

CHAPTER 2: General equilibrium trade policy analysis with structural gravity¹

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A. Overview and learning objectives

A general equilibrium analysis accounts for all the direct and indirect linkages between the various elements in the economic system considered (e.g. countries or sectors), while imposing and satisfying all goods/services market-clearing and resource market-clearing conditions.

Due to the nature of international trade and the significant interdependence between the various economic entities in the world trade system, trade policy analysis is standardly performed in a general equilibrium setting. However, doing competent general equilibrium analysis is not a trivial task. The objective of this chapter is to serve as a practical guide for obtaining the general equilibrium effects of trade policies (and other determinants of bilateral trade) with the structural gravity model.

Although this chapter gives credit to a large number of related studies and offers general implications and analysis whenever possible, it is not intended to be a survey of the related contemporary literature, neither is it intended to be a review of the wide literature devoted to applied and computable general equilibrium (CGE) analysis. That being said, and as explained in Chapter 1, although this *Advanced Guide* focuses on the original Armington-Constant Elasticity of Substitution (CES) gravity model, many of the recommendations made here are quite general and apply to a wider range of trade models that, as demonstrated earlier, all converge to the same structural gravity system, subject to parameter interpretation. In combination with the theory-consistent estimation recommendations formulated in Chapter 1, the tractable structural gravity theory and the novel empirical developments presented in this chapter will help applied economists and practitioners to overcome the challenges to general equilibrium modelling and enable them to perform rigorous evaluation of the general equilibrium effects of various trade policies.

The first part of this chapter will provide a deep analysis of the structural interpretations of the relationships underlying the general equilibrium gravity system, and how they can be exploited to make trade policy inferences. The section also demonstrates how gravity can be integrated with a broader class of general equilibrium models by nesting the structural gravity model within a dynamic production superstructure with capital accumulation. A series of theory-consistent indexes that can be used to summarize, decompose, and aggregate the general equilibrium effects of trade policy will be presented and discussed. Next, the standard procedure to perform general equilibrium counterfactual analysis with the structural gravity model is reviewed. Drawing from recent developments in the empirical gravity literature, which capitalize on the properties of the Poisson Pseudo Maximum Likelihood (PPML) estimator, a simple procedure that can be used to obtain theory-consistent general equilibrium effects of trade policy with the structural gravity model, directly in standard software packages (e.g. STATA software), will be presented. Key elements of the STATA codes needed to obtain the results from the applications are included in the main text, while the complete STATA codes can be downloaded from the *Practical Guide's* website.

The second part of the chapter complements the theoretical developments presented previously with two counterfactual experiments. The first application simulates the removal of existing international borders in the world, while the second counterfactual experiment considers the general equilibrium effects of the North American Free Trade Agreement (NAFTA).

Two exercises are available at the end of the chapter. Data and STATA do-files for the solution of these exercises can be downloaded from the website.

In this chapter, you will learn:

- How to perform general equilibrium counterfactual analysis of trade policy with the structural gravity model;
- How to obtain theory-consistent general equilibrium effects of trade policy with the structural gravity model by capitalizing on the property of the PPML estimator;
- How to construct theory-consistent indexes to aggregate and decompose the general equilibrium effects of trade policy;
- How the structural gravity model can be integrated with a broader class of general equilibrium models;
- How to interpret general equilibrium results to make trade policy inferences.

After reading this chapter, with sound econometric knowledge, and familiarity with STATA, you will be able to perform general equilibrium counterfactual analysis of trade policy directly using STATA, and construct a series of general equilibrium trade cost indexes and their responses to trade policy changes.

B. Analytical tools

1. Structural gravity: general equilibrium context

As reviewed in detail in part B.1 of Chapter 1, and as demonstrated in the Appendices 1.A, 1.B, and 2.B, subject to interpretation of the structural parameters, the following structural gravity system of trade can be derived from many underlying theoretical foundations:

$$X_{ij} = \frac{Y_i E_j}{Y} \left(\frac{t_{ij}}{\Pi_i P_j} \right)^{1-\sigma} \quad (2-1)$$

$$\Pi_i^{1-\sigma} = \sum_j \left(\frac{t_{ij}}{P_j} \right)^{1-\sigma} \frac{E_j}{Y} \quad (2-2)$$

$$P_j^{1-\sigma} = \sum_i \left(\frac{t_{ij}}{\Pi_i} \right)^{1-\sigma} \frac{Y_i}{Y} \quad (2-3)$$

$$p_i = \left(\frac{Y_i}{Y} \right)^{\frac{1}{1-\sigma}} \frac{1}{\alpha_i \Pi_i} \quad (2-4)$$

$$E_i = \varphi_i Y_i = \varphi_i p_i Q_i \quad (2-5)$$

where: X_{ij} denotes nominal trade flows from exporter i to destination j ; E_j is the total expenditure in importer j , Y_i is the value of total production in exporter i ; Y is the value of world output; t_{ij} denotes bilateral trade frictions between partners i and j ; $\sigma > 1$ is the elasticity of substitution among goods from different countries; α_i is the CES preference parameter; P_j and Π_i are structural terms defined by Anderson and van Wincoop (2003) as the inward and outward multilateral resistances, respectively; p_i is the factory-gate price for each variety of goods in the country of origin i ; Q_i is the endowment or quantity supplied of each variety of goods in country i ; and ϕ_i is an exogenous parameter defining the relation between the value of output and aggregate expenditure, such that when $\phi_i > 1$, country i faces a trade deficit, while country i runs a trade surplus when $1 > \phi_i > 0$.

This section starts with a discussion on six appealing properties of the multilateral resistances as the key vehicles to translate the partial equilibrium changes in trade costs into general equilibrium trade policy effects. Next, the effects of hypothetical bilateral trade liberalization scenarios are discussed, demonstrating how a bilateral trade liberalization shock is transmitted via the multilateral resistances throughout the whole economic system. The section concludes with a presentation of several useful general equilibrium indexes that summarize the effects of trade policy and decompose their incidence on producers and consumers in the world.

(a) Properties of the multilateral resistances

Coined by Anderson and van Wincoop (2003) as the multilateral resistances, the terms of the structural gravity systems, Π_i , the outward multilateral resistance (OMR) and P_j , the inward multilateral resistance (IMR) are at the heart of the general equilibrium analysis of trade policy presented in this *Advanced Guide*. In that context, the multilateral resistance terms feature six main (and interrelated) properties.

1. *The multilateral resistances are intuitive structural trade cost terms*

The multilateral resistances bear the intuitive interpretation that, all else equal, two countries will trade more with each other the more remote they are from the rest of the world. Proper account for the multilateral resistances is the key difference between the naive vs. theory-founded applications of the trade gravity model (Anderson and van Wincoop, 2003). While the multilateral resistances developed by Anderson and van Wincoop (2003) offer an elegant structure behind remoteness, Krugman (1995) offers a great intuition for remoteness by comparing the hypothetical levels of trade between two economies that are always at the same distance from each other but once they are on Mars and once they are in the middle of Europe. As discussed in section B.2. of Chapter 1, several researchers have proposed to construct proxies for the multilaterals resistances, often referred to as “remoteness indexes”, such as GDP-weighted distance averages. Although easy to construct, such a-theoretical remoteness indexes are not perfectly consistent with the general equilibrium analysis presented here. This is one of the reasons why, as discussed in Chapter 1, Head and Mayer (2014) advise against their use.

2. *The multilateral resistances are theory-consistent aggregates of bilateral trade costs*

As is evident from the definitions of the multilateral terms from equations (2-2) and (2-3), the multilateral resistances are theory-consistent aggregates of all possible bilateral trade costs to the

country level. In combination with the other properties of the multilateral resistances, this property is very convenient and important for computational and interpretation purposes because, by construction, the multilateral resistance terms can be used to collapse the $N \times N$ -dimensional system of bilateral links in the gravity model into a $2 \times N$ -dimensional series of country-specific indexes.

3. *The multilateral resistances are general equilibrium trade cost indexes*

Of utmost importance for the purpose of this chapter, the multilateral resistances are general equilibrium trade cost terms that capture the fact that a change in bilateral trade costs between any two partners, such as the formation of a RTA, will result in (i) additional effects (in addition to the direct partial effects) for the parties to the RTA but (ii) will also affect all other countries in the world with (iii) possible feedback effects on the original liberalizing partners.

As discussed earlier, trade between two countries depends not only on the direct trade costs between these countries but also on how remote they are from the rest of their trading partners, which is captured by the multilateral resistances. Applying this intuition to the case of trade liberalization between two countries, the general equilibrium forces will translate into lower multilateral resistances for the RTA's members and into higher multilateral resistances for all other countries in the world. The intuition for this result is that when two countries become more integrated with each other, all else equal, they also become relatively more isolated from the rest of the world.

4. *The multilateral resistances decompose the incidence of trade costs*

The multilateral resistances decompose the aggregate incidence of trade costs and their changes on consumers and producers in each country. Equation (2-2) shows that the outward multilateral resistance term is a weighted-average aggregate of all bilateral trade costs for the producers of goods in each country. It is as if each country i shipped its product to a single world market facing supply side incidence of trade costs Π_i .² Similarly, equation (2-3) defines the inward multilateral resistance as a weighted average of all bilateral trade costs that fall on the consumers in each region. It is as if each country j bought its goods from a single world market facing demand side incidence of P_j . Importantly, this property in combination with the two previous ones will enable to quantify and decompose the effects of trade policy changes between any two countries into separate effects on producers and consumers in every country in the world.

5. *The multilateral resistances are straightforward to construct*

With data on output and expenditure, and for given values of the elasticity of substitution (σ) and the vector of bilateral trade costs (t_{ij}), the multilateral resistances can be calculated using equations (2-2) and (2-3).

As emphasized by Anderson and Yotov (2010b), the system of equations (2-2) and (2-3) can be solved for $\{\Pi_i, P_j\}$ only up to a scalar (λ), implying that if $\{\Pi_i^0, P_j^0\}$ is a solution then so is $\{\lambda \Pi_i^0, P_j^0 / \lambda\}$. Therefore, a normalisation is required.³ A natural normalisation procedure sets the inward multilateral resistance for a country of choice (usually the country with the most reliable data) to be equal to one ($P_R = 1$, where R is the reference country). An alternative normalisation strategy,

when counterfactual experiments are performed, is to choose a country that presumably will not be affected much by the counterfactual shock. The idea is that if the reference group is not affected then the “relative” counterfactual changes in the multilateral resistances indexes will be much closer to their “absolute” counterparts. Regardless of the normalisation choice, it is important to remember that the values of all multilateral resistance terms (both inward and outward) can only be solved in relative terms with respect to the country of choice. There are at least three approaches to solve system (2-2)-(2-3) for the multilateral resistance terms:

- (i) Subject to a normalisation, system (2-2)-(2-3) can be directly solved for the multilateral resistance terms Π_i and P_j . A disadvantage of this approach is that system (2-2)-(2-3) are highly non-linear in Π_i and P_j .
- (ii) This challenge can be overcome by noticing that system (2-2)-(2-3) becomes a quadratic system when expressed in terms of the power transforms of the multilateral resistances, $\Pi_i^{1-\sigma}$ and $P_j^{1-\sigma}$. Then, the simple quadratic system (2-2)-(2-3) can be solved easily with any software supporting non-linear solvers.
- (iii) Finally, as demonstrated in Section 2, the multilateral resistance terms can actually be recovered directly from the importer and from the exporter fixed effects when the structural gravity model is estimated with the PPML estimator.

6. *The multilateral resistances are appealing for practical purposes*

In combination, the above properties make the multilateral resistance indexes very appealing for practical purposes from both a policy and structural estimation perspective:

- (i) From a policy perspective, the multilateral resistance terms should be viewed as informative indexes that summarize the general equilibrium effects of trade costs and that can be used to aggregate and decompose the impact of trade policy on consumers and producers in the liberalizing and others (non-members) countries. In addition, as demonstrated in section 2.(d), the multilateral resistances can be used to construct a series of other summary measures of the effects of trade costs and policy.
- (ii) From a structural estimation perspective, the solid theoretical foundation of the multilateral resistance terms makes them an appealing alternative to reduced-form specifications. Two benefits of the structural use of the multilateral resistance terms in estimations are worth mentioning. First, the estimation of the structural gravity model enables to recover and interpret structurally the estimates of the coefficients on the multilateral resistances terms. Anderson et al. (2015c; 2016a) capitalize on this property to recover estimates of the elasticity of substitution from a structural equation that links income to trade openness in the spirit of Frankel and Romer (1999). Second, potential endogeneity concerns can be addressed with a theory-consistent approach.

(b) General equilibrium effects of trade policy

This section offers an intuitive discussion of the general equilibrium effects of trade policy by describing the underlying links and causal mechanisms between trade policy and economic outcomes within the structural gravity model.⁴ Combining the system of equations (2-1)-(2-3) with the market

clearing condition (2-4) and aggregate expenditure expressed in terms of nominal income (2-5) enables to establish a structural gravity system decomposing the effects of trade policy on trade into three different channels (Head and Mayer, 2014):⁵

$$\left. \begin{array}{l} \text{Full} \\ \text{Endowment:} \\ \text{GE} \end{array} \right\} \left\{ \begin{array}{l} \text{Conditional} \\ \text{GE} \end{array} \right\} \left\{ \begin{array}{l} \text{Direct (PE):} \\ \end{array} \right. \left\{ \begin{array}{l} X_{ij} = \frac{Y_i E_j}{Y} \left(\frac{t_{ij}}{\Pi_i P_j} \right)^{1-\sigma} \quad (2-1) \\ \Pi_i^{1-\sigma} = \sum_j \left(\frac{t_{ij}}{P_j} \right)^{1-\sigma} \frac{E_j}{Y} \quad (2-2) \\ P_j^{1-\sigma} = \sum_i \left(\frac{t_{ij}}{\Pi_i} \right)^{1-\sigma} \frac{Y_i}{Y} \quad (2-3) \\ \rho_i = \left(\frac{Y_i}{Y} \right)^{\frac{1}{1-\sigma}} \frac{1}{\alpha_i \Pi_i} \quad (2-4) \\ E_i = \varphi_i Y_i = \varphi_i \rho_i Q_i \quad (2-5) \end{array} \right.$$

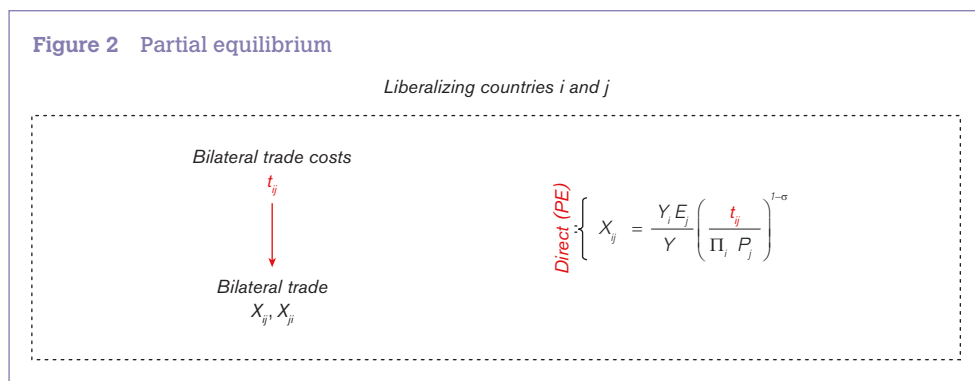
As demonstrated in Appendix B, the structural gravity system (2-1)-(2-5) defined at the aggregate level can also be extended to the sectoral level. Overall, the structural gravity system (2-1)-(2-5) not only enables to decompose the different channels through which trade policy impacts trade, but also to evaluate the relative importance of these channels in the overall impact of trade policy on trade. For clarity and tractability purposes, the analysis presented below is based on a **hypothetical bilateral trade liberalization scenario**, such as the establishment of a RTA between countries i and j .

1. Partial equilibrium (PE) effects

The direct/partial equilibrium effect of a decrease in bilateral trade costs between countries i and j is the initial and, most likely, the strongest effect of trade liberalization on bilateral trade between the two liberalizing countries. As depicted in Figure 2, the partial equilibrium trade creation effect is captured by adjusting the bilateral trade cost (t_{ij}) in equation (2-1), while holding national output (Y_i) and expenditure (E_j), world output (Y), and multilateral resistances (Π_i and P_j) constant.

By definition, the direct effects of trade policy changes are limited to liberalizing members only, and have no implications for trade and welfare of other countries. For example, a 10 percent decrease in bilateral trade costs between partners i and j will translate into a $(0.9^{1-\sigma} - 1) \times 100$ percent increase in bilateral trade between the two countries, with zero effects on the rest of the countries in the world, where σ is the elasticity of substitution. As presented in section B.3 of Chapter 1, the

structural gravity model also allows for a convenient conversion of any partial equilibrium decrease in trade costs into a corresponding tariff equivalent.



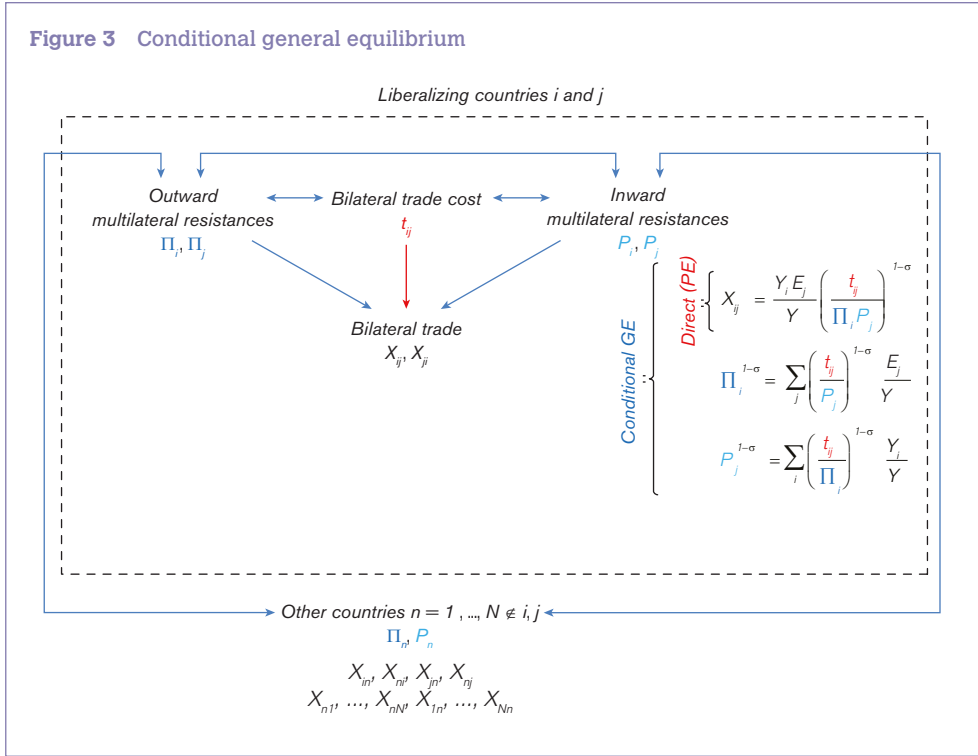
2. Conditional general equilibrium effects

An important limitation of the partial equilibrium analysis of the effects of trade policy is that, by construction, the trade policy is assumed to have no impact on other countries (e.g. non-parties to the RTA). This drawback is overcome by the structural gravity model, which provides a tractable general equilibrium analysis framework operating via the multilateral resistance channels, captured by equations (2-2) and (2-3), in addition to the partial equilibrium effects captured by equation (2-1).

This scenario is qualified as “conditional”, because output (Y_i) and expenditure (E_j) are assumed to remain unchanged following the bilateral trade liberalization between countries i and j . However, as depicted in Figure 3, this scenario is also labelled as a “general equilibrium”, because it allows for the effects of trade liberalization between two countries i and j (t_{ij}) to ripple through the rest of the world via the general equilibrium multilateral resistance terms (Π_i and P_j).

The “conditional general equilibrium” step may seem redundant, because, as discussed above, the “partial equilibrium” effects of trade policy can be translated directly into “full endowment general equilibrium” effects, without the need to perform this intermediate step.⁶ That being said, analysing the “conditional general equilibrium” scenario as a standalone intermediate step between the “partial equilibrium” analysis and the “full endowment general equilibrium” scenario offers at least four benefits:

- (i) From an instructional perspective, and as highlighted in Anderson and van Wincoop (2003), it is important to understand that a change in bilateral trade costs between any two countries will trigger general equilibrium effects that affect the trade costs, and their incidence on consumers and producers, in any other country in the world, even if everything else (e.g. country size) remains the same.
- (ii) From a policy perspective, the “conditional general equilibrium” scenario delivers *total* bilateral trade cost indexes as a combination of the *direct* bilateral trade costs and the corresponding general equilibrium components that are captured by the multilateral resistances, at given output and expenditure levels.



- (iii) From a theoretical perspective, the construction of the conditional trade costs indexes enables to decompose the effects of trade liberalization into the impacts on trade costs and on economic size, separately. As discussed in Section B.1 in Chapter 1, for given output sizes captured by the first term of the structural gravity equation (2-1), $Y_i E_j / Y$, the second structural term, $\left(t_{ij} / (\Pi_i P_j) \right)^{1-\sigma}$, measures the conditional general equilibrium effects of trade policy on trade costs.
- (iv) From a practical perspective, and as demonstrated in Section C, the conditional general equilibrium indexes can be recovered directly from the PPML estimates of the fixed effects associated with the structural gravity model, ensuring a perfect and consistent mapping between theory and empirical analysis.

For expositional reasons, the effects on the liberalizing countries and on the other countries in the conditional general equilibrium scenario are discussed separately. The impacts of bilateral trade liberalization on the liberalizing (or member) countries are defined as “first-order general equilibrium effects”, because they are, by construction, the strongest in magnitude. Conversely, the impacts on outside (or non-member) countries are labelled as “second-order general equilibrium effects”, because they are the results of changes in the member countries’ multilateral resistances.

