is the only supplier in any destination. If all potential exporters draw their productivity from a Pareto distribution with shape parameter k, then the productivity distribution of the lowest cost exporter is Fréchet with shape parameter k (see Norman *et al.*, 1994).

[14] See Tables 3 and 4 for a list of the regions used in the gravity equation ('In Gravity sample') and for a list of regions not used in the gravity equation but used in the equilibrium constraints ('Out of Gravity sample').

[15] Although this is somewhat crude, alternative methods like truncating the sample are not known to perform better or to be theoretically more sound. Note that our zeros are unlikely to be 'true zeros', as this would imply no aggregate manufacturing trade between several U.S. states. In the case of 'true zeros', a Heckman procedure would perform better (Helpman *et al.*, 2008).

flows. Results are little sensitive to the specification used, thus suggesting that the zero flows are true outliers and do not contain relevant information.

4.4 Estimation results

Our estimation results for the gravity equation system are summarized in Table 1. Column 1 presents the benchmark case, whereas columns 2-6 contain alternative specifications used as robustness checks. As can be seen from column 1, all coefficients have the correct sign and are precisely estimated. In our benchmark case, the estimated distance elasticity is -1.2287, which implies that $\widehat{\gamma} = 0.3413$. The border coefficient estimate is 1.6809, which implies that $\widehat{\theta} = 0.4669$. Note that our estimated coefficient is very similar to the one of 1.65 obtained by Anderson and van Wincoop (2003). However, as shown later, the impacts of a border removal on trade flows differ substantially once endogenous wages and firm selection are taken into account.

Insert Table 1 about here.

Columns 2 and 3 report results for different values of k. Column 4 presents results when we use the alternative measure for internal distances, whereas colums 5 and 6 present results obtained when we include internal absorption X_{rr} and when we exclude zero trade flows, respectively. Note that the coefficient of the border dummy remains almost unchanged across all specifications, with adjusted R^2 values close to 0.9.

4.5 Model fit

As stated in the foregoing, we solve the general equilibrium constraints for the wages and upper bounds $(\widehat{w}_r, \widehat{\mu_r^{\max}})$. While there is no data for the latter, we can compare the relative wages generated by our model with observed ones.[16] In our benchmark case, the correlation is 0.68. Thus, the predicted relative wages match observed ones fairly well. Our model also predicts an average exporter share of 1.24% for the U.S.[17] This fits decently with the fact reported by Bernard *et al.* (2005) that 2.6% of all U.S. firms were exporters in 1993. Although the prediction of our model is slightly lower, one should keep in mind that their figure includes exporters to all foreign countries and not just to Canada.

[16]We construct average yearly wages across provinces and states using hourly wage data from Statistics Canada and the Bureau of Labor Statistics. To match the unit of measurement of trade and GDP data, we compute average yearly wages in million Canadian dollars based on an average of 1930 hours worked yearly in Canada, and 2080 hours worked yearly in the U.S. in 1993.

[17]The share of exporters in a U.S. state is defined as the share of firms selling to at least one Canadian province. Formally, it is given by $G_r(\max_{s\in \mathrm{CA}}\{m_{rs}^x\})/G_r(\max_s\{m_{rs}^x\})$. The share of U.S. exporters is then computed as the population weighted average of the states' exporter shares. All figures for the Canadian provinces are computed in an analogous way.

5 Counterfactual analysis

Having estimated the gravity equation system, we now turn to a counterfactual analysis in the spirit of Bernard *et al.* (2003) and Del Gatto *et al.* (2006). We first investigate the impacts of reducing trade frictions generated by the Canada-U.S. border to zero. It is clear that such trade integration would induce various general equilibrium effects, and that regions would be affected differently depending on geography, technology and population sizes. Second, we investigate the impacts of regional population changes between 1993 and 2007, holding trade frictions fixed at their intial level. In both cases, we quantify the changes in wages, productivity, markups, the share of exporters, the mass of varieties produced and consumed, as well as welfare.

5.1 The impacts of removing the border on trade flows

McCallum's (1995) seminal work on border effects shows that, conditional on regional GDP and distance, trade between Canadian provinces is roughly 22 times larger than trade between Canadian provinces and U.S. states. Anderson and van Wincoop (2003) argue that this estimate is substantially upward biased due to the omission of general equilibrium constraints. They find that, on average, the border increases trade between Canadian provinces 'only' by a factor of 10.5 when compared to trade between Canadian provinces and U.S. states. The corresponding number for the U.S. is 2.56. We now investigate how these figures are modified when endogenous wages and firm selection are taken into account.

5.1.1 Computing border effects

We define *bilateral border effects* as the ratio of trade flows from r to s in a borderless world to those in a world with borders:

$$B_{rs} \equiv \frac{\widetilde{X}_{rs}}{\widehat{X}_{rs}} = \mathrm{e}^{k\widehat{\theta}b_{rs}} \left(\frac{\widetilde{w}_s/\widetilde{w}_r}{\widehat{w}_s/\widehat{w}_r}\right)^{k+1} \left(\frac{\widetilde{w}_r}{\widehat{w}_r}\right) \left(\frac{\widetilde{m}_s^d}{m_s^d}\right)^{k+1}, \tag{35}$$

where variables with a tilde refer to values in a borderless world and where variables with a hat denote estimates. To compute B_{rs} we first use the estimated wages $\widehat{w}_r$ and the observed cutoffs m_s^d in the presence of the border to obtain the relevant information for the initial fitted trade flows $\widehat{X}_{rs}$ in (35). Second, holding the shape parameter k as well as the estimated upper bound $\widehat{\mu_r^{\max}}$ and trade frictions $(\widehat{\gamma}, \widehat{\theta})$ constant, we solve (32) and (33) by setting $b_{rs} = 0$ for all r and s. This yields the wages $\widetilde{w}_r$ and the cutoffs $\widetilde{m}_s^d$ that would prevail in a borderless world. Plugging these values into (35), we obtain $61 \times 61 = 3721$ bilateral border effects, each of which gives the change in the trade flows from r to s after the border removal.

The bilateral border effects B_{rs} are typically greater than one when regions r and s are in different countries. The reason is that exports from region r to region s partly replace domestic sales as international trade frictions are reduced. For analogous reasons, the values of B_{rs} are typically less than one when r and s are in the same country. Table 2 provides some descriptive statistics on the computed bilateral border effects. One can see that the various specifications yield virtually identically distributed and strongly correlated bilateral border effects, thus showing that the results are robust to the choice of k.

Insert Table 2 about here.

In order to evaluate the impact of the border removal on overall Canadian and U.S. trade flows, we need to aggregate bilateral border effects at the national level. As an intermediate step, we first define the *regional border effect* for Canadian province r as follows:

$$B_r = \frac{\sum_{s\in\mathrm{US}} \widetilde{X}_{rs} / \sum_{s\in\mathrm{US}} \widehat{X}_{rs}}{\sum_{s\in\mathrm{CA}} \widetilde{X}_{rs} / \sum_{s\in\mathrm{CA}} \widehat{X}_{rs}} = \frac{\sum_{s\in\mathrm{US}} \lambda_{rs}^{\mathrm{US}} B_{rs}}{\sum_{s\in\mathrm{CA}} \lambda_{rs}^{\mathrm{CA}} B_{rs}},$$

where $\lambda_{rs}^{\mathrm{US}} = \widehat{X}_{rs} / \sum_{s\in\mathrm{US}} \widehat{X}_{rs}$ and $\lambda_{rs}^{\mathrm{CA}} = \widehat{X}_{rs} / \sum_{s\in\mathrm{CA}} \widehat{X}_{rs}$ are the fitted trade shares. The numerator is the trade weighted average of international bilateral border effects, whereas the denominator is the trade weighted average of the intranational B_{rs}. It can be easily verified that the *national border effect* for Canada can be simplified as follows:

$$B_{CA} \equiv \frac{\sum_{r\in\mathrm{CA}} \sum_{s\in\mathrm{US}} \widetilde{X}_{rs} / \sum_{r\in\mathrm{CA}} \sum_{s\in\mathrm{US}} \widehat{X}_{rs}}{\sum_{r\in\mathrm{CA}} \sum_{s\in\mathrm{CA}} \widetilde{X}_{rs} / \sum_{r\in\mathrm{CA}} \sum_{s\in\mathrm{CA}} \widehat{X}_{rs}} = \frac{1}{K_{\mathrm{CA}}} \sum_{r\in\mathrm{CA}} B_r,$$

where K_{CA} is the number of Canadian provinces. An analogous definition applies to the U.S. We find that $B_{CA} = 7.15$ while $B_{US} = 4.03$. Below we compare these findings with the corresponding figures provided by Anderson and van Wincoop (2003), who report a national border effect of 2.56 for the U.S. and 10.5 for Canada, respectively.[18]

