Welfare Implications of Solving the Distance Puzzle: Global Evidence from the Last Two Centuries*

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Abstract

This paper theoretically shows that changes in the distance elasticity of trade can be connected to welfare changes that depend on bilateral distance measures and expenditure shares of countries. Empirical results based on international and domestic trade data from the last two centuries show that the negative effects of distance on trade have increased over time when zero trade observations are ignored in inconsistent OLS estimations, confirming the distance puzzle in the literature. The corresponding welfare implications suggest that the world economy has experienced a cumulative welfare loss (about 81%) due to this puzzle in the last two centuries. When the puzzle is solved by considering zero trade observations in PPML estimations, the tables turn such that there are significant welfare gains from trade (about 58%) during the same period due to the decreasing negative effects of distance on trade over time. Welfare gains from further reductions in the negative effects of distance are investigated as well, suggesting significant potential gains from trade in the future.

JEL Classification: F13, F14, F63

Key Words: Welfare Gains from Trade; Distance Elasticity of Trade; Global Welfare

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Abstract

This paper theoretically shows that changes in the distance elasticity of trade can be connected to welfare changes that depend on bilateral distance measures and expenditure shares of countries. Empirical results based on international and domestic trade data from the last two centuries show that the negative effects of distance on trade have increased over time when zero trade observations are ignored in inconsistent OLS estimations, confirming the distance puzzle in the literature. The corresponding welfare implications suggest that the world economy has experienced a cumulative welfare loss (about 81%) due to this puzzle in the last two centuries. When the puzzle is solved by considering zero trade observations in PPML estimations, the tables turn such that there are significant welfare gains from trade (about 58%) during the same period due to the decreasing negative effects of distance on trade over time. Welfare gains from further reductions in the negative effects of distance are investigated as well, suggesting significant potential gains from trade in the future.

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1 Introduction

The negative effects of distance on trade are shown to increase over time in standard gravity regressions, which is against the expectations due to decreasing costs of transportation and communication (e.g., see Hummels (2007) who has shown evidence for decreasing ad valorem freight rates over time). The so-called "distance puzzle" has been investigated extensively in the literature, where several explanations have been offered, including information barriers as in Portes and Rey (2005), augmented trade barriers as in Brun, Carrère, Guillaumont, and De Melo (2005), the role of nontradables as in Engel (2002), marginal costs of transportation as in Estevadeordal, Frantz, and Taylor (2003), the composition of trade as in Berthelon and Freund (2008), zero-trade observations as in Felbermayr and Kohler (2006), trading propensities of entrants as in Head, Mayer, and Ries (2009), domestic versus international integration of markets as in Yotov (2012) or nonhomothetic preferences as in Yilmazkuday (2017). Nevertheless, none of these studies have investigated the welfare implications of the distance puzzle before and after it is solved.

This paper focuses on the welfare implications of the distance puzzle by considering the implications of a standard trade model *à la* Armington (1969). Theoretically, it is shown that changes in the distance elasticity of trade can be connected to the changes in welfare by using bilateral distance measures and bilateral expenditure shares across countries. When international trade is considered together with domestic trade, the changes in welfare can further be decomposed into those due to international versus domestic trade. This is similar to Yotov (2012) who has shown that considering domestic versus international integration of markets can be a solution to the distance puzzle.

In this framework, it is shown that the share of international trade in welfare gains (within overall welfare gains, including those due to domestic trade) can simply be calculated by using distance measures and bilateral expenditure shares of countries, without any formal

estimation (of the distance elasticity of trade). The corresponding empirical results based on the period between 1827 and 2014 reveal that the share of international trade in overall welfare gains of the world has increased from about 1% back in 1820s to about 6% in 2014, suggesting that distance-reducing effects of globalization have increased about 6 times over the last two centuries. Regarding sub-periods, the share of international trade has increased continuously for several countries during the 19th century, confirming the first era of globalization as in studies such as by Bairoch (1974) or Jacks, Meissner, and Novy (2011); this share has increased more during the first than during the second half of the 19th century, also consistent with studies such as by Uebele (2011) who has shown that globalization has accelerated faster in the first than in the second half of the 19th century. After the disruption and volatilities in trade due to the interwar period, the share of international trade has continued increasing in the world, confirming the second era of globalization as in studies such as by Hummels (2007).