Conditional general equilibrium effects on member countries. As shown in Figure 3, the liberalizing countries' "first-order general equilibrium effects" materialize through two different channels: (1) the inward multilateral resistances and (2) the outward multilateral resistances. Both are presented separately below.

First-order general equilibrium effects through inward multilateral resistances. Part of the first-order general equilibrium effects of trade liberalization on member countries are channelled through the inward multilateral resistance, P_j , which according to equation (2-3) suggests that:

- (i) The inward multilateral resistances will decrease for both liberalizing countries following their bilateral trade liberalization.
- (ii) The effects for each liberalizing country will be stronger the larger is the partner country's size.

All else equal, equation (2-1) reveals that the fall in the inward multilateral resistance will work in the opposite direction of the direct effect of trade liberalization. In other words, a fall in inward multilateral resistances will cause country j to import less from all source countries, including j , *ceteris paribus*. These trade diversion effects, often feared by policy makers and popular observers, arise because the more integrated country j is with a particular trading partner i the more remote it becomes relative to all other countries. When the variety from source i becomes cheaper, consumers in country j will substitute away from all other varieties. Alternatively, using the price index interpretation of P_j , the partner country i gains market share in country j (because of the direct/partial effect of trade liberalization), whereas country j 's import market becomes more competitive for non-member countries.

By construction, the decrease in each liberalizing country's inward multilateral resistances will always be smaller in magnitude than the decrease in bilateral trade costs between the two liberalizing countries (i.e. $\Delta t_{ij} > \Delta P_j$). The reason is that, by construction, the change in inward multilateral resistances is obtained as a weighted average of the changes in all bilateral trade costs, where the change in trade costs between the liberalizing countries plays only a small role that depends on their size. As a result, trade diversion effects due to the fall in inward multilateral resistances will never be strong enough to offset the direct trade creation effect of the decrease in bilateral trade costs between the liberalizing countries.

First-order general equilibrium effects through outward multilateral resistances. The other first-order general equilibrium effects of trade liberalization on member countries are channelled via the outward multilateral resistances, Π_j , which, based on equation (2-2), implies that:

- (i) The outward multilateral resistances will decrease for both liberalizing countries as a result of their bilateral trade liberalization.
- (ii) The effects for each liberalizing country will be stronger the larger is the partner country's size.

Similar to the effect of the decrease of inward multilateral resistances, equation (2-1) suggests that each liberalizing member's exports to all countries will decrease following the decrease in outward multilateral resistances. These trade-diversion effects occur because for a given total output, country i will export more to country j and less to every other country, when it experiences lower export costs to this particular partner j . In other words, the more integrated country i is with its trading partner j , the more remote it becomes relative to all other countries. Although, the general

equilibrium trade diversion effects channelled through the outward multilateral resistances can be quite substantial, they will not, by construction, be strong enough to offset the direct trade creation effects due to trade liberalization between the liberalizing countries (i.e. $\Delta t_{ij} > \Delta \Pi_j$).

Conditional general equilibrium effects on non-member countries. As explained above, an important implication of the “conditional general equilibrium” scenario is that it translates the effects of trade liberalization between countries i and j to changes in trade (and welfare) for all other countries in the world. These second-order effects, triggered by changes in the liberalizing countries’ multilateral resistance terms described above, are also channelled through the multilateral resistances. Specifically, equations (2-2) and (2-3) imply that:

- (i) The non-member countries’ outward and inward multilateral resistances will typically increase as a result of the decrease in the liberalizing countries’ outward and inward resistance terms.
- (ii) The effects for each non-member country will be stronger the larger are the liberalizing countries’ sizes.

According to equation (2-1), the increase in non-member countries’ outward and inward multilateral resistance terms will typically, all else being equal, lead to an increase in exports and imports between non-member countries. These trade creation effects arise because, at constant output levels, once non-member countries’ imports and exports are diverted from the liberalizing members (who trade more with each other and less with non-member countries), they will be redirected to other non-member countries and to domestic sales.

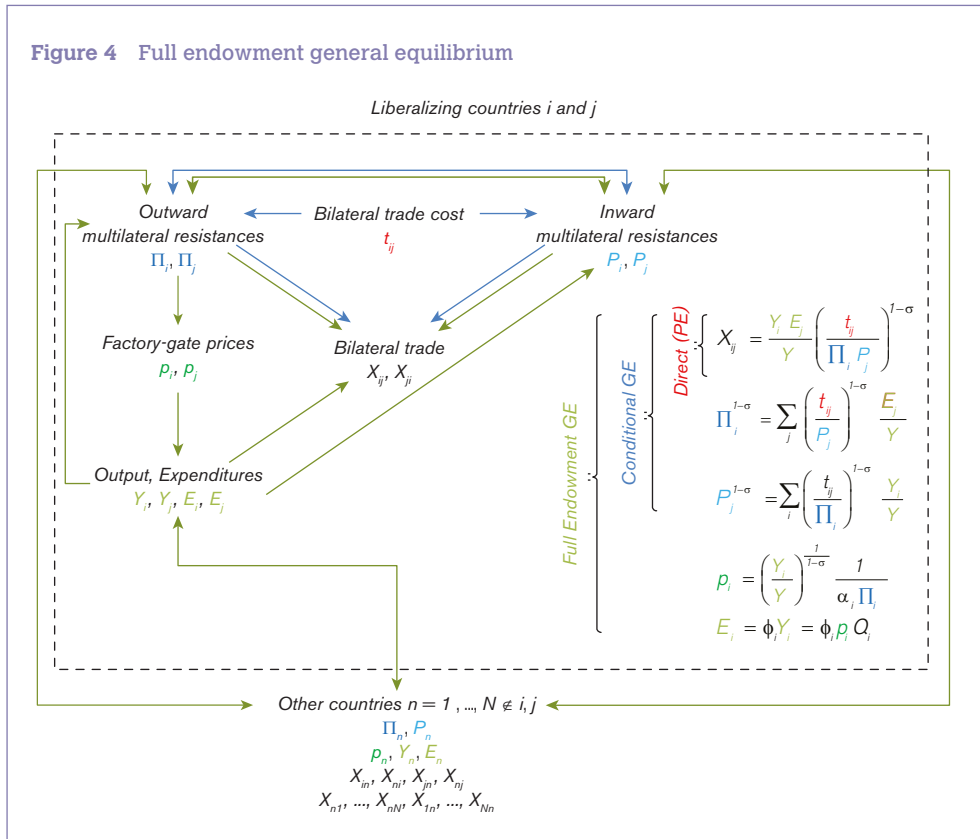
In order to determine the net impact on non-member countries, it is necessary to distinguish between the impact on (1) trade between liberalizing and non-member countries, and on (2) trade among non-member countries. As described above, the first-order trade diversion effects imply that trade between member and non-member countries will be impacted negatively, while the second-order trade creation effects on trade among non-member countries will be unambiguously positive. Since part of non-members’ diverted trade associated with the second-order effects will lead to an increase in *intra-national* trade, the net effect on non-member countries’ international trade will most likely be negative. It is, however, theoretically possible that the net impact on some non-member countries’ trade turns out to be positive, if these non-member countries face very large (prohibitive at the extreme) trade costs with the liberalizing countries. These non-member countries will not be impacted negatively by trade diversion associated with the formation of the RTA, because they traded very little (if at all) with the liberalizing countries in the first place. In addition, some of these non-member countries (outsiders 1) may be good trading partners of other non-member countries (outsiders 2) that actually suffer significant trade diversion resulting from the formation of the RTA. Thus, in principle, it is possible that part of outsiders 2’s exports, which have been diverted from the liberalizing countries, will now be redirected to outsiders 1. That being said, such a scenario remains unlikely given the current levels of integration and interdependence in the world trading system.

Third-order general equilibrium effects on member and non-member countries. Although not discussed in details here, it is important to note that changes in the non-member countries’ multilateral resistances will lead to “third-order general equilibrium effects” on the liberalizing countries as well as on the non-member countries themselves. However, these third-order effects will be, by definition, dominated by the first- and second-order general equilibrium effects presented above.

3. Full endowment general equilibrium effects

The third general equilibrium channel through which trade liberalization between countries i and j will affect trade among all economies in the world is labelled “full endowment general equilibrium effects”. This scenario refers to *full*, because, as shown in Figure 4, this channel endogenizes the value of output/national income (Y_i) and expenditure (E_i) by allowing factory-gate prices (p_i) to respond to trade cost changes (t_{ij}) and the associated ripple effects in multilateral resistances (Π_i and P_j), via equation (2-4), and then translate these changes in factory-gate prices (p_i) into changes in the value of domestic production (Y_i) and aggregate expenditure (E_i), via equation (2-5). Each country i 's production Q_i is assumed to be constant throughout the analysis. That is why this scenario is labelled *endowment*, in order to distinguish it from the general equilibrium effects in a scenario, where production quantities are also endogenous with respect to trade and trade policy. Such a scenario, which allows for endogenous changes in production (Q_i) through the accumulation of physical capital in a dynamic gravity setting, is presented in the next sub-section.

As shown in Figure 4, the direct impact of the change in bilateral trade cost (t_{ij}) on the value of domestic output (Y_i) and expenditure (E_i) will have additional ripple effects throughout the



structural gravity system (2-1)-(2-5) on the multilateral resistances (Π_i and P_j), factory-gate prices (p_i), output (Y_i), expenditure (E_i) and trade (X_{ij}). Each of the main full endowment general equilibrium effects is presented separately.

Direct general equilibrium effects on the value of output. As explained above, equations (2-4) and (2-5) capture how the decreases in the outward multilateral resistances (Π_i), defined as a first-order general equilibrium effect for member countries, formally translate into higher factory-gate prices (p_i) and, in turn, higher output values (Y_i) and expenditure (E_i). The positive impact on output values and expenditures stems from the fact that the producers in the liberalizing member countries will internalize the favourable change in their outward multilateral resistances by increasing their prices. The opposite will happen in non-member countries, where producers will experience higher outward resistance and be forced to decrease their factory-gate prices. The effect on factory-gate prices in non-member countries will be smaller as compared to the effect on member countries because the initial effect on non-member countries' outward multilateral resistances is a second-order effect, as explained previously. In sum, the full endowment general equilibrium effects of trade liberalization on the value of output/nominal income will be positive in the liberalizing countries and likely negative in non-member countries.

Direct general equilibrium effects of the value of output on trade. The changes in the value of output/nominal income as a result of the reduction in bilateral trade costs will further lead to additional direct effects on trade, as reported in equation (2-1). All else being equal, both exports and imports in the liberalizing countries will increase following the increase in the value of their output/nominal income, while trade in non-member countries will typically decrease as a result of the reduction in the value of their output/nominal income. The positive direct general equilibrium effects of the value of output on member countries' trade arises because the formation of the RTA leads the member countries to become effectively richer/larger in terms of value of output and expenditure. Conversely, non-members countries become typically poorer/smaller in terms of value of output and expenditure, and as a result experience a reduction in trade. Yet, trade between member and non-member countries is likely to increase via this channel because the first-order effects on the value of output/income for member countries are stronger than the effects on non-member countries. Importantly, the trade creation size effects can be strong enough to outweigh the conditional general equilibrium trade diversion effects on trade in non-member countries.

Indirect general equilibrium effects of the value of output on multilateral resistances. In addition to their direct impact on trade, the changes in the value of output will have indirect effects on trade through changes in the inward and outward multilateral resistances (Π_i and P_j), as captured by equations (2-2) and (2-3). Due to their increased size, the liberalizing countries will be assigned more weight in the construction of the multilateral resistances. As a result, the impact of trade liberalization among the member countries on all countries will be magnified via this channel. However, by construction, this effect will never be stronger than the first- and second-order conditional general equilibrium effects discussed above, because it was initially triggered by changes in the multilateral resistances. The changes in the multilateral resistance terms will further lead to additional third-order changes in output.

(c) Nested gravity: a dynamic gravity framework

The objective of this section is to demonstrate how the base structural gravity system derived and discussed in detail so far can be nested within a wide class of production superstructures, which thus, opens avenues for a series of more rigorous and more realistic general equilibrium analysis of the effects of trade policies. Importantly, this section demonstrates that this can be achieved without any modifications to the original structural gravity system and, therefore, all features and properties that were presented so far will be preserved and valid.

As demonstrated by Anderson et al. (2015c; 2015d) the structural gravity model can be integrated with a dynamic model of endogenous production and capital accumulation in the spirit of Lucas and Prescott (1971) in order to deliver a simple and tractable dynamic general equilibrium framework establishing a quantifiable relationship between trade liberalization and growth. In particular, retaining all the assumptions made in Chapter 1 and the previous section, the N -country Armington model is nested within a dynamic superstructure where representative households maximize the present discounted value of their lifetime utility. In addition to choosing how they source consumption (as before), consumers now also make endogenous decisions over how much to invest. The representative consumer's problem becomes:

$$\max_{\{C_{j,t}, \Omega_{j,t}\}} \sum_{t=0}^{\infty} \gamma^t \ln(C_{j,t}) \quad (2-6)$$

$$s.t. \quad Y_{j,t} = P_{j,t} C_{j,t} + P_{j,t} \Omega_{j,t} \quad (2-7)$$

$$C_{j,t} = \left(\sum_i \alpha_i^{\frac{1-\sigma}{\sigma}} c_{ij,t}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \quad (2-8)$$

$$\Omega_{j,t} = \left(\sum_i \alpha_i^{\frac{1-\sigma}{\sigma}} l_{ij,t}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \quad (2-9)$$

$$Y_{j,t} = p_{j,t} A_{j,t} L_{j,t}^{1-\eta} K_{j,t}^{\eta} \quad (2-10)$$

$$E_{j,t} = \varphi_{j,t} Y_{j,t} \quad (2-11)$$

$$K_{j,t+1} = \Omega_{j,t}^{\delta} K_{j,t}^{1-\delta} \quad (2-12)$$

$$K_{j,0} : \text{given} \quad (2-13)$$

Equation (2-6) is the consumer's lifetime logarithmic utility function, which translates aggregate consumption into utility, where $\gamma < 1$ is the subjective discount factor. Equation (2-7) represents the consumer budget constraint, according to which, at each point of time t , consumers split their income between aggregate consumption $C_{j,t}$ and aggregate investment $\Omega_{j,t}$. CES aggregate consumption is

defined by equation (2-8). Similarly, equation (2-9) is the CES investment aggregator that combines the investment varieties $I_{j,t}$ into an aggregate investment good $\Omega_{j,t}$. Equation (2-10) defines the value of production. Importantly, the specification of production in equation (2-10) deviates from the original endowment economy assumption by introducing an additional channel, via capital accumulation, which endogenizes production (Q_j) in the gravity model. Equation (2-11) relates aggregate expenditures to the value of production via $\phi_{j,t}$, indicating a trade deficit of country j at time t if $\phi_{j,t} > 1$ and a trade surplus otherwise. The process of capital accumulation is subject to both a law of motion for the capital stock, given by equation (2-12), as well as known initial values, $K_{j,0}$ in equation (2-13).⁷

Solving the consumer's optimization problem given by equations (2-6)-(2-13) delivers the following dynamic gravity system of trade and growth:

$$\left. \begin{array}{l} \text{Dynamic} \\ \text{GE} \end{array} \right\} \left\{ \begin{array}{l} \text{Full} \\ \text{Endowment:} \\ \text{GE} \end{array} \right\} \left\{ \begin{array}{l} \text{Conditional} \\ \text{GE} \end{array} \right\} \left\{ \begin{array}{l} \text{Direct:} \\ \end{array} \right.$$

$$\begin{aligned}
 X_{j,t} &= \frac{Y_{i,t} E_{j,t}}{Y_t} \left(\frac{t_{j,t}}{\Pi_{i,t} P_{j,t}} \right)^{1-\sigma} & (2-14) \\
 \Pi_{i,t}^{1-\sigma} &= \sum_j \left(\frac{t_{j,t}}{P_{j,t}} \right)^{1-\sigma} \frac{E_{j,t}}{Y_t} & (2-15) \\
 P_{j,t}^{1-\sigma} &= \sum_i \left(\frac{t_{j,t}}{\Pi_{i,t}} \right)^{1-\sigma} \frac{Y_{i,t}}{Y_t} & (2-16) \\
 p_{i,t} &= \left(\frac{Y_{i,t}}{Y_t} \right)^{\frac{1}{1-\sigma}} \frac{1}{\alpha_i \Pi_{i,t}} & (2-17) \\
 Y_{i,t} &= p_{i,t} A_{i,t} L_{i,t}^{1-\eta} K_{i,t}^\eta & (2-18) \\
 E_{i,t} &= \phi_i Y_{i,t} & (2-19) \\
 K_{i,t+1} &= \left[\gamma \delta \phi_{i,t} \frac{\eta p_{i,t} A_{i,t} L_{i,t}^{1-\eta} K_{i,t}^{\eta-1}}{(1-\gamma + \delta \gamma) P_{i,t}} \right]^\delta K_{i,t} & (2-20)
 \end{aligned}$$

The dynamic gravity system (2-14)-(2-20) is very similar to the static gravity system (2-1)-(2-5) derived in the previous section. In fact, the first four equations of the two systems are absolutely identical, and if the capital accumulation channel is shut off ($\delta = 0$), the dynamic gravity system (2-14)-(2-20) will collapse to the static system (2-1)-(2-5) with the only difference being that the endowment (Q) is replaced by the production function (2-18). In other words, the original gravity model is indeed nested, without any modifications, in the endogenous production superstructure with capital accumulation. This feature simplifies the analysis of the dynamic general equilibrium effects of trade policy tremendously, since all general equilibrium links presented in the previous section continue to hold, and all new dynamic general equilibrium linkages will be channelled through equations (2-18) and (2-20), which are the only

differences between the systems (2-14)-(2-20) and (2-1)-(2-5). The rest of the discussion in this section will, therefore, focus on describing equations (2-18) and (2-20).

Equation (2-20) is the policy function for capital, which captures the direct relationship between capital accumulation and the levels of technology, labour endowment, and current capital stock. More importantly, equation (2-20) reveals (i) a direct relationship between capital accumulation and domestic factory-gate prices, $p_{i,t}$, and (ii) an inverse relationship between capital accumulation and domestic inward multilateral resistances, $P_{i,t}$:

- (i) The intuition for the positive impact of factory-gate prices on capital accumulation is that, all else equal, an increase in $p_{i,t}$ translates into a higher value of marginal product of capital, captured by the numerator in the square brackets of equation (2-20), which in turn stimulates investment. Given that the factory-gate prices are general equilibrium indexes that, as established earlier, will respond (via the market-clearing conditions) to changes in trade costs between any two countries in the world, a trade policy change in one country will not only affect investment in this country and in its partner countries directly affected by the trade policy, but also in all other countries in the world.
- (ii) The intuition behind the negative relationship between capital accumulation and the inward multilateral resistance, $P_{i,t}$, is twofold. First, recognizing that $P_{i,t}$ is the CES price aggregator for investment goods, the inverse relationship between capital accumulation and $P_{i,t}$ is simply a reflection of the law of demand. Second, recognizing that $P_{i,t}$ is also the CES price aggregator for consumption goods, the inverse relationship can also be explained with the fact that when consumption becomes more expensive, the opportunity cost of investment becomes higher, which leads to a reduction in investment, because a higher share of income will be spent on consumption today and less will be saved and transferred for future consumption via capital accumulation. Importantly, as established earlier, the inward multilateral resistances are general equilibrium indexes and, as such, the inward multilateral resistance in one country responds to trade policy changes in any other country in the world. Equation (2-20) translates the general equilibrium changes in the inward multilateral resistances into changes in capital accumulation. Thus, the changes in the inward multilateral resistances can be viewed as embedded capital accumulation effects of trade liberalization.

In turn, the changes in capital in response to trade policy, as captured by equation (2-20), will translate into direct additional changes in the value of output/income via equation (2-18). The effects on trade of the changes in income due to higher level of capital will be qualitatively identical to the effects of the changes in income in response to changes in factory-gate prices from the endowment scenario that was presented earlier. However, it is important to emphasize that (i) the new capital accumulation effects are due to endogenizing production quantities, and (ii) that these effects will act in addition to the effects of factory-gate prices which are still active in the current setting. Similar to the endowment scenario, the new capital accumulation effects on country size will have (i) a direct and (ii) an indirect effect on trade.

- (i) The direct size effect of capital accumulation on trade is positive for the liberalizing countries and it is negative for outsiders, and it is channelled through the gravity equation (2-14). Increased size of the liberalizing economies, due to capital accumulation in response to trade

liberalization, will lead to more trade between them but also to more trade between them and all other countries too. Decreased capital accumulation in outside countries will translate into smaller country size and, therefore, less exports and imports for these countries. It is possible that the increase in size in the liberalizing country due to capital accumulation may actually stimulate exports from non-members to the extent that these effects dominate the standard trade diversion forces triggered by preferential trade liberalization and the negative size effects on non-members.

- (ii) The indirect effect of capital accumulation on trade is channelled through changes in trade costs, via changes in the multilateral resistances, which in turn lead to changes in trade flows. These effects are captured by equations (2-14)-(2-16) and reveal an additional channel through which preferential trade liberalization, such as the formation of a RTA, may benefit non-member countries. By making investment more attractive, a RTA will stimulate growth in the member countries, leading to lower sellers' incidence in the member countries, but also lower buyers' incidence in non-member countries. It should also be noted, however, that more efficient production in liberalizing countries will have a negative impact on the competing producers in non-member economies. Thus, the potential positive impact on non-members through this channel will be more pronounced for higher initial levels of consumption and for lower initial levels of production in non-member countries.

The analysis in this section demonstrated that the structural gravity system can be nested directly and without any modification into a more complex model of production. Anderson et al. (2015c; 2016a) demonstrate that this is also the case for a production structure with capital accumulation and intermediate goods, as well as when capital accumulates subject to a lineal capital accumulation function. In addition, Anderson et al. (2015c; 2016a) show that system (2-14)-(2-20) translates into an intuitive econometric system that is straightforward to estimate and delivers all key structural parameters that are needed in order to perform general equilibrium simulation analysis.