5.1.2 Decomposing bilateral border effects

What drives bilateral border effects? As can be seen from expression (35), B_{rs} can be decomposed into four components:

- *The pure border effect:* $\mathrm{e}^{k\widehat{\theta} b_{rs}}$
- *The relative wage effect:* $\Delta(w_s/w_r) \equiv [(\widetilde{w}_s/\widetilde{w}_r)/(\widehat{w}_s/\widehat{w}_r)]^{k+1}$
- *The absolute wage effect:* $\Delta w_r \equiv \widetilde{w}_r/\widehat{w}_r$

[18] Strictly speaking, our definition of national border effect differs from that of Anderson and van Wincoop (2003). When using their definition in terms of geometric means (see Feenstra, 2004), we obtain 7.18 for Canada and 4.02 for the U.S. The advantage of our definition of national border effect is that it precisely measures the (multiplicative) impact of the border removal on trade flows.

- *The selection effect:* $\Delta m_s^d \equiv \left(\widetilde{m}_s^d / m_s^d\right)^{k+1}$

Insert Table 3 about here.

Table 3 illustrates this decomposition for our benchmark case. The left half of the table reports the components of B_{rs} for exports from British Columbia (BC) to all possible destinations. Consider, for example, the bilateral border effect with Washington (WA). First, there is a pure border effect of 5.3704, i.e., the value of exports from BC to WA would rise by a factor of 5.3704 after the border removal. This is the bilateral border effect that would prevail if endogenous changes in wages and cutoffs were not taken into account. Second, there are relative and absolute wage effects. On the one hand, the relative wage effect reduces the value of BC exports to WA by a factor of 0.8500. As the relative wage in BC rises, BC firms become less competitive in WA due to relatively higher production costs, which reduces exports by 15%. The absolute wage effect, on the other hand, raises BC exports by a factor of 1.0451 as the higher wage is reflected in the higher prices. When taken together, these two wage effects reduce the bilateral border effect from BC to WA by about 11% (as $0.8500 \times 1.0451 = 0.8883$). Put differently, neglecting the endogenous reaction of wages to the border removal leads to overstating the bilateral border effects by about 11%. Finally, there is a selection effect. The border removal lowers the cutoff productivity level for firms to survive in WA. In other words, trade integration induces tougher selection and makes it harder for BC firms to sell in WA. This selection effect reduces the export value by a factor of 0.9081. Hence, the selection effect further reduces the border effect by about 9.2%. The bilateral border effect is therefore given by $5.3704 \times 0.8500 \times 1.0451 \times 0.9081 = 4.3322$, which is about 19% lower than the pure border effect mentioned above.

Trade flows between regions within the same country are also affected by the removal of the border, and the bilateral border effects can be decomposed for these cases as well. Consider, for example, exports from BC to Ontario (ON). There is of course no pure border effect for this intranational trade flow, but due to the endogenous changes in wages and cutoffs we find a bilateral border effect equal to $1 \times 1.2324 \times 1.0451 \times 0.4683 = 0.6032$. The border removal thus reduces the value of exports from BC to ON by about 40%. This sizeable reduction is entirely attributable to tougher selection in ON, despite the fact that the wage in ON rises relative to that in BC.

The right half of Table 3 provides the B_{rs} for exports from New York (NY) to all possible destinations. As one can see, exports from NY to Québec (QC) would rise by a factor of $5.3704 \times 1.2894 \times 1.0013 \times 0.6139 = 4.2565$. Although the bilateral border effect from NY to QC is roughly similar to the one from BC to WA, their decomposition is quite different. Whereas the selection effect reduces exports significantly in the former case, it is the relative wage effect that mainly does so in the latter case. Last, exports from NY to California (CA) change little after the border removal ($1 \times 0.9851 \times 1.0013 \times 0.9920 = 0.9785$). The explanation is that CA is large and far away from the border, so that little additional selection is induced there, while the wage in NY rises only slightly when compared to that in CA, both in relative and absolute terms.

To sum up, our findings suggest that any computation of border effects needs to take into account changes in wages and firm selection in order to yield accurate results. Neglecting these endogenous adjustments leads to biased predictions for changes in inter- and intra-national trade flows in a borderless world.

5.2 The impacts of removing the border on key economic aggregates

Moving our focus away from the effects on trade flows, we now investigate the predictions of our model on how trade integration affects other key economic aggregates.

5.2.1 Wages and productivity

Column 1 in Table 4 shows that the border removal favors wage convergence, as wages in Canadian provinces rise relative to those in U.S. states.[19] For our benchmark specification, wages in Canadian provinces rise by between 4.51% in British Columbia and 12.27% in Manitoba. It is worth pointing out that wages rise more in less populated regions like Manitoba, Newfoundland, Prince Edward Island and Saskatchewan. Turning to U.S. states, the wage changes are much smaller and can go either way. Less populated regions closer to the border benefit the most, with wage gains of about 1.43-2.02% in Maine, Montana, North Dakota and Vermont. The most remote states like California, Florida, Louisiana and Texas may even experience a slight decrease in their relative wages.

Insert Table 4 about here.

As for changes in cutoffs, one can see from column 2 of Table 4 that they are negative for all regions. This shows that removing the border induces tougher selection and increases average productivity everywhere. The productivity gains are larger in Canada, which can be explained by the fact that it is the smaller economy, so that there is less selection than in the U.S. prior to the border removal. Columns 1 and 2 also reveal that productivity gains always exceed wage gains. Hence, our counterfactual analysis suggests that the border removal yields cost reductions ranging from 3.86% to 9.08% in Canada, and from 0.36% to 2.06% in the U.S.

[19] All wages are expressed in terms of that in Alabama, which we set to one by choice of numeraire. Doing so entails no loss of generality.

The role of endogenous wages is crucial for explaining the difference of our results with those of Anderson and van Wincoop (2003). The border removal raises productivity and thus expected profits everywhere, but relatively more in Canada than in the U.S. Consequently, the relative wages should rise in Canada and fall in the U.S. In a fixed-wage model, the measured Canadian border effect would be overstated, because the export dampening effects of the higher relative wage would not be taken into account. The measured U.S. border effect would be understated for analogous reasons. This may explain why Anderson and van Wincoop (2003), who do not consider endogenous wages, find highly dissimilar border effects for the Canada and the U.S. (10.5 and 2.56, respectively). By contrast, the gap is much smaller in our model (7.15 in Canada and 4.03 in the U.S.) due to endogenous wages and selection.

5.2.2 Markups, exporters, and varieties produced and consumed

Next, we quantify the pro-competitive effects of trade integration. Column 3 of Table 4 shows that average markups fall in all regions, yet not uniformely. There is a reduction by 3.90% to 9.14% in Canada, whereas the corresponding figures for the U.S. range from 0.37% to 2.07%. These pro-competitive effects are driven by the fact that removing the border substantially increases, in every region, the share of firms engaged in cross-border transactions. Initially, 1.24% of U.S. firms export, whereas the corresponding figure for Canada is 5.14% (Column 4). After completely removing the border these figures increase to 2.13% for the U.S. and 13.6% for the Canada (Column 5). This increase in the share of exporters raises consumption diversity everywhere, with values ranging from 0.17-4.17% in the U.S to 8.76-23.6% in Canada (Column 6). Hence, more firms compete in each market, which puts downward pressure on markups.