The next focus is on the level of historical changes in welfare due to distance effects, which requires estimation of the distance elasticity of trade. When trade implications of the model are estimated in a log-linear based on Ordinary Least Squares (OLS) regression by using data on international and domestic trade (where zero-trade observations are ignored by construction), the distance puzzle is confirmed. In particular, according to the OLS results, the distance elasticity of trade estimates are shown to decrease from about 1.8 in 1820s to about 1.2 in 1960s and increase to about 2.1 as of 2014. When these estimates are further combined with distance measures and bilateral expenditure shares of countries to investigate the welfare implications, it is shown that the world economy has a cumulative welfare loss of about 81% due to the distance puzzle in the last two centuries.

Since OLS estimations are problematic not only due to their inconsistency but also due to zero trade observations being ignored in such estimations, the distance puzzle is solved when zero-trade observations are included (as in Felbermayr and Kohler (2006)) in a Pseudo-

Poisson Maximum Likelihood (PPML) regression by using data on international and domestic trade. Specifically, according to PPML results based on the very same trade data, the distance elasticity of trade estimates are shown to decrease from about 3.4 in 1820s to about 2.6 in 1960s and to about 2.1 as of 2014. The corresponding welfare implications suggest that the world economy has a cumulative welfare gain of about 58% due to reductions in the negative effects of distance on trade over time.

Due to the way that countries are aggregated in the theoretical model *à la* Armington (1969), this paper is closest to the study by Yilmazkuday (2020) who has decomposed the welfare gains from *international* trade into those related to each gravity variable by considering distance interval measures as in Eaton and Kortum (2002). Nevertheless, we deviate from this paper in several aspects. First, we focus on the effects of a change in the distance elasticity of trade over time; this allows us to investigate the welfare implications of the distance puzzle. Second, since domestic versus international integration of markets has important implications for the distance puzzle as suggested by Yotov (2012), we distinguish between welfare changes due to *domestic* trade versus *international* trade. Third, we focus on cumulative welfare gains from trade due to changes in the effects of distance on trade by using a data set that covers the last two centuries.

The rest of the paper is organized as follows. The next section provides a theoretical motivation for the empirical investigation. Section 3 introduces the estimation methodology and the data used. Section 4 discusses the effects of distance on welfare over time. Section 5 concludes. Country-specific results are given in the Appendix.

2 Theoretical Motivation

We utilize an N-country trade model *à la* Armington (1969) based on endowments. Welfare is measured by per capita consumption in each country. Aggregation across countries is achieved by using population and income shares of countries.

2.1 Model

This subsection depicts the details of the model that closely follows Yilmazkuday (2020). The objective of the model is to connect the effects of distance to the welfare gains from trade.

2.1.1 Economic Environment

The utility of a representative individual in country n at time t is given by the following function:

$$C_{nt} = \left(\sum_i (\alpha_{int})^{\frac{1}{\eta}} (C_{int})^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}} \tag{1}$$

where C_{int} represents the goods imported from country i, and α_{int} represents preferences toward such goods. Based on the budget constraint of $\sum_i P_{int} C_{int} = E_{nt}$, where P_{int} is the price of C_{int}, and E_{nt} represents per capita gross domestic income (GDI), the optimization results in the following value of imports from country i:

$$P_{int} C_{int} = \alpha_{int} \left(\frac{P_{int}}{P_{nt}} \right)^{1-\eta} P_{nt} C_{nt} \tag{2}$$

where P_{nt} is the price of C_{nt} given by:

$$P_{nt} = \left(\sum_i \alpha_{int} (P_{int})^{1-\eta} \right)^{\frac{1}{1-\eta}} \tag{3}$$

Per capita GDI in country n is further given by:

$$E_{nt} = Y_{nt} P_{nnt} \tag{4}$$

where Y_{nt} represents the per capita endowment of a distinct good, and P_{nnt} is the source price of that good. Finally, trade is subject to (iceberg) trade costs that satisfy:

$$P_{int} = \tau_{int} P_{iit} \tag{5}$$

where $\tau_{int} > 1$ is the gross trade cost from source country i to destination country n at time t, and P_{iit} is the source price.