(d) General equilibrium effects trade costs and policy indexes

Several general equilibrium trade cost indexes have been developed and are often used in the literature to summarize and decompose various aspects of trade policy effects. As discussed earlier, in order to obtain some of these indexes (e.g. effects on consumer and on producer prices), normalisation is necessary because trade gravity models are homogenous of degree zero in prices. In other words, in the trade gravity models considered in this *Advanced Guide* a change in prices for all countries by the same amount would not change any of the real variables, such as quantities produced. Therefore, a normalisation has to be imposed in order to ensure a unique equilibrium. The normalisation implies that some of the general equilibrium trade policy indexes have to be interpreted with caution and keeping in mind the reference group/country that is used for the normalisation. While some general equilibrium trade policy indexes require normalisation, other indexes (e.g. real GDP and welfare) are independent of any normalisation, because these indexes are constructed as a combination of normalised indexes and the normalisation cancels. Accordingly, the discussion of the general equilibrium indexes in this section are grouped into (1) indexes requiring normalisation, and (2) indexes not requiring normalisation. As demonstrated in the next section, the general equilibrium indexes presented

here be recovered directly or as a combination of the estimated exporter and importer fixed effects of the structural gravity specification.

1. General equilibrium effects trade cost indexes subject to normalisation

The indexes presented in this section correspond to some of the equations of the structural gravity system, namely the multilateral resistances which can be recovered from equations (2-2)-(2-3), and the market clearing condition, which can be constructed from equation (2-4). A common feature and potential caveat of the multilateral resistances and factory-gate prices is that these indexes can only be obtained with a normalisation, that is expressed in relative form with respect to a reference group. As a result, these indexes can be compared consistently across countries for a given sector and year, but the required normalisation makes comparisons over time and across sectors difficult. A possible remedy is to choose as a reference group a country for which reliable data are available across all dimensions for the index of interest and, subsequently, these data series can be used to adjust all indexes in order to perform comparisons across any dimension. Alternatively, and as explained above, it might be useful to choose a reference group that is expected to be affected the least from the counterfactual shock. Thus, the relative impact for all affected parties can be expected to approximate closely the corresponding absolute effect

Inward multilateral resistance indexes. As discussed above and in Section B.1. in Chapter 1, the inward multilateral resistances P_j are theory-consistent general equilibrium aggregate indexes that measure the incidence of trade costs on each country's consumers as if these consumers buy from a unified world market. Thus, the inward multilateral resistances, formulated in equation (2-3), can be used to evaluate the effects of domestic and foreign trade policy on consumers in each country.

An alternative definition of P_j , which is also consistent with the structural gravity model, is as a CES price aggregator:

$$P_j = \left[\sum_i (\alpha_i p_i t_{ij})^{1-\sigma} \right]^{\frac{1}{1-\sigma}} \quad (2-21)$$

Based on this definition, P_j can be interpreted as *supplier access* indexes (Redding and Venables, 2004). In their role as CES aggregators, the inward multilateral resistances may, in principle, be interpreted as ideal price indexes, and their variation across countries might be expected to reflect variation in consumer price indexes (CPIs). However, inward multilateral resistances may have more variation than the corresponding CPIs and as a result only loosely track variations in CPIs. The differences between inward multilateral resistances and CPIs have a number of possible explanations (Anderson and Yotov, 2010b). First, the inward incidence of trade costs probably falls on intermediate goods users in a way that does not show up in measured prices. Second, the production weighted inward multilateral resistances are not really conceptually comparable to the consumer price indexes of final goods baskets. Third, the inward multilateral resistances may capture home bias in preferences, which results in attributions to trade costs that cannot show up in prices. Finally, the inward multilateral resistances may be subject to measurement error and the CES model on which they are based may itself be mis-specified.

Outward multilateral resistance indexes. Similarly, as explained earlier, the outward multilateral resistances Π_i are theory-consistent general equilibrium aggregates of the incidence of trade costs on each country's producers, as if they ship to a unified world market. The outward multilateral resistances indexes, defined in equation (2-2), can be used in combination with the inward multilateral resistances indexes to decompose the incidence of trade costs on the consumers and the producers in each country (Anderson and Yotov, 2010b). Different alternative interpretations have been given to outward multilateral resistances in the literature, such as *market access* indexes (Redding and Venables, 2004) and *total factor productivity frictions in distribution* (Anderson and Yotov, 2010a).

Factory-gate price indexes. Factory-gate prices indexes p_i and their changes in response to trade policy can be obtained from the market-clearing conditions expressed in equation (2-4). The factory-gate prices can be used as a complementary index to the outward multilateral resistances in order to evaluate the effects of trade policy and trade cost changes on producers. In addition, as discussed in Section C, the changes in factory-gate prices in response to trade cost changes serve as an important link for integrating the structural gravity model with a series of general equilibrium production models that depart from the endowment economy setting of Anderson (1979) and Anderson and van Wincoop (2003).

2. General equilibrium effects trade cost indexes independent of normalisation

An important use of the multilateral resistances and factory-gate price indexes discussed above is to combine them in order to construct more complex and informative complementary general equilibrium indexes that provide additional insights about the effects of trade policy. However, unlike the standard structural terms (Π_i , P_j and p_i), the general equilibrium indexes presented and discussed below are, by construction, all independent of the normalisation required to compute the multilateral resistances and the factory-gate prices.

Constructed trade bias. Based on the structural gravity model, the *constructed trade bias (CTB)* index, proposed by Agnosteva et al. (2014), is defined as the ratio of the econometrically predicted trade flow \hat{X}_{ij} to the hypothetical frictionless trade flow between origin i and destination j :⁸

$$CTB_{ij} \equiv \frac{\hat{X}_{ij}}{Y_i E_{ij} / Y} = \left(\frac{\hat{t}_{ij}}{\hat{\Pi}_i \hat{P}_j} \right)^{1-\sigma} \quad (2-22)$$

The right-hand side of equation (2-22) corresponds to the predicted/constructed value of the composite trade cost term from the structural gravity equation (2-1). The *CTB* index is therefore a measure of the combined (direct, via the bilateral trade costs t_{ij} , and indirect, via the multilateral resistance terms Π_i and P_j) effects of trade policy, or other trade costs changes, on bilateral trade, making it the most flexible general equilibrium trade cost index. The *CTB* index can be constructed in a conditional general equilibrium setting for given output and expenditure, but also in a full general equilibrium scenario that accounts for the effects of trade policy on the country's output and expenditure.

Besides being independent of the normalisation required to solve the system of equations (2-2) and (2-3) of the multilateral resistances, the *CTB* index displays four other appealing properties (Agnosteva et al., 2014):

- (i) The *CTB* index is independent of the elasticity of substitution σ , because it is constructed using the inferred volume effects that are due to power transforms of the bilateral trade costs $t_{ij}^{1-\sigma}$ and the multilateral resistances $\Pi_i^{1-\sigma}$ and $P_j^{1-\sigma}$.
- (ii) The *CTB* index, as a conditional expectation, shares the gravity model's good fit properties to infer central tendency out of the random errors that notoriously affect mis-measured bilateral trade flow data.
- (iii) The *CTB* index can be extended and consistently aggregated to yield the family of general equilibrium indexes that capture the effects of trade policy on trade costs at various levels of regional aggregation. For example, Anderson and Yotov (2010) introduce the *constructed home bias (CHB)* as the ratio of predicted to hypothetical frictionless internal trade within a given country. Intuitively, the *CHB* measures how far the economy is from a frictionless trade equilibrium. In that sense, the *CHB* is a complementary index to the widely popular *sufficient welfare statistic* of Arkolakis, Costinot and Rodriguez-Clare (2012) discussed below. Anderson et al. (2014) propose the *constructed foreign bias (CFB)* index, defined as the predicted volume of international export trade relative to the hypothetical frictionless volume of trade, and the *constructed domestic bias (CDB)* index, which corresponds to the ratio of fitted to frictionless intra-national trade, excluding trade within sub-regions in a country. The *CFB* index may be particularly useful to assess the effects of trade policy on international trade, while the *CDB* index can be used to evaluate the intra-national effects of trade policy.
- (iv) Finally, the *CTB* index has a general equilibrium counterpart that can be constructed directly from the data, in the spirit of the ratio calibration approaches that are used in the trade literature to recover bilateral trade costs, and which are discussed in the next section. Specifically, if actual trade is used instead of fitted trade, the *trade bias (TB)* index can be constructed as:

$$TB_j \equiv \frac{X_j}{Y_i E_j / Y} \quad (2-23)$$

The *TB* index can still be interpreted as the total bilateral trade cost between i and j . Furthermore, it can be constructed easily, without having to estimate the gravity model, but at the cost of being subject to measurement error.

Terms of trade. It is well known that the *terms of trade (ToT)* and their changes in response to trade policy are notoriously hard to measure, especially if the objective is consistent measurement and comparison across countries, sectors, and time. The structural gravity model offers a convenient solution to obtain consistent *ToT* indexes, defined as follows (Anderson and Yotov, 2016):

$$ToT_i \equiv \frac{\hat{p}_i}{\hat{P}_i} \quad (2-24)$$

where \hat{p}_i represents the constructed values of the factory-gate prices, namely the producer price in country i , and \hat{P}_i is the constructed inward multilateral resistance capturing the corresponding consumer price in country i . Under the endowment economy assumption of the Armington gravity model, the *ToT* index can be interpreted as a welfare/real income measure, because the numerator in equation (2-24) can be interpreted as the change in nominal income $\hat{p}_i = \hat{p}_i Q_i$ in country i in response to trade cost changes, while the denominator in equation (2-24) can be interpreted as the change in consumer prices in country i in response to the same trade cost changes.

While perfectly consistent with the structural gravity model, the *ToT* index formulated in equation (2-24) departs from the conventional definition of *barter of terms of trade*, presented in Chapter 1 of the *Practical Guide to Trade Policy Analysis* and defined as the ratio of *exporter* prices over *importer* prices because, by construction, the factory-gate prices (\hat{p}_i) and the inward multilateral resistances (\hat{P}_i) take into account *intra-national* trade flows. An easy solution is to solve the multilateral resistance system of equations (2-2) and (2-3) without the *intra-national* links: $P_j^{1-\sigma} = \sum_{i \neq j} (t_{ij}/\Pi_i)^{1-\sigma} (Y_i/Y)$ and $\Pi_i^{1-\sigma} = \sum_{j \neq i} (t_{ij}/P_j)^{1-\sigma} (E_j/Y)$. The resulting outward multilateral resistance terms Π_i can then be used to construct corresponding factory-gate prices.

Sufficient welfare statistics. In a recent and very influential paper, Arkolakis, Costinot and Rodriguez-Clare (2012) have demonstrated that the welfare (real consumption) gains from trade liberalization obtained from a wide class of trade models with alternative micro-foundations can all be expressed as a combination of two sufficient statistics: (1) the change in intra-national trade as share of total expenditure, and (2) trade elasticity.⁹ In the context of the baseline structural gravity model considered in this *Advanced Guide*, the general equilibrium welfare gain statistics (*WS*) from trade can be expressed as the ratio between the counterfactual welfare value obtained in response to a change in trade costs and the welfare value prevailing in the baseline scenario:

$$WS_i \equiv \frac{W_i^{CFL}}{W_i^{BLN}} = \left(\frac{\lambda_{ii}^{CFL}}{\lambda_{ii}^{BLN}} \right)^{\frac{1}{1-\sigma}} \quad (2-25)$$

where $W_i = E_i/P_i$ denotes welfare/real consumption in country i , $\lambda_{ii} = X_{ii}/E_i$ is the share of expenditure on home goods, σ is the elasticity of substitution, and superscripts *CFL* and *BLN* denote values in the counterfactual and baseline scenario, respectively.

2. Standard approach to general equilibrium analysis with structural gravity

Capitalizing on solid micro-foundations, both on the supply side (Eaton and Kortum, 2002) and on the demand side (Anderson and van Wincoop, 2003), and on tight connection to the data (Costinot and Rodriguez-Claire, 2014), counterfactual analysis of the effects of various trade policies using the gravity model has been the object of a series of recent studies.¹⁰ This section outlines and discusses the standard steps required to perform general equilibrium counterfactual experiments with the gravity model.

The departing point of the general equilibrium analysis is the structural gravity system:

$$X_{j,t} = \frac{Y_{i,t} E_{j,t}}{Y_t} \left(\frac{t_{j,t}}{\Pi_{i,t} P_{j,t}} \right)^{1-\sigma} \quad (2-1)$$

$$\Pi_{i,t}^{1-\sigma} = \sum_j \left(\frac{t_{j,t}}{P_{j,t}} \right)^{1-\sigma} \frac{E_{j,t}}{Y_t} \quad (2-2)$$

$$P_{j,t}^{1-\sigma} = \sum_i \left(\frac{t_{ji,t}}{\Pi_{i,t}} \right)^{1-\sigma} \frac{Y_{i,t}}{Y_t} \quad (2-3)$$

$$p_{i,t} = \left(\frac{Y_{i,t}}{Y_t} \right)^{\frac{1}{1-\sigma}} \frac{1}{\alpha_i \Pi_{i,t}} \quad (2-4)$$

$$E_{i,t} = \varphi_i Y_{i,t} = \varphi_i p_{i,t} Q_{i,t} \quad (2-5)$$

Step 1: Solve the baseline gravity model

The first stage consists in solving the gravity model in the baseline while describing the actual data as closely as possible, ideally perfectly. This stage requires estimates of the key structural parameters, such as trade costs and trade elasticities, which, in combination with actual data on, for instance, trade and production, will be combined to obtain the key indexes of interest, such as the consumer prices and real GDP, in the baseline scenario. For instructional purposes, this step can be decomposed into three sub-stages:

Step 1.a: Obtain estimates of trade costs and trade elasticities baseline indexes. This first step consists of obtaining estimates of the bilateral trade costs, including estimates of the elasticities of bilateral trade with respect to bilateral trade policy. Ideally, the analysis in this step will deliver estimates of all relevant trade costs and elasticity parameters that capture the response of bilateral trade with respect to bilateral trade policies, such as RTAs or bilateral tariffs, as well as non-discriminatory export-promotion policies, and non-discriminatory import-protection policies, such as MFN tariffs. Three possible approaches to obtain trade costs and trade elasticities have been proposed and used in the existing literature:

- (i) **Estimation:** Obtaining trade costs and trade elasticities by estimating the structural gravity model offers a number of advantages. First, by design, the estimation approach accounts for measurement error in the data. Second, it enables researchers to establish causal relationships between key variables of interest and trade instead of simply assuming that such relationships hold (Krugman, 2011; Dawkins et al., 2001). In fact, this is the main objective of hundreds of papers that use the gravity model to study the effects of various determinants of trade. Third, the estimation approach enables to decompose the effects of various trade components within the same data that will be used in the counterfactuals. Fourth, capitalizing on the remarkable predictive power of the gravity model, the estimation approach can be extended to obtain out-of-sample trade cost estimates, even when corresponding trade data are missing. This is demonstrated in Box 3. Finally, obtaining the own trade costs and elasticity estimates is valuable for validation purposes, because one can compare these estimates with existing counterparts from the literature. For all of the above reasons, researchers should, when reliable data are available, attempt to obtain their own trade cost and trade elasticity estimates from the same sample that will be used in the counterfactuals. A drawback of the estimation approach is that the error term may contain systematic information about trade costs. Possible approaches to address this issue are discussed below.

The following generic econometric gravity model can be estimated in order to obtain estimates of trade costs and trade elasticities:

$$X_{j,t} = \exp\left[\pi_{i,t} + \chi_{j,t} + \mu_{ij} + \beta_1 RTA_{j,t} + \beta_2 ES_{i,t} \times INTL_{ij} + \beta_3 MFN_{j,t} \times INTL_{ij}\right] \times \varepsilon_{j,t} \quad (2-26)$$

As recommended in Chapter 1, specification (2-26) should preferably be estimated with the PPML estimator, using panel *intra-national* and *international* trade data with year intervals, and controlling for *exporter-time* fixed effects ($\pi_{i,t}$), *importer-time* fixed effects ($\chi_{j,t}$), and pair fixed effects (μ_{ij}). The generic econometric gravity model (2-26) enables to estimate the effects of three types of trade policy: (i) bilateral trade policy; (ii) unilateral export-promotion policy; and (iii) non-uniform trade-protection policy. The representative bilateral trade policy corresponds to the variable $RTA_{j,t}$, which indicates the presence of a RTA between countries i and j at time t . The representative unilateral export-promotion policy is captured by the continuous variable for export subsidies $ES_{i,t}$. The representative non-uniform trade policy corresponds to the continuous variable for MFN tariffs $MFN_{j,t}$. Both export-promotion and import-protection policies variables are interacted with the dummy variable $INTL_{ij}$, which is equal to one for *international* trade and zero for *intra-national* trade, in order to capture the fact that both types of policies apply only to international trade. Finally, $\varepsilon_{j,t}$ is a stochastic error term that is assumed to not carry any systematic information about trade costs.¹¹

For exposition simplicity, these different trade policy variables can be grouped in the vector $\mathbf{T}_{j,t}$ and the associated parameters in the parameter vector $\boldsymbol{\beta}$:

$$X_{j,t} = \exp\left[\pi_{i,t} + \chi_{j,t} + \mu_{ij} + \mathbf{T}_{j,t}\boldsymbol{\beta}\right] \times \varepsilon_{j,t} \quad (2-27)$$

Once the structural gravity model (2-26) is estimated with the PPML estimator, the associated parameter estimates can be used, in combination with data on the corresponding covariates, to construct the matrix of baseline (*BLN*) trade costs:

$$\left[\hat{\tau}_{j,t}^{1-\sigma}\right]^{BLN} = \exp\left[\hat{\mu}_{ij} + \mathbf{T}_{j,t}\hat{\boldsymbol{\beta}}\right] \quad (2-28)$$

As explained in Chapter 1, estimating the generic econometric gravity model (2-26) with data on tariffs can deliver directly an estimate of the trade elasticity of substitution, $\hat{\sigma}$, which represents the most important parameter for general equilibrium trade analysis (Arkolakis et al., 2012).

- (ii) **Calibration:** An alternative approach to obtain trade costs is to use a version of the so-called ratio approaches, which recover theory-consistent bilateral trade costs directly from the data by eliminating the country-specific structural terms. The advantage of the calibration approach is that, by construction, it delivers bilateral trade costs that match the trade data perfectly. The three leading trade cost calibration approaches proposed in the literature include:

1. The *odds-ratio method* (Head and Ries, 2001; Novy, 2013) consists of computing the ratio of *international* bilateral trade costs with respect to the *intra-national* trade costs between countries i and j :

$$\frac{t_{ij}t_{ji}}{t_{ii}t_{jj}} = \left(\frac{X_{ij}X_{ji}}{X_{ii}X_{jj}} \right)^{\frac{1}{1-\sigma}} \quad (2-29)$$

2. The *tetrads method* (Head et al., 2010; Romalis, 2007) computes a ratio of ratios by considering the trade flows of countries i and j with respect to two other reference countries: importer l and exporter k :

$$\frac{t_{ij}t_{lk}}{t_{jl}t_{ik}} = \left(\frac{X_{ij}X_{lk}}{X_{jl}X_{ik}} \right)^{\frac{1}{1-\sigma}} \quad (2-30)$$

3. The *three countries method* (Caliendo and Parro, 2015) specifies the relationship between relative trade costs and relative trade flows between three countries, namely i , j and h without specifying any other reference country:

$$\frac{t_{ij}t_{jh}t_{hi}}{t_{ih}t_{hj}t_{ji}} = \left(\frac{X_{ij}X_{jh}X_{hi}}{X_{ih}X_{hj}X_{ji}} \right)^{\frac{1}{1-\sigma}} \quad (2-31)$$

The calibration approach is elegant and useful from a theoretical perspective. However, it may present a number of challenges for policy analysis. First, this approach is unable to identify the effects of specific trade policies. For example, the approach of calibrating trade costs can estimate the effects of a 10 percent decrease in trade costs, but cannot determine what kind of trade policy can lead to such a decrease. Thus, while elegant from a theoretical perspective, the calibration approach may not be very informative from a policy perspective. Another related disadvantage is that calibration cannot test the model specification and underlying hypotheses (Krugman, 2011; Dawkins et al., 2001). In other words, a calibration approach “assumes” an initial impact of trade policy instead of “testing” whether a specific trade policy actually resulted in a significant desired impact.

- (iii) **“Estibration”**: Anderson et al. (2015b) propose a hybrid procedure to construct bilateral trade costs, which combines the most appealing features of the “estimation” and of the “calibration” approaches. Specifically, estimates of trade costs and trade elasticities can be first obtained from a properly specified empirical gravity equation, such as equation (2-26). Then baseline trade costs can be constructed by also taking into account the information contained in the error term:

$$\left[\hat{t}_{ij,t}^{1-\sigma} \right]^{BLN} = \exp \left[\hat{\mu}_{ij} + \mathbf{T}_{ij,t} \hat{\boldsymbol{\beta}} \right] \times \hat{\varepsilon}_{ij,t} \quad (2-32)$$

Equation (2-32) will deliver trade costs, which allow for a decomposition of the key trade cost components and enable to recover key elasticity parameters, while at the same time fitting the trade data perfectly by construction.

Step 1.b (Optional): Recover additional parameters and exogenous variables. This step computes the values of all the remaining parameters of the structural gravity model and the exogenous unobservable variables in order to ensure that the model is perfectly consistent with the data, not only at the bilateral trade level, as ensured in Step 1, but also at all levels in the baseline scenario. Applied to the baseline gravity system (2-1)-(2-5), this step will use the market-clearing conditions (2-4) to construct the set of CES preference parameters α , at the initial normalised factory-gate prices.

This step is labelled “optional” because, as demonstrated in Appendix C, the exact same solution to system (2-1)-(2-5) can be obtained when the gravity system is solved in levels or when it is solved in changes (Dekle et al., 2008). The difference between the two approaches is that solving the system in changes does not require values for some of the exogenous parameters (e.g. CES preference parameters), because these parameters cancel out since they remain constant in the baseline and in the counterfactual scenarios. It should be noted, however, that although solving the gravity system in levels requires computing additional parameters, it offers the advantage of being able to compare these additional parameters with corresponding values from the literature or, even better, directly with corresponding moments from actual data in order to validate the model (Krugman, 2011; Ottaviano, 2016).