Last, Column 7 shows that there is a reduction in production diversity everywhere due to firm selection. This effect is more pronounced in Canada than in the U.S.[20] Even though the magnitudes predicted by our model are too large, they are qualitatively in line with Head and Ries (1999), who report that in the first six years after the Canada-U.S. FTA the number of Canadian plants decreased by about 21%. Exit of firms also occurs in the U.S., but on a smaller scale as the U.S. market is already more competitive and has tougher selection. States close to the border (e.g., Maine, Montana, North Dakota and Vermont) are on average more affected as they are more strongly exposed to competition from Canadian firms.

[20]Consumption diversity expands even when the mass of local firms decreases in all regions. The reason is that less domestic firms are more than compensated for by additional foreign firms. One can indeed check that removing the border decreases all the domestic cutoffs, thus reducing domestic consumption diversity. However, all export cutoffs increase, thereby raising import consumption diversity.

5.2.3 Welfare

Finally, we can quantify the impact of trade integration on welfare. This can be done as follows. Since $\mathrm{e}^{-\alpha q_{sr}(m)} = p_{sr}(m)/p_r^d$ by (13), the indirect utility in region r is given by

$$U_r = \sum_s N_s^E \int_0^{m_{sr}^x} \left[1 - \mathrm{e}^{-\alpha q_{sr}(m)}\right] \mathrm{d}G_s(m) = N_r^c \left(1 - \frac{\overline{p}_r}{p_r^d}\right).$$

Using expression (16), one can verify that $\overline{p}_r = [k/(k+1)]p_r^d + \alpha w_r/N_r^c$, which allows us to express the indirect utility as $U_r = N_r^c/(k+1) - \alpha/(\tau_{rr} m_r^d)$. Since N_r^c is defined as in (19), and making use of the fact that expression (26) holds in equilibrium, we can rewrite the indirect utility as:

$$U_r = \left[\frac{1}{(k+1)\kappa_3} - 1\right] \frac{\alpha}{\tau_{rr} m_r^d}.$$

Hence, welfare is inversely proportional to the cutoff m_r^d.[21] Column 8 of Table 4 provides the changes in welfare due to the border removal. As expected, removing the border would yield welfare gains in all provinces and states. However, Canadian provinces would benefit more. In particular, welfare would rise by approximately 10% in Canada and by roughly 3% in the U.S. The reason for this asymmetry is that consumption diversity expands more strongly, cutoffs fall by a larger margin, and markups decrease more substantially in Canada than in the U.S.

5.3 The impacts of population changes on key economic aggregates

The counterfactual analysis of the border removal is just one of the possible applications of our model. We now propose a second one which quantifies the potential impacts of regional changes in factor endowments. How do regional population changes affect the key economic aggregates? To answer this question, we proceed as follows. First, we estimate the gravity equation system for our benchmark case. Second, holding the shape parameter k as well as the estimated upper bounds $\widehat{\mu_r^{\max}}$ and trade frictions $(\widehat{\gamma}, \widehat{\theta})$ constant, we solve (32) and (33) by replacing the 1993 regional population sizes with those of 2007. This yields the wages $\widetilde{w}_r$ and the cutoffs $\widetilde{m}_s^d$ that would prevail in a hypothetical world where trade frictions are unchanged with respect to 1993 and in which only population would have changed. Table 5 summarizes our main results.

Insert Table 5 about here.

Note first from column 1 that regions and provinces experienced substantially different patterns of population change between 1993 and 2007. Whereas most regions grew in absolute

[21] Alternatively, the equilibrium utility can be written as $U_r = [1/(k+1) - \kappa_3]N_r^c$., i.e., it is proportional to the mass of varieties consumed.

terms (Newfoundland, Saskatchewan and West Virginia being the exceptions) the relative growth rates vastly differ across regions. As is well known, the western provinces (Alberta, British Columbia), and the southern states (Nevada, Arizona, California, Florida, Texas, Georgia) experienced the largest relative growth. As can be seen from column 2 of Table 5, those provinces and states naturally experience the largest cutoff falls and wage gains. Most other regions experience a decline in their relative wage, yet still enjoy lower cutoffs because of tougher selection driven by population growth in the different regions. The only exception is Newfoundland, which experiences a strong decline in its relative wage and a 0.5% decline in its average productivity due to its loss of population.

Note, finally, that welfare changes again mirror the changes in cutoffs and the mass of varieties consumed as shown in Section 5.2.3. Two differences with respect to the border removal counterfactual are worth noting. First, the U.S. states gain on average more than the Canadian provinces because of more sustained increases in regional populations. Second, not all regions gain, as shown by the welfare losses in Newfoundland. This small peripheral region is hurt by its population exodous, its decreasing share of exporters, its lower wages and its worsening average productivity.

6 Conclusions

We have developed a new general equilibrium model of trade with heterogeneous firms and variable demand elasticities in which both wages and productivity respond to trade liberalization and population changes. Trade integration, or a larger local population, intensifies competition and forces the least efficient firms to leave the market, thereby affecting aggregate productivity and factor prices. Our framework, which takes into account the endogenous responses of productivity and wages to changes in the economic environment, is therefore well suited to the analysis of various counterfactuals.

First, we have decomposed the impacts of a full border removal between Canada and the U.S. on trade flows into: (i) a pure border effect; (ii) relative and absolute wage effects; and (iii) a selection effect. We find that ignoring endogenous wages and selection effects systematically biases border effects: Canadian border effects are in fact overestimated, while U.S. border effects are underestimated. Our counterfactual analysis indicates that such a bias is largely due to fixed wages. Indeed, allowing for flexible wages, we show that trade integration induces wage convergence between the two countries, thus narrowing the gap in the border effects between Canada and the U.S. Although there is substantial regional heterogeneity, our results further suggest that aggregate productivity, the share of exporters and the mass of varieties consumed rise everywhere, whereas average markups and the mass of varieties produced fall in all regions. These changes, which largely arise because of selection effects induced by a more competitive environment, map into welfare gains for all U.S. states and, to a larger extent, for all Canadian provinces.

Second, we have investigated how regional population changes between 1993 and 2007 affect wages and average productivity holding trade frictions fixed. The key insight is that differential population growth would mostly benefit the fastest growing regions in western Canada and the southern U.S., whereas small peripheral regions like Newfoundland experience falling wages, a deterioration of their productivity and, ultimately, welfare losses.

As shown in this paper, our model is tractable enough to allow for various extensions. A first one could be to endogenize population changes through interregional and international migration, which would nicely fit with our focus on North America. Doing so would, as a by-product, partly bridge the gap between trade models with heterogeneous firms and the 'new' economic geography literature. A second extension could be an application to the international context where factor prices vastly differ across countries. Given the absence of FPE in our model, it should be especially suited to this exercise. We keep these avenues open for future research.

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Appendix A: Proofs and computations

A.1. Derivation of (8). Using $p^d = m^d w$, the first-order conditions (6) can be rewritten as

$$\ln\left[\frac{m^d w}{p(m)}\right] = 1 - \frac{mw}{p(m)}.$$

Taking exponential of both sides and rearranging terms, we have

$$\mathrm{e}\frac{m}{m^d} = \frac{mw}{p(m)}\mathrm{e}^{\frac{mw}{p(m)}}.$$

Noting that the Lambert W function is defined as $\varphi = W(\varphi)\mathrm{e}^{W(\varphi)}$ and setting $\varphi = \mathrm{e}m/m^d$, we obtain $W(\mathrm{e}m/m^d) = mw/p(m)$, which implies $p(m)$ as given in (8). The derivations of $q(m)$ and $\pi(m)$ follow straightforwardly.