Taking the log of Equation 2 and combining it with the log version of Equation 5 result in the following trade expression for estimation purposes:

$$\underbrace{\log\left(P_{int} C_{int}\right)}_{\text{Bilateral Imports}} = \underbrace{\log \alpha_{int}}_{\text{Preferences}} - \underbrace{(\eta - 1)\,\tau_{int}}_{\text{Trade Costs}} - \underbrace{(\eta - 1)\log\left(P_{iit}\right)}_{\text{Source-Time Fixed Effects}} + \underbrace{\log\left(\left(P_{nt}\right)^{\eta} C_{nt}\right)}_{\text{Destination-Time Fixed Effects}} \tag{6}$$

where the left hand side represents log bilateral imports, whereas right hand side includes variables that are the standard in trade regressions.

2.1.2 Aggregation across Countries

The utility of a representative individual in the world economy is given by the following function:

$$C_t \equiv \prod_i \left(\pi_{it} C_{it}\right)^{\gamma_{nt}} \tag{7}$$

where $\pi_{it} = \frac{H_{it}}{H_t}$ is the population share of country i in the world at time t, with H_{it} and H_t representing country-i and world populations at time t, respectively.

The optimization of a world social planner results in the following expression:

$$\underbrace{H_{nt}P_{nt}C_{nt}}_{\text{GDI of country } n} = \underbrace{\gamma_{nt}}_{\text{Income Share}} \underbrace{\sum_{i} H_{it}P_{it}C_{it}}_{\text{World GDI}} \tag{8}$$

where γ_{nt} is implied as the income share of country n at time t. The GDI per capita ratio between countries n and i is implied as follows:

$$\frac{E_{nt}}{E_{it}} = \frac{\gamma_{nt}\pi_{it}}{\gamma_{it}\pi_{nt}} \tag{9}$$

where the implications of the budget constraint are used.

2.2 The Gains from Trade

Welfare in country n is measured by C_{nt} at time t, which can be written as $C_{nt} = E_{nt}/P_{nt}$ according to the budget constraint. Using Equation 4, it is implied that:

$$C_{nt} = \frac{Y_{nt}P_{nnt}}{P_{nt}} \tag{10}$$

which can be rewritten by using Equation 2 as follows:

$$C_{nt} = Y_{nt}\left(\frac{1}{\alpha_{nnt}}\left(\frac{P_{nnt}C_{nnt}}{P_{nt}C_{nt}}\right)\right)^{\frac{1}{1-\eta}} \tag{11}$$

The changes in welfare can be measured by taking the total derivative of this expression in its log form as follows:

$$d\left(\log C_{nt}\right) = d\left(\log Y_{nt}\right) + \frac{d\left(\log \alpha_{nnt}\right)}{\eta - 1} - \frac{d\left(\log \lambda_{nnt}\right)}{\eta - 1} \tag{12}$$

where $\lambda_{nnt} = \frac{P_{nnt}C_{nnt}}{P_{nt}C_{nt}}$ is the home expenditure share. When the per capita endowment Y_{nt} and preferences for the home good α_{nnt} are not subject to changes, this expression reduces to $d\left(\log C_{nt}\right) = -\frac{d(\log \lambda_{nnt})}{\eta-1}$, which is the typical expression for calculating welfare gains from trade as in studies such as by Arkolakis, Costinot, and Rodríguez-Clare (2012) or Costinot and Rodríguez-Clare (2014). Different from these studies, in this paper, we allow for changes in preferences, whereas we take the per capita endowment Y_{nt} as given. Accordingly, we finally have the following expression regarding the welfare gains from trade in this paper:

$$d\left(\log C_{nt}\right) = \underbrace{\frac{d\left(\log \alpha_{nnt}\right)}{\eta-1}}_{\text{Gains through Preferences}} - \underbrace{\frac{d\left(\log \lambda_{nnt}\right)}{\eta-1}}_{\text{Gains in the Literature}} \tag{13}$$

where there are additional changes in welfare due to changes in preferences.