Step 1.c: Construct baseline indexes. Using the values of the trade costs obtained in Step 1.a (and the values of the additional parameters from Step 1.b) the solution of the structural gravity system (2-2)-(2-5) delivers values of all indexes, such as consumer prices and multilateral resistances, which describe the baseline scenario in addition to actual (or fitted) data.

Step 2: Define a counterfactual scenario

This second step entails defining the counterfactual experiment of interest. Given this *Advanced Guide's* focus on trade policy, the counterfactual scenario involves the introduction or the removal of trade barriers, which will result in a change in bilateral trade costs. The definition of the trade policy variables for the counterfactual trade costs will depend on the policy question under investigation. For example, some popular scenarios include the introduction or elimination of a RTA, or reduction or increase in tariffs. Alternatively, the counterfactual scenario could imply a change in the trade cost elasticities ($\hat{\beta}_1$, $\hat{\beta}_2$, and $\hat{\beta}_3$). However, for expositional simplicity, only counterfactual scenarios where trade cost elasticities remain constant are considered here.

If, for instance, the objective is to assess the effects of a new bilateral trade agreement (e.g. between countries x and y), the RTA dummy variable specified in the empirical gravity model (2-26) would have to be redefined to include this new agreement by replacing the zeros in the observations involving the country pair x - y with ones. In addition, the applied preferential tariffs and/or other trade-related measures negotiated in the bilateral trade agreement that applied exclusively to country x 's exports to country y and vice-versa should also be reflected in the empirical gravity specification. Overall, the structural gravity framework offers the flexibility to adjust all counterfactual policy variables in the vector $\mathbf{T}_{ij,t}$ as needed to reflect the desired trade policy changes in the counterfactual scenario. Any adjustment to the trade policy

variables specified in the structural gravity model will result in a new matrix of counterfactual (CFL) bilateral trade costs:

$$\left[\hat{t}_{j,t}^{1-\sigma} \right]^{CFL} = \exp \left[\hat{\mu}_{ij} + \mathbf{T}_{j,t}^{CFL} \hat{\beta} \right] \quad (2-33)$$

The differences between the baseline trade costs defined in equation (2-28) (or (2-32)) and the counterfactual trade costs reported in equation (2-33) (or (2-33) adding the error term) is $\varepsilon_{j,t}$, the initial trade policy shock introduced in the general equilibrium system. As demonstrated below, this shock will translate into changes in the key economic indicators of interest to the policy maker, such as trade and real consumption.

Step 3: Solve the counterfactual model

Using the values of the trade elasticities and the additional parameters obtained from Step 1, and the counterfactual trade costs from Step 2, the solution of the structural gravity system (2-2)-(2-5) in the counterfactual scenario will deliver the values for the indexes of interest. For instructional purposes, and consistent with the stepwise approach presented in the previous sub-section, the counterfactual indexes can be obtained by computing separately and sequentially the conditional general equilibrium effects and the full endowment general equilibrium effects.

Step 3.a: Obtain “conditional general equilibrium” effects. The conditional general equilibrium effects capture the total (direct plus indirect) effects of any changes in bilateral and/or non-discriminatory trade policy (i.e. any changes in t_{ij}) on the trade costs of all countries in the world, for given output and expenditure. These conditional general equilibrium indexes are computed by solving the system of multilateral resistances (2-2)-(2-3) in order to obtain new values for the multilateral resistance terms (Π_i and P_j), which, in turn, can be used together with data on actual output and expenditures to construct any indexes of interests at the conditional general equilibrium level.

Step 3.b: Obtain “full endowment general equilibrium” effects. The full endowment general equilibrium responses to the counterfactual trade policy changes capture the changes in factory-gate prices, resulting from the changes in the outward multilateral resistances, which lead to changes in the value of output and aggregate expenditures, which in turn impact directly trade and indirectly the multilateral resistances. The full endowment general equilibrium effects are computed by solving simultaneously the structural gravity system (2-1)-(2-5), which consists of $5 \times N$ equations, in order to obtain the values for the outward and inward multilateral resistances (Π_i and P_j), the factory-gate prices (p_i), and the value of output (Y_i) and aggregate expenditure (E_i). Unlike the system of multilateral resistances (2-2)-(2-3) used to derive the conditional general equilibrium effects, the structural gravity system (2-1)-(2-5) is highly non-linear, even when the multilateral resistances are re-defined as power transforms, because of the functional form of the factory-gate prices in the market clearing conditions (2-4). The structural gravity system (2-1)-(2-5) can still be easily solved in any statistical software with matrix and non-linear optimization capabilities. As demonstrated below, it can also be solved in a loop with canned estimation and non-linear optimization commands directly in any standard statistical software packages, such as STATA software.

Step 4: Collect, construct, and report indexes of interest

After computing the conditional and/or full endowment general equilibrium effects trade cost indexes, the standard presentation consists of expressing the general equilibrium effects indexes in terms of percentage changes with respect to the baseline scenario:

$$\Delta\% \hat{\Gamma}_{i,t} = \frac{\left(\hat{\Gamma}_{i,t}^{CFL} - \hat{\Gamma}_{i,t}^{BLN} \right)}{\hat{\Gamma}_{i,t}^{BLN}} \times 100 \quad (2-34)$$

where $\hat{\Gamma}_{i,t}$ can be any index of interest and, as noted above, *BLN* and *CFL* stand for “baseline” and “counterfactual”, respectively.

Step 5: Construct confidence intervals

The last step of the general equilibrium analysis consists in constructing the confidence intervals of the general equilibrium indexes of interest computed in Step 4 in order to take into account the potential estimation error of the direct effects of trade policy obtained in Step 1. Despite its intuitive appeal and economic and policy significance, constructing confidence intervals for general equilibrium effects of trade policy is not as popular procedure as it should be in the trade literature.¹² Yet, constructing confidence intervals is a good practice for at least two reasons:

- (i) Confidence intervals will enable the researcher to gauge the significance of the general equilibrium effects of the trade policy in question.
- (ii) Confidence intervals can serve as uncertainty bounds offering a more conservative and a more liberal estimate of the expected trade policy effects.

Although constructing confidence intervals may be computationally intensive, there are different statistical approaches that are relatively straightforward to implement. One possible method is the bootstrap procedure of Anderson and Yotov (2016), who obtain a general equilibrium confidence interval in four steps:

Step 5.a: Generate bootstrapped gravity estimates. Generate B (e.g. 200) sets of bootstrapped gravity estimates according to Step 1.

Step 5.b: Construct counterfactual trade costs. Construct B corresponding sets of counterfactual bilateral trade costs as described in Step 2.

Step 5.c: Compute general equilibrium trade costs. Compute the general equilibrium effects and construct the B estimates of each of the general equilibrium trade costs indexes of interest following Step 3 and 4.

Step 5.d: Construct the confidence interval. Compute the 95 percent centred bootstrap confidence intervals of the B estimates of each index of interest as follows:

$$\left[2 \times \hat{\Gamma}_{i,t} - \hat{\Gamma}_{i,t}^{BOOT(97.5\% \times B)} ; 2 \times \hat{\Gamma}_{i,t} - \hat{\Gamma}_{i,t}^{BOOT(2.5\% \times B)} \right] \quad (2-35)$$

where $\hat{l}_{i,t}$ can be any index of interest obtained with the original estimates; and $\hat{l}_{i,t}^{BOOT(2.5\% \times B)}$ and $\hat{l}_{i,t}^{BOOT(97.5\% \times B)}$ are, respectively, the $(2.5\% \times B)^{th}$ and the $(97.5\% \times B)^{th}$ indexes from the ranked (from bottom to top) bootstrap sample $(\hat{l}_{i,t}^{BOOT(1)}, \hat{l}_{i,t}^{BOOT(2)}, \dots, \hat{l}_{i,t}^{BOOT(B)})$.

3. A general equilibrium gravity analysis with the Poisson Pseudo Maximum Likelihood (GEPPL)

While the previous section highlighted the main and standard steps required to perform general equilibrium gravity analysis, this section presents a procedure, developed by Anderson et al. (2015b), which builds on the properties of the PPML estimator to implement general equilibrium analysis with the structural gravity model in standard statistical software packages, such as STATA software. Specifically, in order to implement their methods, Anderson et al. (2015b) capitalize on a special additive property of the PPML estimator, as recently documented by Arvis and Shepherd (2013) and Fally (2015), which ensures a perfect match between the structural gravity terms and the corresponding directional (importer and exporter) fixed effects $\pi_{i,t}$ and $\chi_{j,t}$:

$$\exp(\hat{\pi}_{i,t}) = \frac{Y_{i,t}}{\hat{\Pi}_{i,t}^{1-\sigma}} \times E_{R,t} \tag{2-36}$$

$$\exp(\hat{\chi}_{j,t}) = \frac{E_{j,t}}{\hat{P}_{j,t}^{1-\sigma}} \times \frac{1}{E_{R,t}} \tag{2-37}$$

where $\hat{\pi}_{i,t}$ and $\hat{\chi}_{j,t}$ are estimates of the directional fixed effects from a structural gravity estimation equation, such as equation (2-26), $Y_{i,t}$ and $E_{j,t}$ are the corresponding actual values of output and expenditure in year t , $\hat{\Pi}_{i,t}^{1-\sigma}$ and $\hat{P}_{j,t}^{1-\sigma}$ are the corresponding calculated values of the multilateral resistance terms obtained by solving the system of equations (2-2) and (2-3), and $E_{R,t}$ is the expenditure of the reference country R in year t .

The steps of the GEPPL procedure discussed below follow closely the stages of the standard approach to general equilibrium analysis with the structural gravity model.

Step I: Solve the baseline gravity model

Similar to the standard first stage, the first step of the approach requires obtaining estimates of the bilateral trade costs, including estimates of the elasticities of bilateral trade with respect to bilateral trade policy and constructing baseline gravity indexes of interest. The (optional) Step 1.b from the standard procedure above is not needed in the GEPPL procedure because, as demonstrated below, the gravity system will be solved through an iterative procedure that corresponds to the solution in changes from Dekle et al. (2007; 2008). Therefore, the procedure based on PPML eliminates the need to obtain explicit values for the CES share parameters.

Step I.a: Obtain estimates of trade costs and trade elasticities baseline indexes. An important feature of the GEPPML procedure presented here is that it can readily accommodate the three different approaches to treating bilateral trade costs and their elasticities in the existing literature that were described above:

- (i) **Estimation:** The generic econometric gravity model (2-26) can be estimated with the PPML estimator, using panel *intra-national* and *international* trade data with year intervals, and controlling for *exporter-time* fixed effects ($\pi_{i,t}$), *importer-time* fixed effects ($\chi_{j,t}$), and pair fixed effects (μ_{ij}):

$$\begin{aligned} X_{j,t} &= \exp\left[\pi_{i,t} + \chi_{j,t} + \mu_{ij} + \beta_1 RTA_{j,t} + \beta_2 ES_{i,t} \times INTL_{ij} + \beta_3 MFN_{j,t} \times INTL_{ij}\right] \times \varepsilon_{j,t} \\ &= \exp\left[\pi_{i,t} + \chi_{j,t} + \mu_{ij} + \mathbf{T}_{j,t}\boldsymbol{\beta}\right] \times \varepsilon_{j,t} \end{aligned} \quad (2-26)$$

In addition, any other linear or non-linear estimator can be employed to obtain the estimates of the trade cost elasticities $\boldsymbol{\beta}$ in a preliminary step. In fact, the whole vector of bilateral trade costs and associated $\boldsymbol{\beta}$ can even be borrowed from other studies as is routinely done in the literature. In case the estimates of the trade cost elasticities are obtained externally, they have to be imposed as constraints in the PPML estimation of the gravity model (2-26).

As mentioned earlier, one of the advantages of the GEPPML approach is that it can be extended to recover out-of-sample trade costs even when trade data are missing. This is demonstrated in Box 3. Having the complete trade costs matrix is particularly important in order to obtain the full general equilibrium response to trade policy changes. The consequences of not having the complete trade costs matrix are magnified when data are missing for important players.

- (ii) **Calibration:** As discussed earlier, the whole trade cost vector can also be obtained externally by applying any of the ratio methods developed in the literature. The calibrated trade cost vector can then be used in the GEPPML procedure. In that case, the external trade cost vector should be imposed as a constraint in the PPML estimation of the gravity model (2-26), which automatically will adjust the corresponding exporter and importer fixed effects so that the resulting general equilibrium multilateral resistance terms correspond exactly to the calibrated trade cost vector.
- (iii) **“Estibration”:** Trade costs can also be obtained by applying the hybrid procedure proposed by Anderson et al. (2015b), which *estimates* the key elasticities of interest according to equation (2-26), while simultaneously matching the trade flows data perfectly (i.e. *calibrating*), by treating the error term, $\varepsilon_{j,t}$, from specification (2-26) as a component of the vector of trade costs. In that case, the PPML estimation should be carried out with the “estibrated” trade cost vector imposed as constraint.

Independently of how the gravity elasticities and the trade costs are obtained, the construction of the corresponding general equilibrium multilateral resistance indexes requires paying particular attention to the estimation and interpretation of the directional (importer and exporter) fixed effects of the structural gravity specification (2-26). Specifically, due to perfect collinearity, one of the directional fixed effects needs to be dropped in each year. In addition, as discussed earlier, a normalisation of the set of multilateral resistances P_j and Π_i is required to solve the system of

equations (2-2) and (2-3). In order to maintain consistency, the inward multilateral resistance for a representative country (R) is normalized to one, $P_{R,t} = 1$, and the corresponding importer fixed effect, $\chi_{R,t}$, is removed from the specification (2-26). For interpretation ease, it is also recommended to estimate the econometric gravity model (2-26) without the constant term. This will ensure that the importer fixed effect of the reference country will be the only fixed effect that is dropped in the gravity estimation. Taking all of the above considerations into account, the interpretation of the dropped fixed effect in a given year is $\chi_{R,t} = E_{R,t}$, and all the other fixed effects in that year are estimated (and should be interpreted) relative to $\chi_{R,t}$.

Step 1.b: Construct baseline indexes. The PPML estimates of the importer-time fixed effects ($\hat{\chi}_{j,t}$) and of the exporter-time fixed effects ($\hat{\pi}_{i,t}$) from the gravity model (2-26) can be combined with data on output ($Y_{i,t}$) and expenditure ($E_{j,t}$) to construct the baseline multilateral resistances $[\hat{\Pi}_{i,t}^{1-\sigma}]^{BLN}$, and $[\hat{P}_{j,t}^{1-\sigma}]^{BLN}$, according to equations (2-36) and (2-37), while taking into account the normalisation(s) imposed:

$$[\hat{\Pi}_{i,t}^{1-\sigma}]^{BLN} = \frac{Y_{i,t}}{\exp(\hat{\pi}_{i,t})} \times E_{R,t} \quad (2-38)$$

$$[\hat{P}_{j,t}^{1-\sigma}]^{BLN} = \frac{E_{j,t}}{\exp(\hat{\chi}_{j,t})} \times \frac{1}{E_{R,t}} \quad (2-39)$$

where, by construction, $Y_{i,t} = \sum_j X_{ij,t}$ and $E_{j,t} = \sum_i X_{ij,t}$. The baseline multilateral resistance terms can then be used to compute other baseline general equilibrium indexes of interest, such as the terms of trade formulated in equation (2-24) or the welfare/real consumption reported in equation (2-25).

Box 3 Bilateral trade costs with missing trade flow data

One potential issue that may arise when trade flows data are missing or zero for a given pair over the whole period of investigation is the impossibility to identify and obtain the estimates of the complete set of fixed effects pairs, which are used to construct bilateral trade costs. A solution proposed by Anderson and Yotov (2016) consists of implementing a two-stage procedure:

Step 1: Obtain the estimates of pair fixed effects from gravity model

The first stage involves estimating the empirical gravity model in order to obtain the estimates of the bilateral fixed effects ($\hat{\mu}_{ij}$) for country pairs with non-missing (or non-zero) trade flows:

$$X_{ij,t} = \exp[\pi_{i,t} + \chi_{j,t} + \mu_{ij} + \mathbf{T}_{ij,t}\boldsymbol{\beta}] \times \varepsilon_{ij,t}$$

(Continued)

Box 3 (Continued)

Step 2: Regress the estimates of pair fixed effects on gravity variables and country-fixed effects

The inclusion of the exporter and importer fixed effects in the above specification accounts for *intra*-national trade costs and it is required from gravity theory, which implies that only relative trade costs can be identified from an empirical gravity model. Consistent with this intuition, the estimates of the pair fixed effects from the first-stage estimation are obtained relative to *intra*-national trade costs. The estimates of the pair fixed effects ($\hat{\mu}_{ij}$) obtained in the first stage are used as the dependent variable in a regression, where the covariates include the set of standard gravity variables along with importer and exporter fixed effects:

$$\exp[\hat{\mu}_{ij}] = \exp[\pi_i + \chi_j + \beta_1 \ln DIST_{ij} + \beta_2 CNTG_{ij} + \beta_3 LANG_{ij} + \beta_4 CLNY_{ij}] \times \varepsilon_{ij}$$

The (fitted) predicted bilateral trade costs from this second stage regression are computed, $\hat{\tau}_{ij}^{1-\sigma} = \exp[\hat{\pi}_i + \hat{\chi}_j + \hat{\beta}_1 \ln DIST_{ij} + \hat{\beta}_2 CNTG_{ij} + \hat{\beta}_3 LANG_{ij} + \hat{\beta}_4 CLNY_{ij}]$, and then used to fill up the missing trade costs values in order to construct the complete set of bilateral trade costs that can then be used in counterfactual analysis.

Step II: Define a counterfactual scenario

Similar to the standard second stage, the second step of the GEPPML approach requires defining the counterfactual experiment of interest by changing the definition of the policy variables in the vector $\mathbf{T}_{j,t}^{CFL}$, where *CFL* stands for counterfactual. As explained above, it is the differences between the baseline trade costs and the counterfactual trade costs that constitute the initial trade policy shock introduced in the general equilibrium system.

Step III: Solve the counterfactual model

Following the standard third stage presented above, the counterfactual model is solved in two steps by calculating separately and sequentially the conditional general equilibrium effects and the full endowment general equilibrium effects:

Step III.a: Obtain conditional general equilibrium effects. The conditional general equilibrium effects are constructed in two stages:

(i) Estimate the “conditional” gravity model

First, the gravity model (2-26) is re-estimated with the PPML estimator:

$$X_{j,t} = \exp[\pi_{i,t}^{CFL} + \chi_{j,t}^{CFL} + \bar{\mu}_{ij} + \mathbf{T}_{j,t}^{CFL} \bar{\boldsymbol{\beta}}] \times \varepsilon_{j,t}^{CFL} \quad (2-40)$$

where the symbol $\bar{}$ is used to capture the fact that certain coefficients of the gravity model are constrained to be equal to their baseline values.

(ii) **Construct “conditional general equilibrium” indexes**

The new PPML estimates of the fixed effects associated with the constrained structural gravity model can be used, in combination with the original data on output ($Y_{i,t}$) and expenditure ($E_{j,t}$), to construct the conditional general equilibrium values of the multilateral resistance taking into account the normalisation(s) imposed:

$$\left[\hat{\Pi}_{i,t}^{1-\sigma} \right]_{CDL}^{CFL} = \frac{Y_{i,t}}{\exp(\hat{\pi}_{i,t}^{CFL})} \times E_{R,t} \quad (2-41)$$

$$\left[\hat{P}_{j,t}^{1-\sigma} \right]_{CDL}^{CFL} = \frac{E_{j,t}}{\exp(\hat{\chi}_{j,t}^{CFL})} \times \frac{1}{E_{R,t}} \quad (2-42)$$

where *CDL* stands for “conditional”, and $\hat{\pi}_{i,t}^{CFL}$ and $\hat{\chi}_{j,t}^{CFL}$ are the PPML estimates of the exporter-time and import-time fixed effects of the constrained conditional gravity model (2-40), respectively. The counterfactual values of the bilateral trade costs and the multilateral resistances are sufficient (in combination with the original data on output and expenditure) to construct any other conditional general equilibrium indexes of interest.

Step III.b: Obtain “full endowment general equilibrium” effects. When the PPML estimator is used to estimate the structural gravity model, the full endowment general equilibrium effects can be computed with a four-step iterative procedure, as depicted in Figure 5. The iterative procedure presented below can be implemented in any standard statistical software, such as STATA software.