A.2. Existence and uniqueness of the equilibrium cutoff m^d. We show that there exists a unique equilibrium cutoff m^d. To see this, applying the Leibnitz integral rule to the left-hand side of (10) and using $W(\mathrm{e}) = 1$ to obtain

$$\frac{\mathrm{e}L}{\alpha(m^d)^2}\int_0^{m^d} m^2\left(W^{-2}-1\right)W'\mathrm{d}G(m) > 0,$$

where the sign comes from $W' > 0$ and $W^{-2} \geq 1$ for $0 \leq m \leq m^d$. Hence, the left-hand side of (10) is strictly increasing. This uniquely determines the equilibrium cutoff m^d, because

$$\lim_{m^d \to 0}\int_0^{m^d} m\left(W^{-1}+W-2\right)\mathrm{d}G(m) = 0 \quad \text{and} \quad \lim_{m^d \to \infty}\int_0^{m^d} m\left(W^{-1}+W-2\right)\mathrm{d}G(m) = \infty.$$

A.3. Market size, the equilibrium cutoff, and the mass of entrants. Differentiating (10) and using the Leibniz integral rule, we readily obtain

$$\frac{\partial m^d}{\partial L} = -\frac{\alpha F\left(m^d\right)^2}{\mathrm{e}L^2}\left[\int_0^{m^d} m^2\left(W^{-2}-1\right)W'\mathrm{d}G(m)\right]^{-1} < 0,$$

because $W' > 0$ and $W^{-2} \geq 1$ for $0 \leq m \leq m^d$. Differentiating (12) with respect to L yields

$$\frac{\partial N^E}{\partial L} = \frac{F(N^E)^2}{L^2}\left\{1 - \frac{\mathrm{e}L^3}{\alpha F\left(m^d\right)^2}\left[\int_0^{m^d} m^2 W'\mathrm{d}G(m)\right]\frac{\partial m^d}{\partial L}\right\} > 0,$$

where the sign comes from $\partial m^d/\partial L < 0$ as established in the foregoing.

A.4. Existence and uniqueness in the two-region case. Under our assumptions on trade costs, the RHS of (30) is non-negative if and only if $\underline{\omega} < \omega < \overline{\omega}$, where $\underline{\omega} \equiv \rho^{1/(k+1)} \left(\tau_{22}/\tau_{12}\right)^{k/(k+1)}$ and $\overline{\omega} \equiv \rho^{1/(k+1)} \left(\tau_{21}/\tau_{11}\right)^{k/(k+1)}$. Furthermore, the RHS is strictly decreasing in $\omega \in (\underline{\omega}, \overline{\omega})$ with $\lim_{\omega \to \underline{\omega}+}$ RHS $= \infty$ and $\lim_{\omega \to \overline{\omega}-}$ RHS $= 0$. The LHS of (30) is, on the contrary, strictly increasing in $\omega \in (0, \infty)$. Hence, there exists a unique equilibrium $\omega^* \in (\underline{\omega}, \overline{\omega})$.

A.5. Market size, trade frictions, and wages. (i) First, ω^* is increasing in L_1/L_2 as an increase in L_1/L_2 raises the RHS of (30) without affecting the LHS. This implies that if the two regions have equal technological possibilities ($\rho = 1$) and face symmetric trade costs ($\tau_{12} = \tau_{21}$ and $\tau_{11} = \tau_{22}$), the larger region has the higher relative wage. (ii) Since $(\tau_{11}\tau_{22})^k < (\tau_{12}\tau_{21})^k$ holds by assumption, the RHS of (30) shifts up as ρ increases, which then also increases ω^*. This implies that if the two regions are of equal size ($L_1 = L_2$) and face symmetric trade costs ($\tau_{12} = \tau_{21}$ and $\tau_{11} = \tau_{22}$), the region with the better technological possibilities has the higher wage. (iii) Higher internal trade costs in one region reduce the relative wage of that region, because

$$\frac{\partial(\text{RHS})}{\partial \tau_{11}} < 0 \quad \text{iff} \quad \omega^* > \underline{\omega} \quad \text{and} \quad \frac{\partial(\text{RHS})}{\partial \tau_{22}} > 0 \quad \text{iff} \quad \omega^* < \overline{\omega}.$$

(iv) Better access to the foreign market raises the domestic relative wage, whereas better access to the domestic market reduces the domestic relative wage because

$$\frac{\partial(\text{RHS})}{\partial \tau_{12}} < 0 \quad \text{iff} \quad \omega^* < \overline{\omega} \quad \text{and} \quad \frac{\partial(\text{RHS})}{\partial \tau_{21}} > 0 \quad \text{iff} \quad \omega^* > \underline{\omega}.$$

(v) Assuming that $\tau_{12} = \tau_{21} = \tau$ and that $\tau_{11} = \tau_{22} = t$, one can verify that

$$\frac{\partial(\text{RHS})}{\partial \tau} = -\frac{k\rho t^k}{\tau^{k+1}} \frac{L_1}{L_2} \frac{\rho^2 - \omega^{2(k+1)}}{[\omega^{k+1} - \rho(t/\tau)^k]^2} \left\{ \begin{array}{c} > \\ = \\ < \end{array} \right\} 0 \quad \text{for} \quad \left\{ \begin{array}{c} \underline{\omega} < \rho^{\frac{1}{k+1}} < \omega^* < \overline{\omega} \\ \underline{\omega} < \omega^* = \rho^{\frac{1}{k+1}} < \overline{\omega} \\ \underline{\omega} < \omega^* < \rho^{\frac{1}{k+1}} < \overline{\omega} \end{array} \right\}. \qquad (36)$$

Note that when regions are of equal size, but have different upper bounds ($\rho > 1$), the first case of (36) applies since $\omega^* > \rho^{1/(k+1)}$ in equilibrium. To see this, evaluate (30) at $\omega = \rho^{1/(k+1)}$ and recall that $\tau_{21} = \tau_{12} = \tau$ and $L_1 = L_2$. The LHS is equal to $\rho^{k/(k+1)}$, which falls short of the RHS given by ρ (since $\rho > 1$ and $k \geq 1$). Since the LHS is increasing and the RHS is decreasing, it must be that $\omega^* > \rho^{1/(k+1)}$. Hence, lower trade costs reduce the relative wage of the more productive region. Furthermore, when regions have the same upper bounds but different sizes ($L_1 > L_2$), we obtain $\omega^* > \rho^{k/(k+1)} = 1$, so that the first case of (36) applies again.

Appendix B: Integrals involving the Lambert W function

To derive closed-form solutions for various expressions throughout the paper we need to compute integrals involving the Lambert W function. This can be done by using the change in variables suggested by Corless *et al.* (1996, p.341). Let

$$z \equiv W\left(\mathrm{e}\,\frac{m}{I}\right), \quad \text{so that} \quad \mathrm{e}\,\frac{m}{I} = z\mathrm{e}^z, \quad \text{where} \quad I = m_r^d, m_{rs}^x,$$

where subscript r can be dropped in the closed economy. The change in variables then yields $\mathrm{d}m = (1+z)\mathrm{e}^{z-1}I\mathrm{d}z$, with the new integration bounds given by 0 and 1. Under our assumption of a Pareto distribution for productivity draws, the change in variables allows to rewrite integrals in simplified form.

B.1. First, consider the following expression, which appear when integrating firms' outputs:

$$\int_0^I m\left[1 - W\left(\mathrm{e}\frac{m}{I}\right)\right]\mathrm{d}G_r(m) = \kappa_1\left(m_r^{\max}\right)^{-k} I^{k+1},$$

where $\kappa_1 \equiv k\mathrm{e}^{-(k+1)}\int_0^1 (1-z^2)\left(z\mathrm{e}^z\right)^k \mathrm{e}^z \mathrm{d}z > 0$ is a constant term which solely depends on the shape parameter k.

B.2. Second, the following expression appears when integrating firms' operating profits:

$$\int_0^I m\left[W\left(\mathrm{e}\frac{m}{I}\right)^{-1} + W\left(\mathrm{e}\frac{m}{I}\right) - 2\right]\mathrm{d}G_r(m) = \kappa_2\left(m_r^{\max}\right)^{-k} I^{k+1},$$

where $\kappa_2 \equiv k\mathrm{e}^{-(k+1)}\int_0^1 (1+z)\left(z^{-1}+z-2\right)\left(z\mathrm{e}^z\right)^k \mathrm{e}^z \mathrm{d}z > 0$ is also a constant term which solely depends on the shape parameter k.

B.3. Finally, the following expression appears when integrating firms' revenues:

$$\int_0^I m\left[W\left(\mathrm{e}\,\frac{m}{I}\right)^{-1} - 1\right]\mathrm{d}G_r(m) = \kappa_3\left(m_r^{\max}\right)^{-k} I^{k+1},$$

where $\kappa_3 \equiv k\mathrm{e}^{-(1+k)}\int_0^1 (z^{-1}-z)\left(z\mathrm{e}^z\right)^k \mathrm{e}^z \mathrm{d}z > 0$ is a constant term which solely depends on the shape parameter k. Using the expressions for κ_1 and κ_2, one can verify that $\kappa_3 = \kappa_1 + \kappa_2$.

Appendix C: Equilibrium in the open economy

In this appendix we restate the equilibrium conditions using the Lambert W function.

C.1. Using (18), the labor market clearing condition can be rewritten as follows:

$$N_r^E \left\{ \frac{1}{\alpha} \sum_s L_s \tau_{rs} \int_0^{m_{rs}^x} m \left[1 - W\left(\mathrm{e} \frac{m}{m_{rs}^x} \right) \right] \mathrm{d}G_r(m) + F_r \right\} = L_r. \tag{37}$$

C.2. Plugging (18) into (20), zero expected profits require that

$$\frac{1}{\alpha} \sum_s L_s \tau_{rs} \int_0^{m_{rs}^x} m \left[W\left(\mathrm{e} \frac{m}{m_{rs}^x} \right)^{-1} + W\left(\mathrm{e} \frac{m}{m_{rs}^x} \right) - 2 \right] \mathrm{d}G_r(m) = F_r. \tag{38}$$

As in the closed economy case, the zero expected profit condition depends solely on the cutoffs m_{rs}^x and is independent of the mass of entrants.

C.3. Finally, trade balance condition is given by

$$\begin{aligned} N_r^E w_r \sum_{s \neq r} L_s \tau_{rs} \int_0^{m_{rs}^x} m \left[W\left(\mathrm{e} \frac{m}{m_{rs}^x} \right)^{-1} - 1 \right] \mathrm{d}G_r(m) \\ = L_r \sum_{s \neq r} N_s^E \tau_{sr} w_s \int_0^{m_{sr}^x} m \left[W\left(\mathrm{e} \frac{m}{m_{sr}^x} \right)^{-1} - 1 \right] \mathrm{d}G_s(m). \end{aligned} \tag{39}$$

Applying the region-specific Pareto distributions $G_r(m) = (m/m_r^{\max})^k$ to (37)–(39) yields after some algebra expressions (22)–(24) given in the main text.

Table 1: Estimations of the gravity equation system

	Benchmark(1)	Robustness(2)	Robustness(3)	Robustness(4)	Robustness(5)	Robustness(6)
Regions	61 (40)	61 (40)	61 (40)	61 (40)	61 (40)	61 (40)
Flows	1560	1560	1560	1560	1600	1511
k	3.6	1.4	6.5	3.6	3.6	3.6
Internal dist.	AvW	AvW	AvW	RV	AvW	AvW
Coefficients:						
constant	-4.4403	-3.9970	-4.4655	-4.2331	-4.4228	-4.4217
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
$\ln d_{rs}$	-1.2287	-1.4766	-1.2006	-1.5222	-1.2380	-1.2233
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
$\ln d_{rr}$	1.5700	2.5312	1.3853	1.9450	1.5819	1.5630
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
b_{rs}	-1.6809	-1.5378	-1.6812	-1.6504	-1.6795	-1.7682
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
$0-$ dummy	-17.772	-17.813	-17.748	-17.569	-17.775	—
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	—
Adjusted R^2	0.8911	0.8861	0.8916	0.9060	0.8957	0.6094

Notes: p-values in parentheses. Benchmark(1) uses 1560 trade flows (excluding X_{rr} as in Anderson and van Wincoop, 2003). AvW refers to Anderson and van Wincoop's (2003) measure of internal distance while RV refers to Redding and Venables' (2004) measure. The convergence criterion for the iterative procedure is based on the norm of the vector of regression coefficients between two successive iterations, with threshold 10^{-12}. Starting points for the iterative solver are obtained via OLS with importer-exporter fixed effects. We choose $w_{\text{Alabama}} = 1$ as numeraire and set starting wages to $w_r = 1$ for all r. Results are invariant to that choice.

Table 2: Descriptive statistics for bilateral border effects

Descriptive statistics for bilateral border effect series:						
	Benchmark(1)	Robustness(2)	Robustness(3)	Robustness(4)	Robustness(5)	Robustness(6)
Minimum	0.4241	0.5837	0.3903	0.3255	0.4285	0.4142
Maximum	4.5036	4.2804	4.3914	4.6622	4.5107	4.8886
Mean	1.7284	1.7480	1.6847	1.7142	1.7323	1.8117
Std. dev.	1.3042	1.2867	1.2433	1.2908	1.3094	1.4440
Median	0.9650	0.9824	0.9629	0.9746	0.9654	0.9638
Skewness	1.0636	1.0413	1.0769	1.1623	1.0629	1.0656
Kurtosis	2.2443	2.1429	2.3035	2.5842	2.2404	2.2459
Correlation matrix for bilateral border effect series:						
	(1)	(2)	(3)	(4)	(5)	(6)
(1)	1	0.9978	0.9960	0.9708	0.9979	0.9979
(2)		1	0.9997	0.9595	0.9999	0.9999
(3)			1	0.9545	0.9997	0.9997
(4)				1	0.9599	0.9593
(5)					1	0.9999
(6)						1

Table 3: Bilateral border effects decomposition for the province of British Columbia and the state of New York