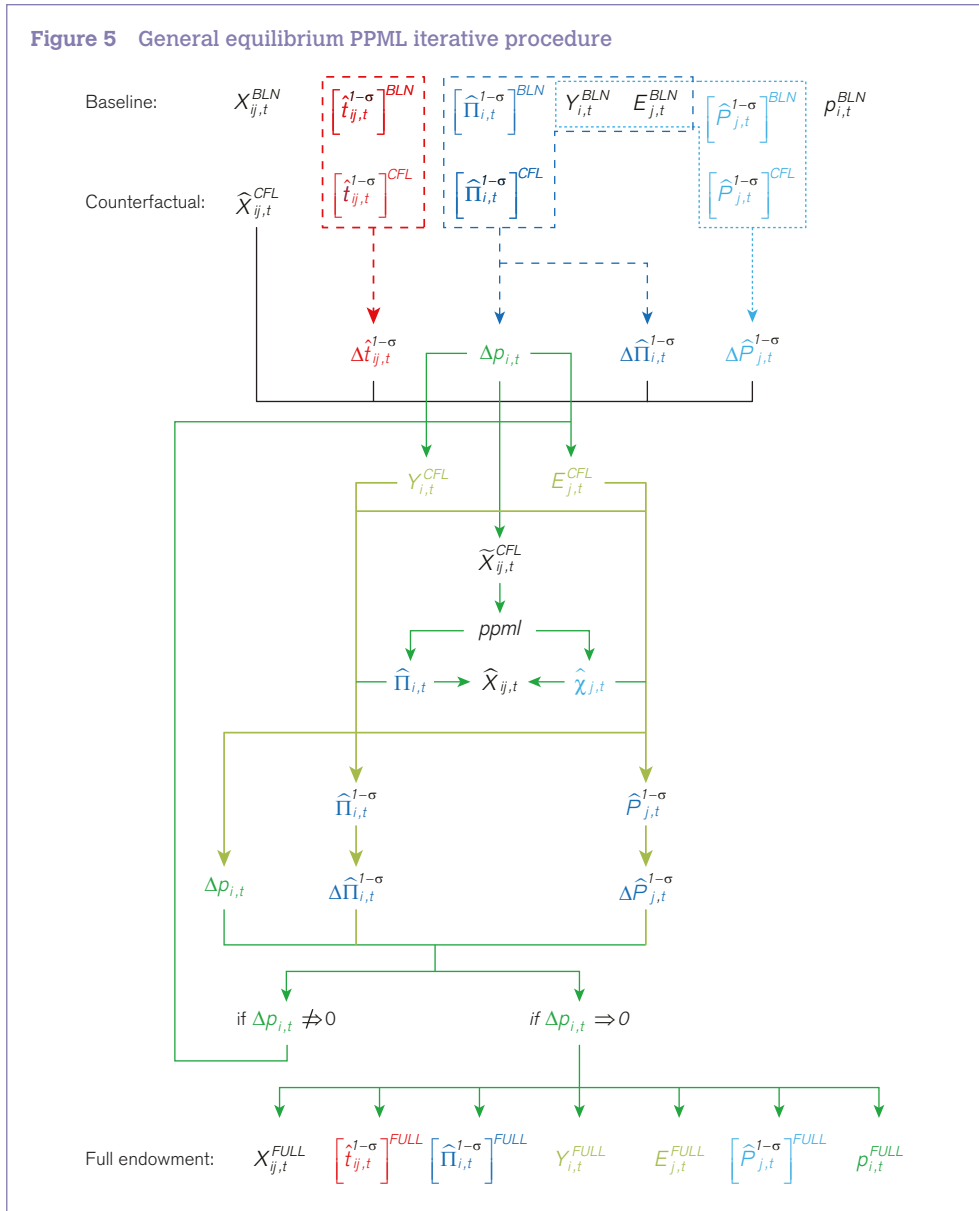
(i) **Allow for endogenous factory-gate prices**

The first stage of the loop requires using the market clearing conditions (2-4) to translate the conditional general equilibrium effects on the multilateral resistances terms obtained in Step III.a into *first-order* changes in factory-gate prices, by applying the definition of the estimated exporter fixed effects given in equation (2-41):¹³

$$\Delta p_{i,t}^{CFL} = \frac{p_{i,t}^{CFL}}{p_{i,t}} = \left(\frac{\exp(\hat{\pi}_{i,t}^{CFL}) / E_{R,t}^{CFL}}{\exp(\hat{\pi}_{i,t}) / E_{R,t}} \right)^{\frac{1}{1-\sigma}} \quad (2-43)$$

(ii) **Allow for endogenous income, expenditures and trade**

The second stage of the loop involves allowing for the endogenous response in the value of output/income $Y_{i,t}^{CFL} = (p_{i,t}^{CFL} / p_{i,t}) Y_{i,t}$ and expenditure $E_{j,t}^{CFL} = (p_{j,t}^{CFL} / p_{j,t}) E_{j,t}$, which in turn will trigger additional changes in the multilateral resistance terms and so forth. Yet, the changes in output, expenditure and the multilateral resistances cannot be accounted for explicitly in the estimation of the structural gravity model, because they are controlled for by the fixed effects.



The solution is to use the structural gravity equation (2-1) to translate the changes in output and expenditure, triggered by the changes in factory-gate prices, into changes in trade flows:

$$X_{ij,t}^{CFL} = \frac{[\hat{t}_{ij,t}^{1-\sigma}]^{CFL}}{\hat{t}_{ij,t}^{1-\sigma}} \times \frac{Y_{i,t}^{CFL} E_{j,t}^{CFL}}{Y_{i,t} E_{j,t}} \times \frac{\Pi_{i,t}^{1-\sigma}}{[\hat{\Pi}_{i,t}^{1-\sigma}]^{CFL}} \times \frac{P_{j,t}^{1-\sigma}}{[\hat{P}_{j,t}^{1-\sigma}]^{CFL}} \times X_{ij,t} \quad (2-44)$$

where the estimated bilateral trade costs in the baseline and counterfactual scenarios, $\hat{\tau}_{j,t}^{1-\sigma}$ and $[\hat{\tau}_{j,t}^{1-\sigma}]^{CFL}$, are computed according to equations (2-28) and (2-33), respectively. Equation (2-44) accounts for the fact that a change in the factory-gate price will lead to changes in trade via several channels, namely changes in output and outward multilateral resistances on the exporter side, and changes in expenditure and inward multilateral resistances on the importer side. More importantly, the changes in trade implied by equation (2-44) are only *first-order* changes and do not reflect the full endowment general equilibrium changes, because they only capture the changes in the conditional outward multilateral resistances and the initial response in the factory-gate prices.

(iii) **Estimate the structural gravity model**

The third stage of the loop consists of repeating Step III.a by re-estimating the PPML gravity model (2-40) with the new value of bilateral trade $X_{j,t}^{CFL}$ from equation (2-44), and then computing the corresponding general equilibrium effects associated with the new fixed effect estimates. The idea behind this step, and more generally behind the iterative procedure, is that by updating the value of trade, the PPML estimator will translate the initial response of factory-gate prices into changes in the gravity fixed effects, which (in combination with the changes in trade) can be used to obtain additional responses in the multilateral resistance terms and in the values of output and expenditure.

Once the set of fixed effects associated with the value of trade from equation (2-44) are estimated, the first stage of the iterative procedure has to be repeated in order to obtain a new set of factory-gate prices associated with these fixed effects. Similarly, the second stage of the loop has to be repeated to compute the new values of output, aggregate expenditures and trade. The structural gravity model (2-40) is then re-estimated with the new value of trade flows freshly computed by the previous step of the iterative procedure. These three steps are repeated until the change in each of the factory-gate prices is close to zero, that is when the structural gravity model has reached its new equilibrium.

(iv) **Construct “full endowment general equilibrium” indexes**

Once convergence is achieved, the latest set of fixed effects obtained can be used, in combination with the original and latest (full general equilibrium) data on output and expenditure, to construct the full endowment general equilibrium values of the multilateral resistance:

$$[\hat{\Pi}_{i,t}^{1-\sigma}]_{FULL}^{CFL} = \frac{Y_{i,t}^{FULL}}{\exp(\hat{\pi}_{i,t}^{FULL})} \times E_{R,t}^{FULL} \quad (2-45)$$

$$[\hat{P}_{j,t}^{1-\sigma}]_{FULL}^{CFL} = \frac{E_{j,t}^{FULL}}{\exp(\hat{\chi}_{j,t}^{FULL})} \times \frac{1}{E_{R,t}^{FULL}} \quad (2-46)$$

where *FULL* stands for “full endowment”, and $\hat{\pi}_{i,t}^{FULL}$ and $\hat{\chi}_{j,t}^{FULL}$ are the latest PPML estimates of the exporter-time and import-time fixed effects of the constrained structural gravity model, respectively, obtained by applying the iterative procedure, and $Y_{i,t}^{FULL}$ and $E_{j,t}^{FULL}$ are the corresponding output and expenditure values, which together with the other endogenous variables of the structural gravity model, can be easily computed as follows:

$$\frac{p_{i,t}^{FULL}}{p_{i,t}^{BLN}} = \left(\frac{\exp(\hat{\pi}_{i,t}^{FULL}) / E_{R,t}^{FULL}}{\exp(\hat{\pi}_{i,t}^{BLN}) / E_{R,t}^{BLN}} \right)^{\frac{1}{1-\sigma}} \quad (2-47)$$

$$Y_{i,t}^{FULL} = \frac{p_{i,t}^{FULL}}{p_{i,t}^{BLN}} \times Y_{i,t}^{BLN} \quad (2-48)$$

$$E_{i,t}^{FULL} = \varphi_i Y_{i,t}^{FULL} \quad (2-49)$$

$$X_{j,t}^{FULL} = \frac{Y_{i,t}^{FULL} E_{i,t}^{FULL}}{Y_{j,t}^{FULL}} \frac{(\hat{t}_{j,t}^{CFL})^{1-\sigma}}{[\hat{\Pi}_{i,t}^{1-\sigma}]_{FULL}^{CFL} [\hat{P}_{j,t}^{1-\sigma}]_{FULL}^{CFL}} \quad (2-50)$$

These full endowment general equilibrium indexes can then be used to compute other more refined general trade cost indexes, such as real GDP or real consumption.

Step IV: Collect, construct, and report indexes of interest

The differences, in percentage, between the baseline indexes from Step I and the counterfactual indexes from Step III.a measure the conditional general equilibrium effects of the simulated trade policy. The differences, in percentage, between the baseline indexes from Step I and the counterfactual indexes from Step III.b measure the full endowment general equilibrium effects of the simulated trade policy.

Step V: Construct confidence intervals

The general equilibrium PPML procedure described here naturally extends itself to the construction of confidence intervals as described in Step 5 of the standard procedure for counterfactual analysis with the gravity model.

C. Applications

This section presents two applications that analyse the general equilibrium effects of two different trade policy experiments. The first hypothetical scenario removes all international borders in the world, while the second application simulates the effects of the North American Free Trade Agreement (NAFTA), negotiated by Canada, Mexico and the United States. The results of both applications, presented primarily for instructional purposes, are obtained by implementing the GEPPML procedure associated with the PPML estimator proposed by Anderson et al. (2015b) and presented in the previous section.

The data used in both applications are similar to the one employed in the applications presented in Chapter 1. The database reports bilateral trade, including *international* and *intra-national* trade, at the aggregated manufacturing level for 69 countries over the period 1986-2006. Information on RTAs and standard gravity variables such as distance, continuous borders, and common language,

are also included in the database. Section 3 of Chapter 1 provides details on the data sources used to construct the database.

1. Trade without borders

The first experiment investigates the effects of a hypothetical removal of all international borders, while preserving the effect of geography. This counterfactual scenario gives an idea of the potential effects of full trade integration where there are no differences for consumers and producers, apart from geographical differences, whether to buy or sell on national or international (i.e. across national borders) markets, respectively.

Although, as discussed in Chapter 1, proper identification of the effects of some gravity covariates (e.g. RTAs) requires panel data, most counterfactual experiments are performed with cross-section data. That is why, and in order to keep the analysis simple and tractable, the first application only employs cross-section data for the year 2006, which is the latest year in the sample. Specifically, the following econometric model is estimated with the PPML estimator in order to obtain point estimates of the effects of international borders, the variable of interest in this application:

$$X_{ij} = \exp\left[\pi_i + \chi_j + \beta_1 \ln DIST_{ij} + \beta_2 CNTG_{ij} + \beta_3 INTL_{ij}\right] \times \varepsilon_{ij} \quad (2-51)$$

where the bilateral trade costs $t_{ij}^{1-\sigma}$ are approximated by the logarithm of bilateral distance ($\ln DIST_{ij}$), an indicator variable for contiguity ($CNTG_{ij}$), as well as an indicator variable for international borders ($INTL_{ij}$) taking the value of one for international trade and zero otherwise. The exporter and importer fixed effects (π_i and χ_j), respectively, account for the multilateral resistances as well as for outputs and expenditures. The econometric gravity specification (2-51) is therefore consistent with the structural gravity system (2-1)-(2-5) presented in the previous section.

The treatment of international borders considered in this application through the variable $INTL_{ij}$ offers two advantages but also two disadvantages, which should be kept in mind when interpreting the results. The border variable has the advantage of being, by construction, exogenous. The second advantage is that the border variable comprehensively captures the effects of all possible determinants of trade, in addition to geography, which is modelled explicitly, driving a wedge between internal and international trade. Conversely, the border variable assumes a common border effect across all pairs of countries in the sample, which has the drawback of ignoring the fact that border effects are quite heterogeneous across countries. This caveat is addressed in one of the exercises at the end of this chapter. The second caveat is that the model specification does not explicitly decompose the possible determinants of international borders, which implies that only hypothetical scenarios in terms of percentage decrease of international borders can be considered. As explained above, the hypothetical scenario of this application is the complete removal of all international borders. The analysis is performed in the STATA software by closely following the steps of the GEPPML procedure outlined in the previous section. The interested reader may refer to Larch and Yotov (2016a), who demonstrate that identical results are obtained by solving the general equilibrium gravity system with a non-linear solver, such as Matlab software.

Step I: Solve the baseline gravity model

The first step of the GEPPML procedure delivers estimates of the trade costs and trade elasticities in the baseline scenario necessary to compute the baseline indexes of interest.

The first stage of this step consists of estimating the econometric gravity specification (2-51) in order to obtain the point estimates of the effects of distance, contiguity and international borders on international trade flows:

$$X_{ij} = \exp \left[\hat{\pi}_i + \hat{\chi}_j - 0.791 \times \ln DIST_{ij} + 0.674 \times CNTG_{ij} - 2.474 \times INTL_{ij} \right] \times \hat{\varepsilon}_{ij} \quad (2-52)$$

(0.050) (0.107) (0.119)

For brevity, all coefficient estimates are reported directly in the estimating equation with standard errors in parentheses under the corresponding estimate. All PPML estimates are in accordance with prior expectations. The estimate of the coefficient of the distance variable is negative and highly statistically significant, and readily comparable to the corresponding median meta-analysis estimate of -0.89 reported by Head and Mayer (2014). The estimate of the impact of contiguity is positive, highly significant, and also close to the median summary index of 0.49 reported by Head and Mayer (2014). Finally, the estimates suggest that the effects of international borders are, on average, very large, even after controlling for geography (namely distance and contiguity). Specifically, the estimate of the coefficient on the variable $INTL_{ij}$ implies that, all else equal, international borders decrease trade by an average of $[\exp(\hat{\beta}_3) - 1] \times 100 = [\exp(-2.474) - 1] \times 100 = 91.6$ percent, whose associated standard error equal to 1.005 has been constructed with the delta method.

```
* STATA commands to estimate the baseline gravity model:
* Create variables for output and expenditure
bysort exporter: egen Y = sum(trade)
bysort importer: egen E = sum(trade)
* Define the country of reference (here Germany)
generate E_deuBLN = E if importer == "DEU"
replace exporter = "ZZZ" if exporter == "DEU"
replace importer = "ZZZ" if importer == "DEU"
egen E_deu = mean(E_deuBLN)

* Estimate the gravity model with the PPML estimator
describe IMPORTER_FE*
global N = r(r)
global N_1 = $N - 1
ppml trade EXPORTER_FE* IMPORTER_FE1-IMPORTER_FE$N_1 ln_DIST CNTG INTL, ///
cluster(pair_id) noconstant
predict tradehat_BLN, mu
```

The second stage of the first step involves using the PPML estimates of the exporter and of the importer fixed effects from specification (2-52) in order to construct all the baseline values of the inward and outward multilateral resistances terms, which in turn can be used in combination with data on output and expenditure to obtain all other general equilibrium indexes of interest in the baseline.

These baseline values are not reported here for brevity. However, they will be used to calculate their changes in response to the counterfactual shock, i.e. the removal of international borders.

```
* STATA commands to obtain baseline trade costs:
* Construct the variables for export- and import-fixed effects
forvalues i = 1 (1) $N_1 {
    replace EXPORTER_FE`i' = EXPORTER_FE`i' * (exp(_b[EXPORTER_FE`i']))
    replace IMPORTER_FE`i' = IMPORTER_FE`i' * (exp(_b[IMPORTER_FE`i']))
}

replace EXPORTER_FE$N = EXPORTER_FE$N * exp(_b[EXPORTER_FE$N])
replace IMPORTER_FE$N = IMPORTER_FE$N * exp(0)
egen exp_pi_BLN = rowtotal(EXPORTER_FE1-EXPORTER_FE$N)
egen exp_chi_BLN = rowtotal(IMPORTER_FE1-IMPORTER_FE$N)

* Compute the variables of bilateral trade costs and multilateral resistances
generate tij_BLN = exp(_b[ln_DIST] * ln_DIST + _b[CNTG] * CNTG + _b[INTL] * INTL)
generate OMR_BLN = Y * E_deu / exp_pi_BLN
generate IMR_BLN = E / (exp_chi_BLN * E_deu)

* Compute the estimated international trade for given output and expenditures
generate tempXi_BLN = tradehat_BLN if exporter != importer
bysort exporter: egen Xi_BLN = sum(tempXi_BLN)
```

Step II: Define a counterfactual scenario

The second step of the GEPPML procedure consists of defining the scenario that simulates the hypothetical removal of all international borders in the world. This can be achieved in different ways. One possibility is to simply eliminate the border variable from the construction of the counterfactual trade costs. Another possibility, useful for instructional purposes, is to define a new, counterfactual border variable that is equal to zero for each possible pair of countries in the sample.

```
* STATA commands to define counterfactual scenario of removing international borders
* Option 1: eliminate the border variable
generate tij_CFL = exp(_b[ln_DIST]*ln_DIST + _b[CNTG]*CNTG)

* Option 2: define a new counterfactual border variable
generate INTL_CFL = 0
generate tij_CFL = exp(_b[ln_DIST]*ln_DIST + _b[CNTG]*CNTG + _b[INTL]*INTL_CFL)

* Generate the logged trade costs used in the constraint
generate ln_tij_CFL = log(tij_CFL)
```

Step III: Solve the counterfactual model

The third stage of the GEPPML procedure delivers the values of the counterfactual indexes of interest in the “conditional” and in the “full endowment” general equilibrium scenarios of abolishing international borders.

Conditional general equilibrium effects. Obtaining the “conditional general equilibrium” effects from the removal of international borders is achieved by re-estimating the econometric gravity specification (2-51) under a number of constraints to reflect the counterfactual scenario, namely there is no longer international border ($\bar{\beta}_3 = 0$) but the effects of geography remain constant ($\bar{\beta}_1 = -0.791$ and $\bar{\beta}_2 = 0.674$):

$$X_{ij} = \exp\left[\pi_i^{CFL} + \chi_j^{CFL} - 0.791 \times \ln DIST_{ij} + 0.674 \times CNTG_{ij}\right] \times \varepsilon_{ij}^{CFL} \quad (2-53)$$

where the superscript *CFL* denotes the counterfactual values.

```
* STATA commands to estimate the conditional gravity model:
* Re-create a new set of exporter and importer fixed effects
drop EXPORTER_FE* IMPORTER_FE*
tabulate exporter, generate(EXPORTER_FE)
tabulate importer, generate(IMPORTER_FE)

* Estimate the constrained gravity model with the PPML estimator
ppml trade EXPORTER_FE* IMPORTER_FE1-IMPORTER_FE$N_1, cluster(pair_id) ///
    noconstant offset(ln_tij_CFL)
predict tradehat_CD, mu
```

The new set of estimates of fixed effects from specification (2-53) and the constrained coefficients of the trade cost variables are used to construct the corresponding “conditional general equilibrium” multilateral resistances, total exports, and real consumption for each of the 69 countries in the sample. As explained in the previous section, the multilateral resistance terms have to be normalized by setting the multilateral resistance terms of a given country, here Germany, equal to one.

```
* STATA commands to obtain conditional general equilibrium effects:
* Construct the variables for export- and import-fixed effects
forvalues i = 1 (1) $N_1 {
    replace EXPORTER_FE`i' = EXPORTER_FE`i' * (exp(_b[EXPORTER_FE`i']))
    replace IMPORTER_FE`i' = IMPORTER_FE`i' * (exp(_b[IMPORTER_FE`i']))
}

replace EXPORTER_FE$N = EXPORTER_FE$N * exp(_b[EXPORTER_FE$N])
replace IMPORTER_FE$N = IMPORTER_FE$N * exp(0)
egen exp_pi_CD = rowtotal(EXPORTER_FE1-EXPORTER_FE$N)
egen exp_chi_CD = rowtotal(IMPORTER_FE1-IMPORTER_FE$N)

* Compute the conditional general equilibrium effects of multilateral resistances
generate OMR_CD = Y * E_deu / exp_pi_CD
generate IMR_CD = E / (exp_chi_CD * E_deu)

* Compute the conditional general equilibrium effects of trade
generate tempXi_CD = tradehat_CD if exporter != importer
bysort exporter: egen Xi_CD = sum(tempXi_CD)
```