	Benchmark(1)									
	Exporter: British Columbia					**Exporter: New York**				
	Pure border $e^{\widehat{\theta} b_{rs}}$	Rel. wage $\Delta(w_s/w_r)$	Abs. wage Δw_r	Selection Δm_s^d	Bil. border B_{rs}	Pure border $e^{\widehat{\theta} b_{rs}}$	Rel. wage $\Delta(w_s/w_r)$	Abs. wage Δw_r	Selection Δm_s^d	Bil. border B_{rs}
Importer:	**In Gravity sample**									
Alberta	1.0000	1.1415	1.0451	0.5368	0.6404	5.3704	1.3902	1.0013	0.5368	4.0129
British Columbia	1.0000	1.0000	1.0451	0.6796	0.7103	5.3704	1.2179	1.0013	0.6796	4.4509
Manitoba	1.0000	1.3902	1.0451	0.3778	0.5489	5.3704	1.6931	1.0013	0.3778	3.4394
New Brunswick	1.0000	1.2588	1.0451	0.4509	0.5932	5.3704	1.5331	1.0013	0.4509	3.7172
Newfoundland	1.0000	1.3673	1.0451	0.3892	0.5561	5.3704	1.6651	1.0013	0.3892	3.4845
Nova Scotia	1.0000	1.0793	1.0451	0.5932	0.6692	5.3704	1.3144	1.0013	0.5932	4.1930
Ontario	1.0000	1.2324	1.0451	0.4683	0.6032	5.3704	1.5009	1.0013	0.4683	3.7795
Prince Edw. Isl.	1.0000	1.2753	1.0451	0.4406	0.5872	5.3704	1.5532	1.0013	0.4406	3.6795
Quebec	1.0000	1.0587	1.0451	0.6139	0.6793	5.3704	1.2894	1.0013	0.6139	4.2565
Saskatchewan	1.0000	1.3150	1.0451	0.4171	0.5733	5.3704	1.6015	1.0013	0.4171	3.5924
Alabama	5.3704	0.8162	1.0451	0.9761	4.4717	1.0000	0.9941	1.0013	0.9761	0.9715
Arizona	5.3704	0.8256	1.0451	0.9565	4.4321	1.0000	1.0054	1.0013	0.9565	0.9629
California	5.3704	0.8089	1.0451	0.9920	4.5036	1.0000	0.9851	1.0013	0.9920	0.9785
Florida	5.3704	0.8133	1.0451	0.9824	4.4844	1.0000	0.9905	1.0013	0.9824	0.9743
Georgia	5.3704	0.8156	1.0451	0.9773	4.4742	1.0000	0.9934	1.0013	0.9773	0.9721
Idaho	5.3704	0.8543	1.0451	0.9000	4.3151	1.0000	1.0404	1.0013	0.9000	0.9375
Illinois	5.3704	0.8169	1.0451	0.9747	4.4690	1.0000	0.9948	1.0013	0.9747	0.9710
Indiana	5.3704	0.8222	1.0451	0.9636	4.4465	1.0000	1.0013	1.0013	0.9636	0.9661
Kentucky	5.3704	0.8223	1.0451	0.9633	4.4459	1.0000	1.0014	1.0013	0.9633	0.9659
Louisiana	5.3704	0.8143	1.0451	0.9802	4.4801	1.0000	0.9917	1.0013	0.9802	0.9734
Maine	5.3704	0.8948	1.0451	0.8286	4.1614	1.0000	1.0897	1.0013	0.8286	0.9041
Maryland	5.3704	0.8126	1.0451	0.9838	4.4872	1.0000	0.9897	1.0013	0.9838	0.9749
Massachusetts	5.3704	0.8181	1.0451	0.9720	4.4636	1.0000	0.9964	1.0013	0.9720	0.9698
Michigan	5.3704	0.8406	1.0451	0.9263	4.3701	1.0000	1.0237	1.0013	0.9263	0.9495
Minnesota	5.3704	0.8355	1.0451	0.9362	4.3906	1.0000	1.0176	1.0013	0.9362	0.9539
Missouri	5.3704	0.8190	1.0451	0.9703	4.4601	1.0000	0.9974	1.0013	0.9703	0.9690
Montana	5.3704	0.8813	1.0451	0.8514	4.2114	1.0000	1.0733	1.0013	0.8514	0.9150
New Hampshire	5.3704	0.8467	1.0451	0.9144	4.3454	1.0000	1.0311	1.0013	0.9144	0.9441
New Jersey	5.3704	0.8206	1.0451	0.9669	4.4531	1.0000	0.9994	1.0013	0.9669	0.9675
New York	5.3704	0.8211	1.0451	0.9658	4.4509	1.0000	1.0000	1.0013	0.9658	0.9670
North Carolina	5.3704	0.8199	1.0451	0.9683	4.4561	1.0000	0.9985	1.0013	0.9683	0.9681
North Dakota	5.3704	0.8715	1.0451	0.8685	4.2482	1.0000	1.0614	1.0013	0.8685	0.9230
Ohio	5.3704	0.8250	1.0451	0.9576	4.4344	1.0000	1.0048	1.0013	0.9576	0.9634
Pennsylvania	5.3704	0.8236	1.0451	0.9607	4.4406	1.0000	1.0030	1.0013	0.9607	0.9648
Tennessee	5.3704	0.8202	1.0451	0.9677	4.4548	1.0000	0.9989	1.0013	0.9677	0.9679
Texas	5.3704	0.8148	1.0451	0.9792	4.4780	1.0000	0.9923	1.0013	0.9792	0.9729
Vermont	5.3704	0.8852	1.0451	0.8446	4.1965	1.0000	1.0781	1.0013	0.8446	0.9117
Virginia	5.3704	0.8194	1.0451	0.9694	4.4583	1.0000	0.9979	1.0013	0.9694	0.9686
Washington	5.3704	0.8500	1.0451	0.9081	4.3322	1.0000	1.0352	1.0013	0.9081	0.9412
Wisconsin	5.3704	0.8325	1.0451	0.9423	4.4031	1.0000	1.0139	1.0013	0.9423	0.9566
Importer:	**Out of Gravity sample**									
Alaska	5.3704	0.8327	1.0451	0.9420	4.4025	1.0000	1.0141	1.0013	0.9420	0.9565
Arkansas	5.3704	0.8220	1.0451	0.9640	4.4473	1.0000	1.0010	1.0013	0.9640	0.9662
Colorado	5.3704	0.8166	1.0451	0.9753	4.4702	1.0000	0.9945	1.0013	0.9753	0.9712
Connecticut	5.3704	0.8250	1.0451	0.9577	4.4347	1.0000	1.0047	1.0013	0.9577	0.9635
Delaware	5.3704	0.8262	1.0451	0.9551	4.4293	1.0000	1.0062	1.0013	0.9551	0.9623
Dist. of Columbia	5.3704	0.8198	1.0451	0.9684	4.4563	1.0000	0.9985	1.0013	0.9684	0.9682
Hawaii	5.3704	0.8487	1.0451	0.9105	4.3372	1.0000	1.0336	1.0013	0.9105	0.9423
Iowa	5.3704	0.8260	1.0451	0.9556	4.4303	1.0000	1.0060	1.0013	0.9556	0.9625
Kansas	5.3704	0.8207	1.0451	0.9667	4.4528	1.0000	0.9995	1.0013	0.9667	0.9674
Mississippi	5.3704	0.8174	1.0451	0.9736	4.4666	1.0000	0.9955	1.0013	0.9736	0.9704
Nebraska	5.3704	0.8256	1.0451	0.9564	4.4319	1.0000	1.0055	1.0013	0.9564	0.9629
Nevada	5.3704	0.8187	1.0451	0.9708	4.4612	1.0000	0.9971	1.0013	0.9708	0.9692
New Mexico	5.3704	0.8282	1.0451	0.9512	4.4213	1.0000	1.0086	1.0013	0.9512	0.9606
Oklahoma	5.3704	0.8231	1.0451	0.9617	4.4427	1.0000	1.0024	1.0013	0.9617	0.9652
Oregon	5.3704	0.8372	1.0451	0.9330	4.3840	1.0000	1.0196	1.0013	0.9330	0.9525
Rhode Island	5.3704	0.8284	1.0451	0.9506	4.4202	1.0000	1.0089	1.0013	0.9506	0.9603
South Carolina	5.3704	0.8228	1.0451	0.9622	4.4438	1.0000	1.0021	1.0013	0.9622	0.9655
South Dakota	5.3704	0.8481	1.0451	0.9117	4.3397	1.0000	1.0329	1.0013	0.9117	0.9429
Utah	5.3704	0.8388	1.0451	0.9297	4.3772	1.0000	1.0216	1.0013	0.9297	0.9510
West Virginia	5.3704	0.8322	1.0451	0.9429	4.4044	1.0000	1.0135	1.0013	0.9429	0.9569
Wyoming	5.3704	0.8280	1.0451	0.9516	4.4221	1.0000	1.0083	1.0013	0.9516	0.9608

Notes: Border effects are decomposed as indicated by (35).

Table 4: Impacts of fully removing the border, holding all other parameters fixed

	Benchmark (1)							
	Wage $\Delta(w_r)\%$	Cutoff $\Delta(m_r^d)\%$	Markup $\Delta(\alpha E_r/N_r^c)\%$	Initial % of exporters	Final % of exporters	Consumed $\Delta(N_r^c)\%$	Produced $\Delta(N_r^p)\%$	Welfare $\Delta U_r^*\%$
State/province	**In Gravity sample**							
Alberta	7.5642	-12.6501	-6.0428	2.3633	14.9207	14.4821	-38.5468	14.4821
British Columbia	4.5131	-8.0525	-3.9028	3.0069	17.8384	8.7577	-26.0831	8.7577
Manitoba	12.2724	-19.0725	-9.1407	2.5842	18.4735	23.5673	-53.3183	23.5673
New Brunswick	9.8759	-15.8991	-7.5934	1.9725	13.0564	18.9048	-46.3855	18.9048
Newfoundland	11.8673	-18.5492	-8.8832	0.6401	4.4570	22.7735	-52.2225	22.7735
Nova Scotia	6.2608	-10.7310	-5.1420	0.6954	4.1891	12.0209	-33.5457	12.0209
Ontario	9.3696	-15.2038	-7.2588	3.0667	20.1687	17.9299	-44.7726	17.9299
Prince Edward Isl.	10.1873	-16.3224	-7.7978	0.3870	2.5819	19.5063	-47.3506	19.5063
Quebec	5.8181	-10.0642	-4.8316	4.2744	25.4465	11.1904	-31.7413	11.1904
Saskatchewan	10.9235	-17.3097	-8.2771	2.2684	15.6725	20.9332	-49.5529	20.9332
Alabama	0.0000	-0.5251	-0.5251	0.5974	2.4410	0.5278	-1.8773	0.5278
Arizona	0.2474	-0.9623	-0.7172	1.3872	5.6017	0.9716	-3.4210	0.9716
California	-0.1973	-0.1742	-0.3712	0.7466	3.2289	0.1745	-0.6257	0.1745
Florida	-0.0789	-0.3849	-0.4636	0.8554	3.4874	0.3864	-1.3788	0.3864
Georgia	-0.0156	-0.4974	-0.5129	0.6965	2.8449	0.4998	-1.7789	0.4998
Idaho	0.9951	-2.2655	-1.2929	1.6960	7.4970	2.3180	-7.9185	2.3180
Illinois	0.0168	-0.5548	-0.5381	1.3945	5.4074	0.5579	-1.9830	0.5579
Indiana	0.1571	-0.8031	-0.6472	1.0195	4.2731	0.8096	-2.8609	0.8096
Kentucky	0.1607	-0.8093	-0.6500	0.8182	3.4295	0.8160	-2.8831	0.8160
Louisiana	-0.0518	-0.4332	-0.4847	0.4159	1.6522	0.4350	-1.5506	0.4350
Maine	2.0177	-4.0051	-2.0681	2.8319	12.3393	4.1722	-13.6835	4.1722
Maryland	-0.0957	-0.3551	-0.4505	0.2358	0.9813	0.3564	-1.2726	0.3564
Massachusetts	0.0506	-0.6147	-0.5644	0.6961	2.8713	0.6185	-2.1954	0.6185
Michigan	0.6404	-1.6507	-1.0208	3.0560	12.9833	1.6784	-5.8161	1.6784
Minnesota	0.5095	-1.4222	-0.9199	3.5620	14.0049	1.4427	-5.0259	1.4427
Missouri	0.0725	-0.6535	-0.5815	1.1937	4.6360	0.6578	-2.3328	0.6578
Montana	1.6802	-3.4363	-1.8138	2.8597	12.0188	3.5586	-11.8282	3.5586
New Hampshire	0.7991	-1.9265	-1.1428	0.9073	3.8217	1.9644	-6.7635	1.9644
New Jersey	0.1158	-0.7300	-0.6151	0.8510	3.4884	0.7354	-2.6033	0.7354
New York	0.1295	-0.7542	-0.6257	1.4457	5.9290	0.7599	-2.6886	0.7599
North Carolina	0.0975	-0.6977	-0.6009	0.9245	3.7881	0.7026	-2.4889	0.7026
North Dakota	1.4348	-3.0194	-1.6279	2.4809	10.2899	3.1134	-10.4499	3.1134
Ohio	0.2331	-0.9371	-0.7062	1.7841	7.4937	0.9460	-3.3327	0.9460
Pennsylvania	0.1944	-0.8688	-0.6761	1.4866	6.2371	0.8764	-3.0924	0.8764
Tennessee	0.1056	-0.7120	-0.6072	0.9501	3.6932	0.7171	-2.5395	0.7171
Texas	-0.0387	-0.4564	-0.4949	1.6317	6.5363	0.4584	-1.6332	0.4584
Vermont	1.7802	-3.6052	-1.8893	1.0820	5.2072	3.7401	-12.3822	3.7401
Virginia	0.0838	-0.6735	-0.5902	0.7297	2.9887	0.6780	-2.4033	0.6780
Washington	0.8846	-2.0746	-1.2083	3.8231	18.5861	2.1186	-7.2694	2.1186
Wisconsin	0.4306	-1.2841	-0.8590	2.5627	10.0535	1.3009	-4.5463	1.3009
State/province	**Out of Gravity sample**							
Alaska	0.4346	-1.2910	-0.8621	0.2520	1.1155	1.3079	-4.5702	1.3079
Arkansas	0.1521	-0.7942	-0.6433	0.9901	3.8538	0.8005	-2.8296	0.8005
Colorado	0.0097	-0.5422	-0.5326	0.6254	2.5086	0.5452	-1.9384	0.5452
Connecticut	0.2314	-0.9341	-0.7049	0.7055	2.9016	0.9430	-3.3223	0.9430
Delaware	0.2651	-0.9934	-0.7310	0.2843	1.1704	1.0034	-3.5304	1.0034
Hawaii	0.8519	-2.0180	-1.1833	1.1719	5.2488	2.0595	-7.0762	2.0595
Iowa	0.2589	-0.9825	-0.7262	1.5910	6.2115	0.9923	-3.4922	0.9923
Kansas	0.1181	-0.7342	-0.6169	0.8324	3.2369	0.7396	-2.6179	0.7396
Mississippi	0.0316	-0.5810	-0.5496	0.5127	1.9889	0.5844	-2.0759	0.5844
Nebraska	0.2485	-0.9642	-0.7181	0.9387	3.6637	0.9736	-3.4279	0.9736
Nevada	0.0657	-0.6414	-0.5762	0.3591	1.5296	0.6456	-2.2900	0.6456
New Mexico	0.3157	-1.0824	-0.7701	1.0928	4.4214	1.0942	-3.8421	1.0942
Oklahoma	0.1810	-0.8453	-0.6658	1.3490	5.4372	0.8525	-3.0098	0.8525
Oregon	0.5519	-1.4962	-0.9526	1.6925	8.1520	1.5190	-5.2825	1.5190
Rhode Island	0.3225	-1.0944	-0.7754	0.4307	1.7760	1.1065	-3.8842	1.1065
South Carolina	0.1742	-0.8332	-0.6605	0.9215	3.7837	0.8402	-2.9672	0.8402
South Dakota	0.8358	-1.9901	-1.1709	1.4998	6.0644	2.0305	-6.9809	2.0305
Utah	0.5953	-1.5721	-0.9861	1.8548	7.5632	1.5972	-5.5447	1.5972
West Virginia	0.4225	-1.2699	-0.8527	1.0094	4.2621	1.2862	-4.4965	1.2862
Wyoming	0.3106	-1.0735	-0.7662	0.3791	1.5335	1.0851	-3.8109	1.0851
Washington DC	0.0961	-0.6952	-0.5998	0.1239	0.5184	0.7001	-2.4802	0.7001

Notes: See Section 5 for details on computations.