Full endowment general equilibrium effects. This step delivers the “full endowment general equilibrium” effects from the removal of international borders by implementing the four-stage iterative procedure that allows for endogenous factory-gate prices, income, expenditure and trade to adjust to the counterfactual shock.

```

* STATA commands to construct the iterative procedure to converge to full endowment
* general equilibrium effects:

    * Set the criteria of convergence
    local s = 3
    local sd_dif_change_p = 1
    local max_dif_change_p = 1
    while (`sd_dif_change_p' > 0.001) | (`max_dif_change_p' > 0.001) {
        local s_1 = `s' - 1
        local s_2 = `s' - 2
        local s_3 = `s' - 3

* i. Create the new dependent variable and estimate the gravity model with PPML
    generate trade_`s_1' = change_tij * tradehat_`s_2' * change_pricei_`s_2' * ///
        change_pricej_`s_2' / (change_OMR_FULL_`s_2' * change_IMR_FULL_`s_2')
    drop EXPORTER_FE* IMPORTER_FE*
    tabulate exporter, generate(EXPORTER_FE)
    tabulate importer, generate(IMPORTER_FE)
    capture ppml trade_`s_1' EXPORTER_FE* IMPORTER_FE1-IMPORTER_FE$N_1, ///
        cluster(pair_id) offset(ln_tij_CFL) noconstant iter(30)
    predict tradehat_`s_1', mu

* ii. Update output and expenditures
    bysort exporter: egen Y_`s_1' = total(tradehat_`s_1')
    generate tempE_`s_1' = phi * Y_`s_1' if exporter == importer
    bysort importer: egen E_`s_1' = mean(tempE_`s_1')
    generate tempE_deu_`s_1' = E_`s_1' if importer == "ZZZ"
    egen double E_deu_`s_1' = mean(tempE_deu_`s_1')

* iii. Update factory-gate prices and multilateral resistances
    forvalues i = 1 (1) $N {
        replace EXPORTER_FE`i' = EXPORTER_FE`i' * (exp(_b[EXPORTER_FE`i']))
        replace IMPORTER_FE`i' = IMPORTER_FE`i' * (exp(_b[IMPORTER_FE`i']))
    }
    egen exp_pi_`s_1' = rowtotal(EXPORTER_FE1-EXPORTER_FE$N)
    egen exp_chi_`s_1' = rowtotal(IMPORTER_FE1-IMPORTER_FE$N)
    generate tempvar1 = exp_pi_`s_1' if exporter == importer
    bysort importer: egen exp_pi_j_`s_1' = mean(tempvar1)
    generate change_pricei_`s_1' = ((exp_pi_`s_1' / exp_pi_`s_2') ///
        / (E_deu_`s_1' / E_deu_`s_2'))^(1/(1-sigma))
    generate change_pricej_`s_1' = ((exp_pi_j_`s_1' / exp_pi_j_`s_2') ///
        / (E_deu_`s_1' / E_deu_`s_2'))^(1/(1-sigma))
    generate OMR_FULL_`s_1' = (Y_`s_1' * E_deu_`s_1') / exp_pi_`s_1'
    generate change_OMR_FULL_`s_1' = OMR_FULL_`s_1' / OMR_FULL_`s_2'
    generate IMR_FULL_`s_1' = E_`s_1' / (exp_chi_`s_1' * E_deu_`s_1')
    generate change_IMR_FULL_`s_1' = IMR_FULL_`s_1' / IMR_FULL_`s_2'

* iv. Iterate until the change in factory-gate prices has converged to zero
    generate dif_change_p_`s_1' = change_pricei_`s_2' - change_pricei_`s_3'
    summarize dif_change_p_`s_1'
    local sd_dif_change_p = r(sd)
    local max_dif_change_p = abs(r(max))
    local s = `s' + 1
    drop temp*
}

```

As soon as the change in factory-gate price has converged to zero, all full endowment general equilibrium indexes of interest can be constructed as well.

```
* STATA commands to obtain full endowment general equilibrium effects:
* Define the last number of iterations
local S = `s' - 2

* Compute the full endowment general equilibrium of factory-gate price
generate change_pricei_FULL = ((exp_pi_`S'/exp_pi_0) ///
/ (E_deu_`S' / E_deu_0))^(1/(1-sigma))

* Compute the full endowment general equilibrium of output
generate Y_FULL = change_pricei_FULL * Y_BLN

* Compute the full endowment general equilibrium of aggregate expenditures
generate tempE_FULL = phi * Y_FULL if exporter == importer
bysort importer: egen E_FULL = mean(tempE_FULL)

* Compute the full endowment general equilibrium of the multilateral resistances
generate OMR_FULL = Y_FULL * E_deu_`S' / exp_pi_`S'
generate IMR_FULL = E_`S' / (exp_chi_BLN * E_deu)

* Compute the full endowment general equilibrium of trade
generate X_FULL = (Y_FULL * E_FULL * tij_CPL) / (IMR_FULL * OMR_FULL)
generate tempXi_FULL = X_FULL if exporter != importer
bysort exporter: egen Xi_FULL = sum(tempXi_FULL)
```

Step IV: Collect, construct, and report indexes of interest

Once the “conditional” and “full endowment” general equilibrium effects associated with the removal of international borders have been obtained, the changes, expressed in percentage, of the different indexes of interest between the baseline scenario and the “conditional” and “full endowment” scenarios can be computed.

```
* STATA commands to construct the percentage change of the general equilibrium indexes:
* Construct the percentage changes on export/production side
collapse(mean) OMR_BLN OMR_CDL OMR_FULL change_pricei_FULL Xi_BLN Xi_CDL ///
Xi_FULL Y_BLN Y_FULL, by(exporter)

* Change in full endowment general equilibrium factory-gate price
generate change_price_FULL = (change_pricei_FULL - 1) / 1 * 100

* Change in conditional and full general equilibrium outward multilateral resistances
generate change_OMR_CDL = (OMR_CD^(1/(1-sigma)) - OMR_BLN^(1/(1-sigma)))
/ OMR_BLN^(1/(1-sigma)) * 100
generate change_OMR_FULL = (OMR_FULL^(1/(1-sigma)) - OMR_BLN^(1/(1-sigma))) ///
/ OMR_BLN^(1/(1-sigma)) * 100

* Change in conditional and full general equilibrium international trade
generate change_Xi_CDL = (Xi_CDL - Xi_BLN) / Xi_BLN * 100
generate change_Xi_FULL = (Xi_FULL - Xi_BLN) / Xi_BLN * 100
```

Figure 6 and Figure 7 summarize the results of the application by plotting some of the key general equilibrium indexes simulating the uniform removal of world borders against the log of national GDP. The interested reader may refer to Larch and Yotov (2016a) for a more detailed presentation and discussion of the country-specific indexes.

Figure 6 depicts the change in the “conditional” and “full endowment” equilibrium exports in response to the removal of international borders for each country in the sample. The “conditional general equilibrium” effects on trade are particularly large and heterogeneous, which stem from the fact that the “direct/partial equilibrium” effect of international borders is also large ($\hat{\beta}_3 = -2.474$). The significant increase in exports in the “conditional” scenario is further reinforced in the “full endowment” setting, whose effects vary between 41 and 91 percentage points as compared to the “conditional” scenario. The results of the application further suggest a strong positive correlation between the removal of international borders and country size, as measured by the value of output.

Figure 7 depicts the changes of real GDP associated with the removal of international borders and decomposes these changes into effects on the consumers (via the inward multilateral resistances defined as $-1 \times P_{j,t}$) and on the producers (via the factory-gate prices) for each of the countries in the sample. Four main findings stand out.

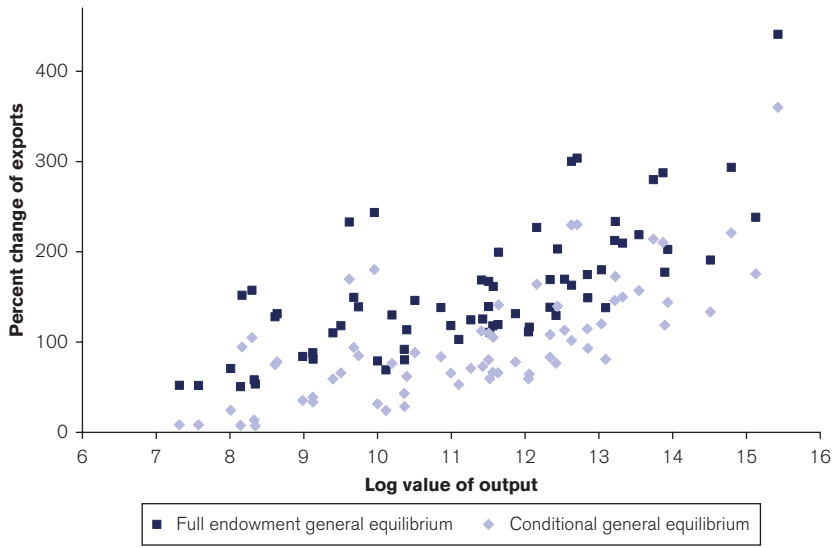
First, the “full endowment” general equilibrium effects on real GDP are large. A comparison of these values with the corresponding indexes obtained by Costinot and Rodriguez-Clare (2014), who investigate a move from observed levels of trade to autarky, shows that the results are qualitatively similar for the same countries or comparable countries, suggesting that at this stage the world has enjoyed at most half of the possible gains from trade and trade liberalization and that there is significant scope for further gains from trade in the future.¹⁴

Second, the real GDP effects vary significantly across the countries in the sample. Specifically, the indexes suggest that less developed and smaller economies would benefit significantly more from the hypothetical uniform border removal as compared to developed and large countries. This result is in line with the intuition that the smaller of two countries gains more moving from autarky to free trade and that larger countries with a larger home market share gain less (Anderson et al., 2015b; Arkolakis et al., 2012).

Third, it is important to interpret this result together with the previous finding that it is actually the high income countries that would benefit more from the removal of borders in terms of exports. In combination, the two results imply that the real GDP gains for the low income countries would actually come mostly on the consumer side, through more favourable prices. This is captured in Figure 7, which shows that, indeed, the contribution of consumer prices to the real GDP change is the largest for low income countries. The reader is reminded that all indexes on the producer and on the consumer side should be interpreted relative to the changes in consumer prices, inward multilateral resistances, in the reference country, Germany.

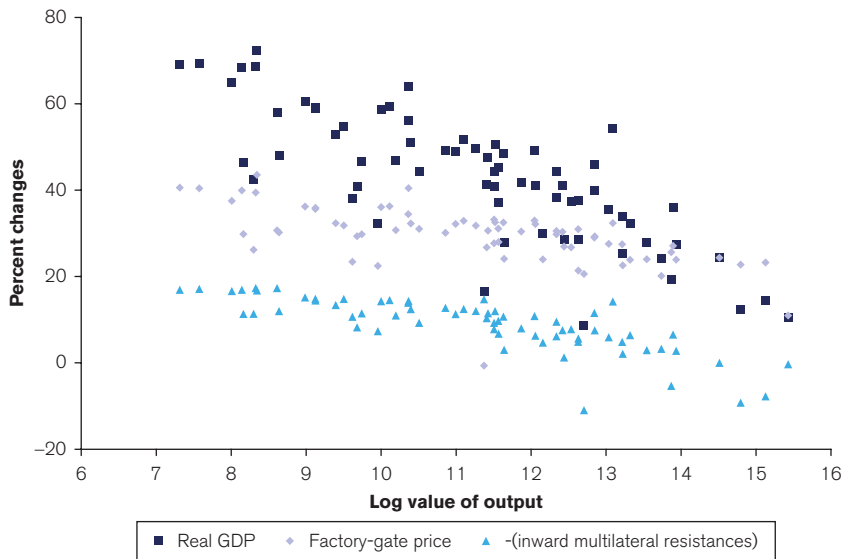
Finally, the “full endowment” general equilibrium effects from the removal of the borders on producers (through changes in factory-gate price relative to Germany) appear to be larger than the “full endowment” general equilibrium effects on consumers. This result is consistent with the findings

Figure 6 Effects of abolishing international borders on exports



Source: Authors' calculations

Figure 7 Effects of abolishing international borders on real GDP



Note: The inward multilateral resistances have been reformulated by multiplying their value by minus one.

Source: Authors' calculations

of Anderson and Yotov (2010b), who decompose the incidence of trade costs on the consumers and producers sides in Canada, and conclude that most of the gains from globalization accrue on the producer side.

2. Impact of regional trade agreements

The second experiment investigates the general equilibrium effects of regional trade agreements, in particular the effects of NAFTA. The choice of NAFTA is due to the fact that it is one of the most widely studied RTAs.¹⁵ In addition to focusing on RTAs, whose effects have been a topic of significant policy interest, this application introduces three practical extensions that are valuable from an instructional perspective. First, unlike the previous application, this experiment takes advantage of the panel dimension of the dataset in order to identify the effects of RTAs and to comprehensively capture the impact of all time-invariant trade costs with the use of pair fixed effects. Second, the application implements the two-stage procedure of Anderson and Yotov (2016) to recover missing bilateral trade costs. Finally, the application demonstrates how the first stage of the GEPPML procedure can be implemented as a constrained regression with an external trade cost vector.

The analysis begins by specifying the following panel version of the empirical gravity model in order to obtain estimates of bilateral trade costs including an estimate of the average effects of all RTAs:

$$X_{j,t} = \exp[\pi_{i,t} + \chi_{j,t} + \mu_{ij} + \beta_1 RTA_{j,t}] \times \varepsilon_{ij,t} \quad (2-54)$$

where $RTA_{j,t}$ is an indicator variable that is equal to one if two countries are members of the same RTA at time t , and zero otherwise. Following the best-practice recommendations formulated in Chapter 1, specification (2-54) is estimated with the PPML estimator using panel data with 4-year interval that include consistent *international* and *intra-national* trade flows, *exporter-time* fixed effects ($\pi_{i,t}$) and *importer-time* fixed effects ($\chi_{j,t}$). The *pair* fixed effects (μ_{ij}) are also included in order to alleviate potential endogeneity concerns of the RTA dummy variable and to control for all possible (observable and unobservable) time-invariant trade costs at the bilateral level. The GEPPML procedure outlined in the previous section is applied in the STATA software to evaluate the hypothetical scenario of removing NAFTA. Although not reported here, identical results are obtained by solving explicitly the general equilibrium gravity system with a non-linear solver, such as Matlab software (Larch and Yotov, 2016b).

Step I: Solve the baseline gravity model

The first step of the GEPPML procedure requires estimating the baseline gravity model (2-54) in order to obtain point estimates of the effect of RTAs and the *pair* fixed effects and to construct the bilateral trade costs matrix required to compute the baseline indexes of interest. As discussed in Box 3, while it may be important to construct the complete matrix of bilateral trade costs in order to perform sound counterfactual analysis, it is often not possible to identify the

complete set of pair fixed effects estimates in the gravity model when trade flows data are missing (or zero) for a given pair throughout the whole period under investigation. Following Anderson and Yotov (2016), the two-stage procedure is implemented in order to recover the complete set of bilateral trade costs.

Stage 1: Obtain the estimates of pair fixed effects and the effects of RTAs. The first stage consists of estimating equation (2-54) in order to obtain the estimates of the bilateral fixed effects for country-pairs with non-missing (or non-zero) trade flows:

$$X_{ij,t} = \exp \left[\hat{\pi}_{i,t} + \hat{\chi}_{j,t} + \hat{\mu}_{ij} + \underset{(0.0506)}{0.557} \times RTA_{ij,t} \right] \quad (2-55)$$

The estimate of β_1 implies that, on average, the RTAs have led to about $[\exp(\hat{\beta}_1) - 1] \times 100 = [\exp(0.557) - 1] \times 100 = 75$ percent increase in trade among members, whose associated standard error equal to 9.736 has been constructed with the delta method.

```
* STATA commands to obtain the estimates of pair fixed effects from gravity model:
ds PAIR_FE*
    global NT_ij = `: word count `r(varlist)''
    global NT_ij_1 = $NT - 1
    global NN_ij_8 = $NT - 8

ds EXPORTER_TIME_FE*
    global NT = `: word count `r(varlist)''

tabulate year, generate(TIME_FE)
ds TIME_FE*
    global Nyr = `: word count `r(varlist)''
    global NT_yr = $NT - $Nyr

ppml trade PAIR_FE1-PAIR_FE$NTij_1 EXPORTERTIME_FE* IMPORTER_TIME_FE1- ///
    IMPORTER_TIME_FE$NT_yr RTA, cluster(pair_id) noconst iter(30)
scalar RTA_est = _b[RTA]
```

Stage 2: Regress the estimates of pair fixed effects on gravity variables and country fixed effects. The second stage involves using the estimates of the pair fixed effects ($\hat{\mu}_{ij}$) from equation (2-55) as the dependent variable in a regression where the covariates include the set of standard gravity variables along with importer and exporter fixed effects:

$$\hat{\mu}_{ij}^{1-\sigma} = \exp(\hat{\mu}_{ij}) = \exp \left[\pi_i + \chi_j + \beta_1 \ln DIST_{ij} + \beta_2 CNTG_{ij} + \beta_3 LANG_{ij} + \beta_3 COLONY_{ij} \right] \times \varepsilon_{ij} \quad (2-56)$$

The predictions from regression (2-56) are then used to fill in the missing trade cost values in order to obtain the complete set of bilateral trade costs $\hat{t}_{ij}^{1-\sigma}$.

```
* STATA commands to construct the full matrix of bilateral trade costs:
* Collect the estimates of the pair fixed effects
forvalues ijt = 1 (1) $NTij_8 {
    quietly replace PAIR_FE`ijt' = PAIR_FE`ijt' * _b[PAIR_FE`ijt']
}
egen gamma_ij = rowtotal(PAIR_FE1-PAIR_FE$NTij)
replace gamma_ij = . if gamma_ij == 1 & exporter != importer
replace gamma_ij = 0 if gamma_ij == 1 & exporter == importer
generate tij_bar = exp(gamma_ij)
generate tij_BLN = exp(gamma_ij + RTA_est * RTA)

* Replace missing trade costs with the predictions from the standard regression
keep if year == 1994
generate tij = exp(gamma_ij)
tabulate exporter, generate(EXPORTER_FE)
tabulate importer, generate(IMPORTER_FE)
ppml tij EXPORTER_FE* IMPORTER_FE* LN_DIST CNTG LANG CLNY ///
    if exporter!=importer, cluster(pair_id)
predict tij_noRTA, mu
replace tij_noRTA = 1 if exporter == importer
replace tij_bar = tij_noRTA if tij_bar == .
replace tij_BLN = tij_bar * exp(RTA_est * RTA) if tij_BLN == .
generate ln_tij_BLN = log(tij_BLN)
```

Once the full vector of bilateral trade costs is constructed, it can be imposed as a constraint in the baseline gravity specification (2-55), which will deliver estimates of the importer and of the exporter fixed effects that are consistent with this trade cost vector and can be used to directly recover the corresponding values of the multilateral resistances. It is worth noting that a similar constrained estimation procedure should be performed in general when the trade cost vector is obtained externally, including when it is constructed with a calibration method.

```
* STATA commands to solve the "constrained" baseline gravity model:
drop EXPORTER_FE* IMPORTER_FE*
tabulate exporter, generate(EXPORTER_FE)
tabulate importer, generate(IMPORTER_FE)
ppml trade EXPORTER_FE* IMPORTER_FE1-IMPORTER_FE$N_1, ///
    cluster(pair_id) offset(ln_tij_BLN) noconstant iter(30)
predict tradehat_BLN, mu
```

All other baseline indexes of interest can be obtained by applying the exact same procedure as described in the previous application.

Step II: Define a counterfactual scenario

The second step of the GEPPML procedure requires defining the hypothetical removal of NAFTA. This is done by re-defining the RTA dummy variable, $RTA_{ij,t}^{CFL}$, as if NAFTA were not in place by setting the original RTA indicator variable to be equal to zero for trade between Canada, Mexico and the United States after 1993.¹⁶

```
* STATA commands to define counterfactual scenario of removal of NAFTA:
generate RTA_CFL = RTA
    replace RTA_CFL = 0 if (exporter == "CAN" & importer == "USA") | ///
        (exporter == "CAN" & importer == "MEX") | ///
        (exporter == "MEX" & importer == "USA") | ///
        (exporter == "MEX" & importer == "CAN") | ///
        (exporter == "USA" & importer == "MEX") | ///
        (exporter == "USA" & importer == "CAN") & year > 1993
generate tij_CFL = tij_bar * exp(RTA_est * RTA_CFLA)
generate ln_tij_CFL = log(tij_CFL)
```

Step III: Solve the counterfactual model

The third stage of the GEPPML procedure consists of constructing the counterfactual indexes of interest in the “conditional” and in the “full endowment” general equilibrium scenarios of removing NAFTA. Despite the fact that the counterfactual considered in this experiment is totally different from the one considered in the previous application, the exact same procedure applies to first obtain the “conditional general equilibrium” effects and then compute the “full endowment general equilibrium” effects.

Conditional general equilibrium effects. The “conditional general equilibrium” effects from the removal of NAFTA are computed by re-estimating the econometric gravity specification (2-54) for 1994, the year of entry into force of NAFTA, subject to a number of constraints reflecting the counterfactual scenario:¹⁷

$$X_{ij} = \exp\left[\pi_i^{CFL} + \chi_j^{CFL} + \hat{t}_{ij}^{1-\sigma} + \hat{\beta}_1 RTA_{ij}^{CFL}\right] \times \varepsilon_{ij}^{CFL} \quad (2-57)$$

Equation (2-57) is estimated under the constraints that NAFTA was never concluded (RTA_{ij}^{CFL}) and the coefficient of the RTA dummy as well as the bilateral fixed effects are equal to their baseline values, $\hat{\beta}_1$ and $\hat{t}_{ij}^{1-\sigma}$, respectively, ensuring that no part of the trade costs besides the RTA dummy is changing. The PPML estimates of the directional fixed effects from equation (2-57) can then be used to recover the conditional multilateral resistance indexes $\hat{\Pi}_i^{CFL}$ and \hat{P}_j^{CFL} subject to normalisation (with Germany chosen as reference country).

Full endowment general equilibrium effects. The values of the “full endowment general equilibrium” effects of the removal of NAFTA are directly obtained by implementing the iterative procedure, outlined in the previous section, which sequentially allows for endogenous factory-gate prices, followed by income, expenditure and trade to adjust to the counterfactual shock.

Step IV: Collect, construct, and report indexes of interest

Table 4 reports the results of the counterfactual analysis, including the percentage difference between the baseline values and their “full endowment” counterparts of the main variables of interest for each country in the sample. As reported in column (1) of Table 4, the results of the application suggest that all the members of NAFTA experience a significant direct increase in exports due to the trade agreement, ranging from 19 to 57 percent of their respective total exports. By construction, countries that did not conclude NAFTA are not subject to any direct/partial equilibrium effects.

Column (2) of Table 4 reveals that, under the conditional general equilibrium scenario, the member countries of NAFTA experience the largest increase in exports, ranging from 15 to 42 percent of their respective total exports. These “conditional” effects are significantly smaller than the “direct/partial” effects because of trade diversion. Part of the increase in trade with member countries comes at the expense of trade with non-members. Trade diversion explains also why the “conditional general equilibrium” effects on non-NAFTA countries’ exports are negative, albeit small (less than 1 percent for the vast majority of countries). Non-member countries facing the largest “conditional” decrease in exports (amounting to less than 2 percent) appear to be geographically close to the three economies, while the countries experiencing the smallest “conditional” effect tend to be countries with weak trade ties.