Table 5: Impacts of population changes (1993–2007), holding the trade frictions fixed

	Benchmark (1)								
	% Pop. change 1993-2007	Wage $\Delta(w_r)\%$	Cutoff $\Delta(m_r^d)\%$	Markup $\Delta(\alpha E_r/N_r^c)\%$	Initial % of exporters	Final % of exporters	Consumed $\Delta(N_r^c)\%$	Produced $\Delta(N_r^p)\%$	Welfare $\Delta U_r^*\%$
State/province	**In Gravity sample**								
Alberta	30.2362	0.9476	-4.9646	-4.0641	2.3633	2.4055	5.2240	-16.7494	5.2240
British Columbia	22.7855	0.5764	-4.3385	-3.7871	3.0069	3.0025	4.5352	-14.7579	4.5352
Manitoba	6.1790	-0.8462	-1.8781	-2.7085	2.5842	2.5604	1.9141	-6.5978	1.9141
New Brunswick	0.1295	-1.3864	-0.9179	-2.2916	1.9725	1.9398	0.9265	-3.2654	0.9265
Newfoundland	-12.7020	-2.1698	0.5009	-1.6798	0.6401	0.6155	-0.4984	1.8150	-0.4984
Nova Scotia	1.0950	-1.5391	-0.6438	-2.1731	0.6954	0.6809	0.6480	-2.2985	0.6480
Ontario	19.7922	0.1099	-3.5424	-3.4364	3.0667	3.1410	3.6725	-12.1765	3.6725
Prince Edward Island	4.9076	-1.2261	-1.2045	-2.4158	0.3870	0.3823	1.2192	-4.2688	1.2192
Quebec	7.6242	-0.9423	-1.7084	-2.6346	4.2744	4.2570	1.7381	-6.0149	1.7381
Saskatchewan	-0.9917	-1.1135	-1.4049	-2.5028	2.2684	2.2304	1.4249	-4.9659	1.4249
Alabama	10.3679	0.0000	-3.3534	-3.3534	0.5974	0.6185	3.4698	-11.5554	3.4698
Arizona	58.7312	2.2688	-7.1422	-5.0355	1.3872	1.5251	7.6916	-23.4147	7.6916
California	17.3563	0.1896	-3.6792	-3.4966	0.7466	0.7746	3.8198	-12.6241	3.8198
Florida	33.0887	1.1578	-5.3165	-4.2202	0.8554	0.9148	5.6150	-17.8538	5.6150
Georgia	38.4483	1.1994	-5.3858	-4.2510	0.6965	0.7458	5.6924	-18.0700	5.6924
Idaho	36.1602	1.0392	-5.1182	-4.1322	1.6960	1.8021	5.3943	-17.2327	5.3943
Illinois	9.6074	-0.5992	-2.3124	-2.8977	1.3945	1.4043	2.3671	-8.0774	2.3671
Indiana	11.2825	-0.5301	-2.4333	-2.9505	1.0195	1.0013	2.4940	-8.4863	2.4940
Kentucky	11.8447	-0.4146	-2.6350	-3.0386	0.8182	0.8062	2.7063	-9.1655	2.7063
Louisiana	0.1973	-0.9823	-1.6377	-2.6039	0.4159	0.4143	1.6650	-5.7713	1.6650
Maine	6.3760	-0.7992	-1.9610	-2.7446	2.8319	2.8797	2.0002	-6.8816	2.0002
Maryland	13.6740	-0.4057	-2.6505	-3.0454	0.2358	0.2351	2.7226	-9.2175	2.7226
Massachusetts	7.3013	-0.9696	-1.6601	-2.6136	0.6961	0.7045	1.6881	-5.8486	1.6881
Michigan	5.6939	-0.8509	-1.8700	-2.7049	3.0560	2.9741	1.9056	-6.5698	1.9056
Minnesota	14.9482	-0.2619	-2.9006	-3.1549	3.5620	3.6215	2.9873	-10.0546	2.9873
Missouri	12.2315	-0.3756	-2.7028	-3.0683	1.1937	1.2097	2.7779	-9.3932	2.7779
Montana	14.0479	0.3160	-3.8954	-3.5917	2.8597	2.9777	4.0533	-13.3280	4.0533
New Hampshire	17.2553	-0.5041	-2.4787	-2.9704	0.9073	0.9304	2.5417	-8.6397	2.5417
New Jersey	10.2989	-0.6804	-2.1699	-2.8356	0.8510	0.8643	2.2181	-7.5939	2.2181
New York	6.3769	-1.0438	-1.5286	-2.5565	1.4457	1.4533	1.5524	-5.3947	1.5524
North Carolina	30.4231	0.7169	-4.5763	-3.8922	0.9245	0.9767	4.7957	-15.5182	4.7957
North Dakota	0.3901	-0.5193	-2.4523	-2.9588	2.4809	2.5070	2.5140	-8.5505	2.5140
Ohio	3.5819	-1.0365	-1.5415	-2.5621	1.7841	1.7272	1.5657	-5.4392	1.5657
Pennsylvania	3.4159	-1.1316	-1.3727	-2.4888	1.4866	1.4352	1.3918	-4.8543	1.3918
Tennessee	21.0602	0.1374	-3.5897	-3.4572	0.9501	0.9769	3.7234	-12.3313	3.7234
Texas	32.8260	1.1298	-5.2697	-4.1994	1.6317	1.7382	5.5628	-17.7075	5.5628
Vermont	8.2316	-0.7367	-2.0710	-2.7925	1.0820	1.0883	2.1148	-7.2572	2.1148
Virginia	19.2937	0.0637	-3.4630	-3.4016	0.7297	0.7569	3.5873	-11.9160	3.5873
Washington	23.2620	0.6285	-4.4268	-3.8261	3.8231	3.8287	4.6318	-15.0407	4.6318
Wisconsin	10.8069	-0.4996	-2.4866	-2.9738	2.5627	2.5880	2.5500	-8.6662	2.5500
State/province	**Out of Gravity sample**								
Alaska	14.4868	-0.1346	-3.1210	-3.2515	0.2520	0.2445	3.2216	-10.7874	3.2216
Arkansas	16.9595	-0.0079	-3.3397	-3.3474	0.9901	1.0138	3.4551	-11.5103	3.4551
Colorado	36.5255	1.4534	-5.8077	-4.4387	0.6254	0.6722	6.1658	-19.3777	6.1658
Connecticut	7.0282	-0.9408	-1.7111	-2.6358	0.7055	0.7113	1.7409	-6.0243	1.7409
Delaware	23.6304	-0.1773	-3.0471	-3.2191	0.2843	0.2929	3.1429	-10.5421	3.1429
Hawaii	10.4933	-0.0340	-3.2948	-3.3277	1.1719	1.1883	3.4071	-11.3621	3.4071
Iowa	5.9394	-0.5973	-2.3157	-2.8992	1.5910	1.6023	2.3706	-8.0885	2.3706
Kansas	8.9650	-0.4607	-2.5546	-3.0035	0.8324	0.8415	2.6216	-8.8953	2.6216
Mississippi	10.7457	-0.2911	-2.8499	-3.1327	0.5127	0.5208	2.9335	-9.8852	2.9335
Nebraska	10.0749	-0.3964	-2.6667	-3.0525	0.9387	0.9507	2.7398	-9.2720	2.7398
Nevada	85.8707	2.8851	-8.1314	-5.4809	0.3591	0.4016	8.8511	-26.3111	8.8511
New Mexico	21.9809	0.6845	-4.5215	-3.8680	1.0928	1.1497	4.7357	-15.3437	4.7357
Oklahoma	12.0318	-0.0060	-3.3430	-3.3488	1.3490	1.3920	3.4586	-11.5210	3.4586
Oregon	23.4954	0.6569	-4.4749	-3.8474	1.6925	1.6964	4.6846	-15.1948	4.6846
Rhode Island	6.0109	-0.9553	-1.6855	-2.6246	0.4307	0.4341	1.7143	-5.9359	1.7143
South Carolina	21.2739	0.3432	-3.9419	-3.6122	0.9215	0.9633	4.1037	-13.4789	4.1037
South Dakota	11.1630	-0.2008	-3.0065	-3.2013	1.4998	1.5275	3.0997	-10.4071	3.0997
Utah	41.0096	1.2921	-5.5402	-4.3196	1.8548	1.9847	5.8651	-18.5502	5.8651
West Virginia	-0.2282	-0.7210	-2.0987	-2.8046	1.0094	0.9859	2.1437	-7.3515	2.1437
Wyoming	11.4698	0.2163	-3.7250	-3.5167	0.3791	0.3936	3.8691	-12.7734	3.8691
Washington DC	2.0706	-0.9009	-1.7816	-2.6665	0.1239	0.1204	1.8140	-6.2668	1.8140

Notes: See Section 5 for details on computations. Populations in 1993 and in 2007 are taken from Statistics Canada and the U.S. Bureau of Census.