As highlighted in column (3) of Table 4, the values of the “full endowment” general equilibrium effects of NAFTA on exports are qualitatively identical to the corresponding “conditional” equilibrium effects, even though there are a number of quantitative differences. First, the “full endowment” general equilibrium effects on NAFTA’s members are slightly larger suggesting that part of the decrease in bilateral trade costs due to the creation of NAFTA translates into additional gains for the producers in the member countries who enjoy higher producer prices. In most cases, the increase in the size of NAFTA members mitigates the negative effects on non-members’ exports. As reported in column (4) of Table 4, the counterfactual analysis further suggests that the “full endowment” welfare effects of NAFTA are positive for its members, ranging between 0.3 and 3.8 percent, and slightly negative or null for non-member countries.¹⁸

The decomposition of the “full endowment” general equilibrium effects reported, respectively, in column (5), (6) and (7) suggests that both consumers and producers in member countries of NAFTA face positive effects with lower inward multilateral resistances (for consumers) and lower outward multilateral resistances, which translate into higher factory-gate prices (for producers) relative to the effects on the consumers in the reference country, here Germany. Conversely, producers in many non-member countries experience negative “full endowment” general equilibrium effects because of lower producer prices, while consumers in some non-member countries enjoy lower prices. This positive effect could be driven by the decrease of producer prices in many non-member countries and/or by improvements in efficiency in NAFTA member countries. Overall, despite some specification and data limitations, the results presented and discussed above are comparable with findings from existing related studies.

Table 4 General equilibrium effects of NAFTA

Country	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	<i>Partial effect</i>	<i>Conditional GE</i>	<i>Full Endowment General Equilibrium</i>				
	% Δ exports	% exports	% Δ exports	% Δ real GDP	% Δ IMRs	% Δ OMRs	% Δ price
ARG	0.00	-0.66	-0.69	-0.01	0.01	0.00	0.00
AUS	0.00	-0.49	-0.51	-0.01	0.02	-0.01	0.01
AUT	0.00	-0.07	-0.10	-0.01	0.00	0.01	-0.01
BEL	0.00	-0.09	-0.12	0.00	0.00	0.00	0.00
BGR	0.00	-0.05	-0.07	0.00	0.00	0.00	0.00
BOL	0.00	-0.47	-0.48	-0.02	0.03	-0.01	0.01
BRA	0.00	-0.65	-0.69	-0.01	-0.01	0.02	-0.02
CAN	55.05	34.99	37.46	3.40	-1.48	-2.14	1.87
CHE	0.00	-0.14	-0.17	-0.01	0.00	0.01	-0.01
CHL	0.00	-0.81	-0.83	-0.03	0.01	0.03	-0.03
CHN	0.00	-0.34	-0.38	-0.01	-0.01	0.03	-0.02
CMR	0.00	-0.13	-0.16	-0.01	0.01	0.00	0.00
COL	0.00	-1.80	-1.73	-0.03	0.09	-0.07	0.06
CRI	0.00	-1.03	-1.04	-0.07	0.06	0.01	-0.01
CYP	0.00	-0.09	-0.11	0.00	0.01	-0.01	0.01
DEU	0.00	-0.14	-0.17	-0.01	0.00	0.01	-0.01
DNK	0.00	-0.06	-0.09	-0.01	0.00	0.01	0.05
ECU	0.00	-0.93	-0.89	-0.02	0.08	-0.06	0.01
EGY	0.00	-0.31	-0.33	-0.01	0.02	-0.02	-0.01
ESP	0.00	-0.13	-0.15	-0.01	0.00	0.01	-0.01
FIN	0.00	-0.09	-0.11	-0.01	0.00	0.01	0.00
FRA	0.00	-0.13	-0.15	-0.01	0.00	0.01	0.00
GBR	0.00	-0.23	-0.25	-0.01	0.01	0.01	0.00
GRC	0.00	-0.08	-0.11	0.00	0.01	0.00	-0.01
HKG	0.00	-0.20	-0.23	-0.02	0.01	0.01	0.00
HUN	0.00	-0.04	-0.07	0.00	0.00	0.01	-0.01
IDN	0.00	-0.19	-0.24	-0.01	0.00	0.01	0.00
IND	0.00	-0.30	-0.33	-0.01	0.01	0.00	-0.02
IRL	0.00	-0.10	-0.13	-0.03	0.01	0.02	0.01
IRN	0.00	-0.13	-0.16	0.00	0.01	-0.01	0.01
ISL	0.00	-0.23	-0.25	-0.01	0.02	-0.01	0.00
ISR	0.00	-0.38	-0.41	-0.02	0.02	0.00	0.01
ITA	0.00	-0.12	-0.15	-0.01	0.00	0.01	0.02
JOR	0.00	-0.28	-0.30	0.00	0.02	-0.02	-0.03
JPN	0.00	-0.35	-0.42	-0.01	-0.02	0.03	0.02
KEN	0.00	-0.22	-0.24	0.00	0.02	-0.02	-0.02
KOR	0.00	-0.41	-0.45	-0.02	-0.01	0.03	0.00
KWT	0.00	-0.23	-0.26	0.01	-0.01	0.00	0.00
LKA	0.00	-0.30	-0.33	-0.01	0.02	-0.01	-0.02
MAC	0.00	-0.21	-0.24	-0.05	0.02	0.03	0.00
MAR	0.00	-0.08	-0.10	0.00	0.00	0.00	1.32
MEX	56.65	41.64	43.51	3.81	-2.40	-1.52	-0.01
MLT	0.00	-0.13	-0.15	-0.02	0.01	0.01	0.01
MMR	0.00	-0.13	-0.18	0.00	0.01	-0.01	0.00
MUS	0.00	-0.06	-0.09	-0.01	0.01	0.00	0.01
MWI	0.00	-0.18	-0.19	-0.01	0.02	-0.01	-0.02
MYS	0.00	-0.22	-0.27	-0.03	0.01	0.03	-0.01
NER	0.00	-0.11	-0.13	-0.02	0.02	0.01	0.02
NGA	0.00	-0.37	-0.39	0.00	0.03	-0.03	-0.01

(Continued)

Table 4 (Continued)

Country	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	<i>Partial effect</i>	<i>Conditional GE</i>	<i>Full Endowment General Equilibrium</i>				
	% Δ exports	% exports	% Δ exports	% Δ real GDP	% Δ IMRs	% Δ OMRs	% Δ price
NLD	0.00	-0.07	-0.09	-0.01	0.00	0.01	0.00
NOR	0.00	-0.24	-0.25	-0.01	0.02	0.00	0.01
NPL	0.00	-0.22	-0.25	-0.01	0.02	-0.01	0.00
PAN	0.00	-0.60	-0.62	-0.02	0.03	0.00	-0.02
PHL	0.00	-0.29	-0.33	-0.03	0.01	0.02	0.00
POL	0.00	-0.05	-0.07	0.00	0.00	0.00	0.00
PRT	0.00	-0.06	-0.08	0.00	0.00	0.00	-0.01
QAT	0.00	-0.19	-0.22	-0.01	0.01	0.01	0.00
ROM	0.00	-0.08	-0.10	0.00	0.00	0.00	0.01
SEN	0.00	-0.08	-0.10	0.00	0.01	-0.01	-0.02
SGP	0.00	-0.15	-0.19	-0.03	0.01	0.02	-0.01
SWE	0.00	-0.11	-0.13	-0.01	0.00	0.01	-0.01
THA	0.00	-0.25	-0.29	-0.01	0.00	0.02	-0.06
TTO	0.00	-0.86	-0.88	-0.08	0.02	0.07	0.00
TUN	0.00	-0.04	-0.07	0.00	0.00	0.00	0.00
TUR	0.00	-0.14	-0.16	0.00	0.00	0.00	0.01
TZA	0.00	-0.16	-0.17	-0.01	0.02	-0.01	-0.01
URY	0.00	-0.42	-0.44	-0.02	0.01	0.01	0.15
USA	18.33	14.48	14.88	0.33	-0.18	-0.17	0.00
ZAF	0.00	-0.31	-0.34	-0.01	0.01	0.00	-0.01

Source: Authors' calculations

Notes: This table reports results of NAFTA counterfactual analysis. Column (1) reports the average partial equilibrium percentage changes in total exports of a country. The conditional general equilibrium (GE) scenario, reported in column (2) takes the direct and indirect trade cost changes into account but holds GDPs constant. The full endowment GE scenario, reported in columns (3) to (7), additionally takes general equilibrium income effects into account. In particular, column (3) reports the average percentage changes in total exports of a country, column (4) the average percentage changes in real GDP (which may be taken as a welfare measure), column (5) reports the average percentage changes in the inward multilateral resistances (IMRs), and column (6) the corresponding average outward multilateral resistances (OMRs). The last column, column (7), reports the average changes in producer prices. See text for further details.

D. Exercises

1. Calculating the general equilibrium impacts of removing a specific border

The aim of this exercise is to assess the general equilibrium impacts of the border between two countries of the reader's choice (e.g. countries A and B) within the framework developed in the chapter. This border removal scenario is hypothetical, especially given that the partial equilibrium border estimates obtained most probably capture more than just impediments to trade, such as preferences.

- (i) Select two countries (A and B) available in the sample of the data file "Chapter2Exercise1.dta", which share a common border and assume that the "direct/partial equilibrium" effect of the border between country A and country B is equal to the average border effect in the world. Use

and modify the STATA do-file associated with Application 1 on trade without borders in order to simulate the removal of the border between country A and country B **only**, while preserving all other borders in the world in place. Discuss the results in terms of effects on trade, real GDP, and effects on consumers and producers in each country.

Hint: Only the definition of the counterfactual scenario in Step II needs to be changed.

- (ii) Given the specific relationship between countries A and B, one may expect that the border between these two nations would be smaller or larger than the average border in the world. Modify the STATA code from part (1) in order to allow for a differential partial border effect between country A and country B. Are the expectations for a lower or larger border between countries A and B confirmed? What are the volume effects of the border?

Hint: The gravity model should be re-estimated with a new border variable for countries A and B.

- (iii) Use the new border estimates from part (2) to obtain the general equilibrium effects of the removal of the border between countries A and B. Discuss the results and compare them with those from part (1).

Hint: Change the definition of the counterfactual scenario in Step II.

- (iv) Some politicians believe that their country will benefit more if trading partners remove the impediments for this country's exports, while the country in question preserves its borders on imports from abroad. Use the partial estimates from part (2) to simulate a unilateral removal of the border for exports from country A to country B. Discuss the results relative to the estimates from part (3).

Hint: Change the definition of the counterfactual scenario in Step II.

2. Calculating the general equilibrium impacts of a regional trade agreement

The aim of this exercise is to re-assess the general equilibrium impact on trade of the formation of NAFTA. Unlike the Application 2 presented in the previous section, the assumption that the partial effects of an individual RTA are equal to the average effect of all RTAs entered into force in the sample during the period of investigation is removed. As a deep RTA with many provisions, NAFTA's effects were likely to be stronger than those of most other RTAs.

- (i) Following the above intuition, use and modify the STATA do-file associated with Application 2 in order to allow for specific partial effects of NAFTA. Did the results confirm the expectations for stronger effects for NAFTA as compared to the effects of all other RTAs?

Hint: The gravity model should be re-estimated with a separate RTA dummy for NAFTA.

- (ii) Use the NAFTA-specific estimates from part (1) to obtain general equilibrium effects of NAFTA. Discuss the results and compare them with the main estimates from Application 2.

Hint: Change the definition of the counterfactual scenario in Step II.

- (iii) Use and modify the STATA do-file in order to obtain the estimates from Application 2 to *ex ante* simulate the effects of a potential RTA of your choice by focusing on the last year in the sample.

Hint: Repeat steps (i) and (ii) above to obtain results for the agreement of your choice.

Appendices

Appendix A: Counterfactual analysis using supply-side gravity framework

In the demand-side model, the assumption of an endowment economy implies that the model can be closed by using the market clearing condition. Assuming an endowment economy is at odds with the supply side in the supply-side framework. However, it is still possible to close the model in a simple way for counterfactual analysis. Specifically, firms are assumed to produce a final good with one unit of the single production factor labour, i.e. $\zeta_i = w_i$.

Under this assumption, equation (1.A.8) of the structural gravity from the supply side (Eaton and Kortum, 2002) derived in Appendix A of Chapter 1 can be rewritten as:

$$T_i w_i^{-\theta} = \frac{Y_i}{\sum_{j=1}^N \frac{t_{ij}^{-\theta}}{\Phi_j} E_j} = \frac{\frac{Y_i}{Y}}{\sum_{j=1}^N \gamma^{-\theta} \left(\frac{t_{ij}}{P_j} \right)^{-\theta} \frac{E_j}{Y}} = \gamma^\theta \frac{Y_i}{Y} \Pi_i^\theta \quad (2.A.1)$$

Solving equation (2.A.1) for wages w_i yields:

$$w_i = \gamma^{-1} T_i^{\frac{1}{\theta}} \left(\frac{Y_i}{Y} \right)^{-\frac{1}{\theta}} \Pi_i^{-1} \quad (2.A.2)$$

Equation (2.A.2) replaces the expression for p_i in equation (2-4) in the structural gravity system derived from the demand side.

As labour is the only factor of production, equation (2-5) in the system derived from the demand side is replaced by:

$$Y_i = w_i L_i \quad (2.A.3)$$

Similar to the general equilibrium analysis in the demand-side model, counterfactuals are established under the assumption of exogenous trade imbalances, i.e. $E_i = \phi_i Y_i$, where $\phi_i > 1$ denotes a trade deficit in country i , and $0 < \phi_i < 1$ captures a trade surplus in country i .

Hence, the general equilibrium analysis using the structural gravity system derived from the supply side is given by:

$$X_{ij} = \frac{Y_i E_j}{Y} \left(\frac{t_{ij}}{\Pi_i P_j} \right)^{-\theta} \quad (2.A.4)$$

$$P_j^{-\theta} = \sum_{i=1}^N \left(\frac{t_{ij}}{\Pi_i} \right)^{-\theta} \frac{Y_i}{Y} \quad (2.A.5)$$

$$\Pi_i^{-\theta} = \sum_{j=1}^N \left(\frac{t_{ij}}{P_j} \right)^{-\theta} \frac{E_j}{Y} \quad (2.A.6)$$

$$w_i = \left(\frac{Y_i}{Y} \right)^{-\frac{1}{\theta}} \frac{T_i^{\frac{1}{\theta}}}{\gamma \Pi_i} \quad (2.A.7)$$

$$Y_i = w_i L_i \quad (2.A.8)$$

$$E_i = \varphi_i Y_i \quad (2.A.9)$$

It follows that the counterfactual change in total output can be computed as:

$$\frac{Y_i^{CFL}}{Y_i^{BLN}} = \frac{w_i^{CFL}}{w_i^{BLN}} = \frac{\gamma T_i^{\frac{1}{\theta}} \left(\frac{Y_i^{CFL}}{Y^{CFL}} \right)^{-\frac{1}{\theta}} (\Pi_i^{CFL})^{-1}}{\gamma T_i^{\frac{1}{\theta}} \left(\frac{Y_i^{BLN}}{Y^{BLN}} \right)^{-\frac{1}{\theta}} (\Pi_i^{BLN})^{-1}} = \frac{\left(\frac{Y_i^{CFL}}{Y^{CFL}} \right)^{-\frac{1}{\theta}} (\Pi_i^{CFL})^{-1}}{\left(\frac{Y_i^{BLN}}{Y^{BLN}} \right)^{-\frac{1}{\theta}} (\Pi_i^{BLN})^{-1}} \quad (2.A.10)$$

where the superscript *BLN* and *CFL* denotes the value in the baseline and counterfactual scenario, respectively.

Appendix B: Structural gravity with sectors

The objectives of this appendix are to demonstrate how the aggregate structural gravity model can be extended to the sectoral level, to compare the aggregate and the sectoral gravity system, to discuss implications of moving to the sectoral level, and to present and compare two sectoral versions of the structural gravity model; one on the demand side and one on the supply side. The derivation of the gravity on the demand side follows Larch and Wanner (2014) and Anderson and Yotov (2016), while the derivation of the gravity system on the supply side is based on Eaton and Kortum (2002). The interested reader may also refer to Costinot et al. (2012), Caliendo and Parro (2015) and Donaldson (2016).

Sectoral gravity on the demand side

Sectoral gravity on the demand side is obtained by extending the standard assumptions from Anderson (1979) to accommodate sectors. Specifically, the model considers many (K) goods, where, within each good's class $k \in K$, varieties are differentiated by place of origin as before. Similarly to the aggregate setting from the main analysis, the economy is defined in an endowment setting, but this time at the sectoral level:

$$Y_i^k = p_i^k Q_i^k \quad (2.B.1)$$

where, Q_i^k is the endowment of goods in class k in country i ; p_i^k is the corresponding factory-gate price, and Y_i^k is the sectoral income in country i . Finally, on the demand side, consumer preferences within each class of goods are assumed to be based on a constant elasticity of substitution (CES), as in the main analysis. However, this time the CES preferences across varieties within each class of goods are nested in a Cobb-Douglas utility function that reflects preference across different goods classes. As a result, for each country, the expenditure in each class of goods, E_i^k , is obtained as a constant share η^k of this country's total expenditure E_i :

$$E_i^k = \eta^k E_i = \eta^k \phi_i Y_i \quad (2.B.2)$$

where, as in the main analysis, the rightmost equality reflects the fact that national trade imbalances vary exogenously ($\phi_i \neq 1$). Solving the consumer optimization problem and imposing market clearing at delivered prices for each sector obtains the demand-side structural gravity system:

$$X_{ij}^k = \frac{Y_i^k E_j^k}{Y^k} \left(\frac{t_{ij}^k}{\Pi_i^k P_j^k} \right)^{1-\sigma_k} \quad (2.B.3)$$

$$(\Pi_i^k)^{1-\sigma_k} = \sum_j \left(\frac{t_{ij}^k}{P_j^k} \right)^{1-\sigma_k} \frac{E_j^k}{Y^k} \quad (2.B.4)$$

$$(P_j^k)^{1-\sigma_k} = \sum_i \left(\frac{t_{ij}^k}{\Pi_i^k} \right)^{1-\sigma_k} \frac{Y_i^k}{Y^k} \quad (2.B.5)$$

$$p_i^k = \left(\frac{Y_i^k}{Y^k} \right)^{\frac{1}{1-\sigma}} \frac{1}{\alpha_i^k \Pi_i^k} \quad (2.B.6)$$

$$E_i^k = \eta^k \varphi_i Y_i \quad (2.B.7)$$

$$Y_i = \sum_k Y_i^k = \sum_k p_i^k Q_i^k \quad (2.B.8)$$

$$Y^k = \sum_i Y_i^k = \sum_i p_i^k Q_i^k \quad (2.B.9)$$

The sectoral system (2.B.3)-(2.B.9) is remarkably similar to the aggregate structural gravity system (2-1)-(2-5). In fact, from an expositional perspective, the only difference between the two gravity systems is the addition of the superscript and subscript “ k ” in the sectoral system (2.B.3)-(2.B.9), the addition of the expenditure share η^k in the sectoral system in equation (2.B.7), and the addition of the adding up expression for the total value of output in a country in equation (2.B.8) as well as for the total value of output in a sector in the world in equation (2.B.9). One nice implication of this result is the so-called “separability” property of structural gravity, that is, the gravity system holds separately for each sector. From an estimation perspective, two important implications of the sectoral gravity system have to be highlighted:

- (i) The gravity equation can be estimated for each sector using exactly the same estimation techniques and best practice estimation approaches that apply to aggregate data discussed in Chapter 1.
- (ii) If the gravity model is estimated with data pooled across sectors, then the exporter and the importer fixed effects that are used to account for the multilateral resistances should also vary by sector. In other words, the gravity model should control for *exporter-sector* and *importer-sector* fixed effects.

The most important difference between the sectoral system (2.B.3)-(2.B.9) and the aggregate gravity system (2-1)-(2-5) is that the latter captures intersectoral linkages that arise on the demand side, i.e. due to the substitutability of goods across goods classes. The intuition is that in the sectoral setting consumers substitute not only varieties within each class of goods, but they also substitute goods from different classes with each other. The main implication of this result is that a change in trade costs between any given pair of countries in the world or in any given sector may potentially affect prices in all other sectors and in all other countries in the world. These links are captured by the system of market clearing conditions (2.B.6), which can be rewritten using the definitions of income, expenditure, and the multilateral resistances as follows:

$$\frac{p_i^k Q_i^k}{\sum_i p_i^k Q_i^k} = \sum_j \frac{(\alpha_i^k p_i^k t_{ij}^k)^{1-\sigma_k}}{\sum_i (\alpha_i^k p_i^k t_{ij}^k)^{1-\sigma_k}} \times \frac{\eta^k \varphi_j \sum_k p_j^k Q_j^k}{\sum_i p_i^k Q_i^k} \quad \forall i, k \quad (2.B.10)$$

The system (2.B.10) consists of $N \times K$ equations in $N \times K$ unknown p_i^k . However, similar to the aggregate gravity system, the sectoral gravity system can only be solved subject to normalisation for each sector because the system is homogeneous of degree zero in the vector of factory-gate prices. Anderson and Yotov (2016) propose and impose a natural normalisation by holding world real resources constant:

$$\sum_{i,k} p_i^k a_i^k = \sum_{i,k} p_i^{k_0} a_i^k = \sum_{i,k} Y_i^{k_0} \quad \forall i,k \quad (2.B.11)$$

Subject to this normalisation, the system (2.B.10) would deliver a unique vector of changes in factory-gate prices in response to a given change in sectoral bilateral trade costs. Importantly, it is clear from system (2.B.10) that a change in any possible sector-pair trade costs t_{ij}^k will result in factory-gate price changes in all countries and all sectors in the world.

(a) Sectoral gravity from the supply side

Following the Appendix A of Chapter 1, which presents the derivation of the structural gravity framework at the aggregate level from the supply side, the aggregate structural gravity system is extended to the sectoral level by modifying some of the standard assumptions, as for example suggested by Eaton and Kortum (2002).

For each sector k , consumer preferences are still assumed to be homothetic, globally common/identical across countries, and approximated by a CES utility function:

$$U_j^k = \left[\int_0^1 c^{k,l} (l)^{\frac{\sigma_k-1}{\sigma_k}} dl \right]^{\frac{\sigma_k}{\sigma_k-1}} \quad (2.B.12)$$

where j denotes the country and σ_k is the sector-specific elasticity of substitution among different varieties $l \in [0,1]$ of sector k . As for the sectoral demand-side derivation, goods from different sectors are combined by a Cobb-Douglas utility function that reflects preference across different goods classes. As a result, for each country, the expenditure in each class of goods, E_i^k , is obtained as a constant share η^k of this country's total expenditure E_i :

$$E_i^k = \eta_k E_i = \eta_k \varphi_i Y_i \quad (2.B.13)$$

Now it holds in each sector that with constant returns to scale the cost of producing a unit of good l in sector k in country i is $\varsigma_i^k / z_i^k(l)$, with ς_i^k denoting the input costs in sector k in country i . Taking iceberg trade costs into account, delivering a unit of good l of sector k produced in country i to country j costs:

$$p_{ij}^k(l) = \left(\frac{\varsigma_i^k}{z_i^k(l)} \right) t_{ij}^k \quad (2.B.14)$$

Keeping all other assumptions on the supply side for each sector k , similar steps to derive the lowest price across all sources, the distribution of prices, and exact price index leads to the following expression for the fraction of its expenditures on goods in sector k from country i , X_{ij}^k :

$$X_{ij}^k = \frac{T_i^k (\varsigma_i^k t_{ij}^k)^{-\theta_k}}{\Phi_j^k} E_j^k = \frac{T_i^k (\varsigma_i^k t_{ij}^k)^{-\theta_k}}{\sum_{i=1}^N T_i^k (\varsigma_i^k t_{ij}^k)^{-\theta_k}} E_j^k \quad (2.B.15)$$

Using market clearance, the expressions for the multilateral resistance terms can be derived at the sectoral level. As in the aggregate case, the sectoral supply-side model is closed in a simple way for counterfactual analysis by assuming that there is a single factor of production, labour, where one unit of labour can produce one unit of output in each sector k , such that $\varsigma_i^k = w_i^k$. Accordingly, the market-clearing condition can be expressed as follows:

$$T_i^k (w_i^k)^{-\theta_k} = \frac{Y_i^k}{\sum_{j=1}^N \frac{(t_{ij}^k)^{-\theta_k}}{\Phi_j^k} E_j^k} = \frac{\frac{Y_i^k}{Y^k}}{\sum_{j=1}^N (\gamma^k)^{-\theta_k} \left(\frac{t_{ij}^k}{P_j^k} \right)^{-\theta_k} \frac{E_j^k}{Y^k}} = (\gamma^k)^{\theta_k} \frac{Y_i^k}{Y^k} (\Pi_i^k)^{\theta_k} \quad (2.B.16)$$

The sectoral gravity system derived from the supply side can then be written as:

$$X_{ij}^k = \frac{Y_i^k E_j^k}{Y^k} \left(\frac{t_{ij}^k}{\Pi_i^k P_j^k} \right)^{-\theta_k} \quad (2.B.17)$$

$$(\Pi_i^k)^{-\theta_k} = \sum_{j=1}^N \left(\frac{t_{ij}^k}{P_j^k} \right)^{-\theta_k} \frac{E_j^k}{Y^k} \quad (2.B.18)$$

$$(P_j^k)^{-\theta_k} = \sum_{i=1}^N \left(\frac{t_{ij}^k}{\Pi_i^k} \right)^{-\theta_k} \frac{Y_i^k}{Y^k} \quad (2.B.19)$$

$$w_i^k = \left(\frac{Y_i^k}{Y^k} \right)^{-\frac{1}{\theta_k}} \frac{(T_i^k)^{\theta_k}}{\gamma^k \Pi_i^k} \quad (2.B.20)$$

$$E_i^k = \eta_k \varphi_i Y_i \quad (2.B.21)$$

$$Y_i = \sum_k Y_i^k = \sum_k w_i^k L_i^k \quad (2.B.22)$$

$$Y^k = \sum_i Y_i^k = \sum_i w_i^k L_i^k \quad (2.B.23)$$

Hence, the aggregate structural gravity system described in Appendix A of Chapter 1 readily extends to the sectoral level. It also compares directly with the demand-side sectoral gravity system given by the system (2.B.3)-(2.B.9), with the only notable change of replacing $1-\sigma_k$ by $-\theta_k$.

In the aggregate case, equation (2.B.20) was used to solve for wages. However, in a sector-setting, there is one such condition for each sector k . Unlike the aggregate model, there is not only one total labour supply L_i , but also sectoral labour allocations that have to be determined. Following Eaton and Kortum (2002), two cases can be considered to close the model: (1) labour is sectoral and internationally immobile; and (2) labour is mobile across sectors but not across countries.

Immobile labour

The case of immobile labour is close to the assumption of sectoral given endowments made in the derivation of the demand-side sectoral model as sectoral labour allocations L_i^k are assumed to be exogenous. Equation (2.B.16) can be used together with the fact that the value of output in sector k of country i can be written as $Y_i^k = w_i^k L_i^k$ to obtain an expression for w_i^k :

$$\frac{w_i^k L_i^k}{\sum_i w_i^k L_i^k} = \frac{T_i^k (w_i^k)^{-\theta_k}}{(\gamma^k)^{\theta_k} (\Pi_i^k)^{\theta_k}} \quad (2.B.24)$$

Replacing Π_i^k by its definition and F_j^k by the expression $\left((\gamma^k)^{-\theta_k} \sum_{i=1}^N T_i^k (w_i^k t_{ij}^k)^{-\theta_k} \right)^{\frac{1}{\theta_k}}$, equation (2.B.24) can be rewritten as:

$$\begin{aligned} \frac{w_i^k L_i^k}{\sum_i w_i^k L_i^k} &= \frac{T_i^k (w_i^k)^{-\theta_k}}{(\gamma^k)^{\theta_k}} \left(\frac{\sum_{j=1}^N \frac{(t_{ij}^k)^{-\theta_k}}{(\gamma^k)^{-\theta_k} \sum_{i=1}^N T_i^k (w_i^k t_{ij}^k)^{-\theta_k}} \times \frac{\eta^k \varphi_j \sum_k w_j^k L_j^k}{\sum_i w_i^k L_i^k}}{\sum_{j=1}^N \frac{T_j^k (w_j^k t_{ij}^k)^{-\theta_k}}{(\gamma^k)^{-\theta_k} \sum_{i=1}^N T_i^k (w_i^k t_{ij}^k)^{-\theta_k}} \times \frac{\eta^k \varphi_j \sum_k w_j^k L_j^k}{\sum_i w_i^k L_i^k}} \right) \\ &= \left(\frac{\sum_{j=1}^N \frac{T_j^k (w_j^k t_{ij}^k)^{-\theta_k}}{(\gamma^k)^{-\theta_k} \sum_{i=1}^N T_i^k (w_i^k t_{ij}^k)^{-\theta_k}} \times \frac{\eta^k \varphi_j \sum_k w_j^k L_j^k}{\sum_i w_i^k L_i^k}}{\sum_{j=1}^N \frac{T_j^k (w_j^k t_{ij}^k)^{-\theta_k}}{(\gamma^k)^{-\theta_k} \sum_{i=1}^N T_i^k (w_i^k t_{ij}^k)^{-\theta_k}} \times \frac{\eta^k \varphi_j \sum_k w_j^k L_j^k}{\sum_i w_i^k L_i^k}} \right) \end{aligned} \quad (2.B.25)$$

These $N \times K$ market-clearing conditions solve for the $N \times K$ sectoral wages w_i^k . Note that this equation resembles equation (2.B.10) from the demand-side. Similarly, a numeraire for each sector has to be defined. With the same corresponding parameter values, the results under this scenario will be identical to the results from the endowment, demand-side model.

Mobile labour

The case of perfectly mobile labour across sectors implies a common wage across sectors in country i w_i , and endogenous sectoral labour allocations L_i^k . Taking the same steps as before, the same equation (2.B.25) is derived. As in the case of immobile labour only the total labour endowment in a country is given. In addition, the additional constraint $L_i = \sum_k L_i^k$ implies that $K-1$ sectoral labour allocations in each country have to be solved for by using equation (2.B.25). For the remaining sector, equation (2.B.25) can be used to solve for wages w_i . Note that this equation, which requires defining a numeraire for each sector, resembles equation (2.B.10) from the demand-side, even though the counterfactual results under the assumption of mobile labour will differ from those in the endowment setting.

Appendix C: Structural gravity system in changes

The gravity system given by equations (2-1)-(2-5) can also be written and expressed in changes, referred to as the *exact hat algebra* (Dekle et al., 2007, 2008). In deriving the system in changes, the objective is to stick as close as possible to equations (2-1)-(2-5), and specifically also keep the multi-lateral resistance terms. Doing so, however, shows that information about baseline trade costs is used when formulating the system in changes. Dekle et al. (2007, 2008) use observed trade flows to formulate the system in changes in terms of trade shares. In this case, only changes of trade costs, but not baseline levels of trade costs for solving the counterfactual values are necessary.

Let baseline and counterfactual values be denoted with a superscript *BLN* and *CFL*, respectively. The change for any variable Z is defined as $\tilde{Z} = Z^{CFL}/Z^{BLN}$. Given the multiplicative nature of the trade flow equation (2-1), the change in bilateral trade flow can be computed by dividing the counterfactual values by the baseline values:

$$\tilde{X}_{ij} = \frac{\tilde{Y}\tilde{E}_j}{\tilde{Y}} \left(\frac{\tilde{t}_{ij}}{\tilde{\Pi}_i\tilde{P}_j} \right)^{1-\sigma}$$

Note that typically \tilde{t}_{ij} defines the counterfactual scenario of interest. For example, if the objective is to evaluate the trade and welfare effects of a given RTA, the *RTA* dummy would be set to zero for the countries that are party to the RTA, defining t_{ij}^{CFL} . Hence, \tilde{t}_{ij} is exogenously given.

Using equation (2-2) and the fact that $\tilde{X}X^{BLN} = X^{CFL}$, the change in outward multilateral resistances is given by:

$$\left(\Pi_i^{BLN}\right)^{1-\sigma} \tilde{\Pi}_i^{1-\sigma} = \sum_{j=1}^N \left(\frac{t_{ij}^{BLN}\tilde{t}_{ij}}{P_j^{BLN}\tilde{P}_j} \right)^{1-\sigma} \frac{E_j^{BLN}\tilde{E}_j}{Y^{BLN}\tilde{Y}}$$

Similarly, using equation (2-3), the change in inward multilateral resistances is expressed as:

$$\left(P_j^{BLN}\right)^{1-\sigma} \tilde{P}_j^{1-\sigma} = \sum_{i=1}^N \left(\frac{t_{ij}^{BLN}\tilde{t}_{ij}}{\Pi_i^{BLN}\tilde{\Pi}_i} \right)^{1-\sigma} \frac{Y_i^{BLN}\tilde{Y}_i}{Y^{BLN}\tilde{Y}}$$

Using equation (2-4) the changes of factory-gate prices is given by:

$$\tilde{p}_i = \frac{(\tilde{Y}_i/\tilde{Y})^{1-\sigma}}{\tilde{\Pi}_i}$$

where

$$\tilde{Y} = \frac{\sum_{i=1}^N Y_i^{CFL}}{\sum_{i=1}^N Y_i^{BLN}} \quad \longrightarrow \quad Y^{BLN}\tilde{Y} = \sum_{i=1}^N Y_i^{BLN}\tilde{Y}_i$$

Since endowments are assumed to remain constant, equation (2-5) can be used to express the change in total nominal output for country i as:

$$\tilde{Y}_i = \tilde{p}_i = \frac{(\tilde{Y}_i/\tilde{Y})^{1-\sigma}}{\tilde{\Pi}_i}$$

In addition, total nominal output changes and total spending changes are linked as follows:

$$\tilde{E}_i = \tilde{\varphi}_i \tilde{Y}_i$$

where $\tilde{\varphi}_i$ are the exogenous changes in the trade imbalances of country i .

Hence, the structural gravity system in changes is given by the following set of equations:

$$\tilde{X}_{ij} = \frac{\tilde{Y}_i \tilde{E}_j}{\tilde{Y}} \left(\frac{\tilde{t}_{ij}}{\tilde{\Pi}_i \tilde{P}_j} \right)^{1-\sigma} \quad (2.C. 1)$$

$$(\Pi_i^{BLN})^{1-\sigma} \tilde{\Pi}_i^{1-\sigma} = \sum_{j=1}^N \left(\frac{t_{ij}^{BLN} \tilde{t}_{ij}}{P_j^{BLN} \tilde{P}_j} \right)^{1-\sigma} \frac{E_j^{BLN} \tilde{E}_j}{Y^{BLN} \tilde{Y}} \quad (2.C. 2)$$

$$(P_j^{BLN})^{1-\sigma} \tilde{P}_j^{1-\sigma} = \sum_{i=1}^N \left(\frac{t_{ij}^{BLN} \tilde{t}_{ij}}{\Pi_i^{BLN} \tilde{\Pi}_i} \right)^{1-\sigma} \frac{Y_i^{BLN} \tilde{Y}_i}{Y^{BLN} \tilde{Y}} \quad (2.C. 3)$$

$$\tilde{p}_i = \frac{(\tilde{Y}_i/\tilde{Y})^{1-\sigma}}{\tilde{\Pi}_i} \quad (2.C. 4)$$

$$Y^{BLN} \tilde{Y} = \sum_{i=1}^N Y_i^{BLN} \tilde{Y}_i \quad (2.C. 5)$$

$$\tilde{Y}_i = \tilde{p}_i \quad (2.C. 6)$$

$$\tilde{E}_i = \tilde{\varphi}_i \tilde{Y}_i \quad (2.C. 7)$$

This system requires only data on total nominal output (Y_i^{BLN}), total spending (E_i^{BLN}), and trade costs (t_{ij}^{BLN}) in the baseline, and a value for the elasticity of substitution σ . Specifically, information about the constant elasticity of substitution preference parameter α_i is not needed. With given nominal output, expenditures, and trade costs, the baseline Π_i^{BLN} and P_j^{BLN} can also be recovered. Hence, the structural gravity system in changes is readily solvable, since the system involves seven equations with seven unknown changes \tilde{X}_{ij} , $\tilde{\Pi}_i$, \tilde{P}_j , \tilde{p}_i , \tilde{Y} , \tilde{Y}_i , and \tilde{E}_i .

Endnotes

- 1 This chapter is based on the paper “General Equilibrium Trade Policy Analysis with Structural Gravity” prepared by Larch and Yotov (2016a).
- 2 If the actual set of bilateral trade costs is replaced by $\tilde{\tau}_{ij} = \Pi_i P_j$, all budget constraints and market clearance conditions continue to hold, and factory-gate prices and supply and expenditure shares remain constant. Thus, the multilateral resistances can be thought of as the general equilibrium similar to a tax incidence decomposition. The interested reader may refer to Anderson and van Wincoop (2004) for a related discussion.
- 3 No explicit normalisation is needed in the less realistic case with symmetric trade costs and balanced trade. In this case the multilateral resistances system collapses to a system of N equations under the implicit normalisation $P_j \equiv \Pi_j$.
- 4 Alvarez and Lucas, Jr. (2007) and Allen et al. (2014) have established the uniqueness of the equilibria in the structural gravity system presented here.
- 5 Note that these channels are defined slightly differently than in Head and Mayer (2014): the “direct/partial equilibrium” channel corresponds to the “partial trade impact” (PTI); the “conditional general equilibrium” corresponds to the “modular trade impact” (MTI); and the “full endowment general equilibrium” corresponds to the “general equilibrium trade impact” (GETI). The names of the channels are different in this *Advanced Guide* to highlight the fact that the analysis does not only apply to trade, but also to output, expenditure, prices, and welfare.
- 6 In order to see this point, the system of equations (2-2)-(2-5) can be expressed only in terms of factory-gate prices as the only endogenous variable by applying the definitions of the multilateral resistances. Thus, the multilateral resistance system collapses to a system of N equations in N unknowns, which can translate any change in bilateral trade costs directly into a change in factory-gate prices (Balistreri and Hillberry, 2007; Balistreri and Hillberry, 2008). Moreover, in combination with the (exogenous) change in bilateral trade costs, the change in factory-gate price is sufficient to construct a unique corresponding set of changes in inward and outward multilateral resistances.
- 7 Equation (2-12) departs from the standard linear law of motion for capital accumulation. However, a great advantage of this functional form is that it delivers a closed-form solution for the transition path of capital accumulation, which is extremely convenient for analysis and decomposition of the general equilibrium effects of trade policy. Anderson et al. (2015c; 2016a) discuss the empirical implications of the assumption of log-linear capital accumulation specification. More importantly, Anderson et al. (2015c; 2016a) demonstrate that the only difference between the dynamic gravity system presented here and the one with linear capital accumulation is that the closed-form solution for capital accumulation presented below will be replaced by a standard Euler equation, with no implications for the baseline structural gravity system.
- 8 Two *CTB*-related indexes have been proposed in the literature (Anderson et al., 2014). The *constructed foreign bias (CFB)* index is defined as the predicted volume of international export trade relative to the hypothetical frictionless volume of trade. The *constructed domestic bias (CDB)* index corresponds to the ratio of fitted to frictionless intra-national trade, excluding trade within sub-regions in a country. The *CFB* index may be particularly useful to assess the effects of trade policy on international trade, while the *CDB* index can be used to evaluate the intra-national effects of trade policy.
- 9 The different models considered by Arkolakis et al. (2012) share four main assumptions including (i) Dixit-Stiglitz preferences; (ii) one factor of production; (iii) linear cost functions; and (iv) perfect or monopolistic competition. In addition, the following macro-level conditions must be satisfied: (i) balanced trade; (ii) aggregate profits representing a constant share of aggregate revenues; and (iii) the import demand system is CES.
- 10 Among a universe of general equilibrium models that calibrate and simulate trade, the following are notable examples that all feature actual gravity estimations that accompany their counterfactual analysis: Anderson and Yotov (2010b); Egger and Larch (2011); Egger et al. (2011); Ossa (2011); Fieler (2011); Costinot et al. (2012); Behrens et al. (2014); Eaton et al. (2013); Arkolakis et al. (2013); Allen et al. (2014); Felbermayr et al. (2015); Heid (2015); Caliendo and Parro (2015); and Heid and Larch (2016).
- 11 Although it is possible that despite best efforts to capture all possible drivers of trade frictions, the error term in the gravity estimations may still contain some systematic information about trade costs, the assumption of stochastic errors does not seem too strong in structural gravity estimations in the presence of a rich structure of fixed effects (i.e. directional time-varying fixed effects and pair fixed effects).

- 12 The interested reader may refer to Anderson and Yotov (2010b); Aichele et al. (2014); Larch and Wanner (2014); and Anderson and Yotov (2016), who construct confidence intervals for specific general equilibrium effects of trade policy. In principle, the approach from Anderson et al. (2015b) may be used to deliver standard errors for general equilibrium effects directly from the estimates of the gravity fixed effects. In addition, only recently the consistency of the model parameter estimates in nonlinear panel models with two types of fixed effects has been shown by Fernández-Valz and Weidner (2016). Hence, exploring the possibility to construct standard errors from the gravity directional fixed effects is an interesting future research area.
- 13 Although specification (2-43) looks very similar to the *exact hat algebra* procedures from Dekle et al. (2008), the changes in the factory-gate prices implied by equation (2-43) do not capture the full endowment general equilibrium changes, because they only reflect the conditional outward multilateral resistances without allowing immediate changes in the value of output. That is why these initial changes in the factory-gate prices are labelled *first-order*.
- 14 According to the results based on a perfect competition framework with intermediates reported in Table 4.1 in Costinot and Rodriguez-Clare (2014), the welfare gains for the United States are obtained to be 8.3 percent, which is very close to the value of the potential gains from the removal of borders calculated at 10.6 percent. Similarly, the welfare increase for Germany calculated to be 21.3 percent is relatively similar to the 24.3 percent in welfare gains associated with the removal of international borders.
- 15 Recent studies that evaluate the effects of NAFTA include Shikher (2012), Rolfeigh (2013), Zylkin (2014), Anderson et al. (2015c, 2016a) and Caliendo and Parro (2015). Earlier examples include Kehoe (2003), Lederman et al. (2005), Trefler (2004), and Romalis (2007). Finally, NAFTA has been the object of interest of a series of papers in the computational general equilibrium literature from the nineties (Brown et al., 1992a, 1992b; McCleery, 1992; Klein and Salvatore, 1995; Fox, 1999; Krueger, 1999).
- 16 This experiment follows the top-down approach of Felbermayr et al. (2015) and Anderson and Yotov (2016) and makes the implicit assumption that the effect of NAFTA is equal to the average effect of the RTAs from the period of investigation. This approach has the advantage of being easy to implement and of capturing additional non-tariff barriers to trade without requiring additional data. However, it could potentially under- or over-estimate the effects of NAFTA. If NAFTA goes deeper than the average agreement, the effect will be underestimated, while it will lead to an overestimation of the effects of NAFTA if the easy barriers to trade have already been eliminated (such as huge tariffs). An alternative approach, which is the object of an exercise in the next section, is to obtain a specific estimate of the RTA under investigation by introducing an additional indicator covariate for NAFTA in the gravity specification and then using the estimate of NAFTA dummy to obtain the general equilibrium effects (Zylkin, 2014; Baier et al., 2016).
- 17 Note that in order to perform the conditional and the full endowment general equilibrium analysis, only data for one base year is needed. In principle, it is possible to estimate phasing-in effects of NAFTA, which will vary over time, and then use the full panel dimension of the sample in order to obtain the general equilibrium effects that correspond to the partial equilibrium phasing-in indexes in each year.
- 18 It should be noted that the analysis presented here does not take into account the effects of the original RTA between Canada and the United States from the late eighties.