Since our main focus is on the welfare effects of change in the distance elasticity of trade costs, we will consider an alternative representation of Equation 13. In particular, using Equations 3 and 5, we represent the same welfare of $C_{nt} = E_{nt}/P_{nt}$ as follows:

$$C_{nt} = \frac{E_{nt}}{\left(\sum_i \alpha_{int}\left(\tau_{int}P_{iit}\right)^{1-\eta}\right)^{\frac{1}{1-\eta}}} \tag{14}$$

Further using Equations 4 and 9 results in:

$$C_{nt} = \left(\sum_i \alpha_{int}\left(\frac{\gamma_{it}\pi_{nt}\tau_{int}}{\gamma_{nt}\pi_{it}Y_{it}}\right)^{1-\eta}\right)^{\frac{1}{\eta-1}} \tag{15}$$

After considering the population share of countries as given, the welfare effects of a change in trade costs can be measured by taking the total derivative of Equation 15 in its log form

as follows, which is an alternative representation of Equation 13:

$$\underbrace{d\left(\log C_{nt}\right)}_{\text{Changes in Welfare}} = \underbrace{\frac{\sum_i \lambda_{int} d\left(\log \alpha_{int}\right)}{\eta - 1}}_{\text{Changes in Preferences}} - \underbrace{\sum_i \lambda_{int} d\left(\log \tau_{int}\right)}_{\text{Changes in Trade Costs}} \tag{16}$$

where λ_{int} is the share of expenditure on goods from country i in country n at time t that can be written as follows:

$$\lambda_{int} = \frac{P_{int} C_{int}}{P_{it} C_{it}} = \frac{\alpha_{int} \left(\frac{\gamma_{it} \pi_{nt}}{\gamma_{nt} \pi_{it} Y_{it}} \tau_{int}\right)^{1-\eta}}{\sum_k \alpha_{knt} \left(\frac{\gamma_{kt} \pi_{nt}}{\gamma_{nt} \pi_{kt} Y_{kt}} \tau_{knt}\right)^{1-\eta}} \tag{17}$$

Therefore, consistent with studies such as by Lai, Fan, and Qi (2015), the welfare effects of a change in trade costs (in percentage terms) depend on the weighted average of the percentage changes in bilateral trade costs, where weights are bilateral expenditure shares. As is evident, the right hand side of Equation 16 also considers changes in preferences, which is important to capture welfare changes due to the effects of distance on preferences versus on trade costs as in studies such as by Hummels and Schaur (2013) or Yilmazkuday (2016).

Since our main objective is to measure the effects of a change in the distance elasticity of trade, we further define preferences as a function of distance as follows:

$$\alpha_{int} = \frac{\varepsilon^p_{int}}{\left(D_{in}\right)^{\delta^p_t}} \tag{18}$$

where D_{in} is the distance between countries i and n, δ^p_t is the time-varying distance elasticity of preferences capturing demand shifters such as time to trade as in Hummels and Schaur (2013) or Yilmazkuday (2016), and ε^p_{int} represents preferences independent of distance effects. According to Equation 18, consumers prefer consuming products coming from closer countries, after controlling for other effects, such as relative prices.

Similarly, trade costs are defined as a function of distance as follows:

$$\tau_{int} = (D_{in})^{\delta_t^\tau} \varepsilon_{int}^\tau \tag{19}$$

δ_t^τ is the time-varying distance elasticity of trade costs as in several studies in the literature (e.g., see Anderson and Van Wincoop (2004)), and ε_{int}^τ represents trade costs independent of distance effects capturing the effects of other gravity variables as follows:

$$\varepsilon_{int}^\tau = \exp\left(\beta_{con}\varphi_{int}^{con} + \beta_{col}\varphi_{int}^{col} + \beta_{lan}\varphi_{int}^{lan}\right) \tag{20}$$

where φ_{int}^{con}, φ_{int}^{col} and φ_{int}^{lan} represent dummy variables taking a value of one when countries i and n are contiguous, have a colonial relationship and have a common language, respectively, while β's represent their the magnitude of their effect on trade costs.

Combining Equations 6, 18, 19 and 20 results in the following expression for log bilateral imports for estimation purposes:

$$\underbrace{\log\left(P_{int}C_{int}\right)}_{\text{Bilateral Imports}} = \underbrace{-\mu_t \log\left(D_{in}\right)}_{\text{Distance Effects}} \underbrace{- \left(\eta-1\right)\left(\beta_{con}\varphi_{int}^{con} + \beta_{col}\varphi_{int}^{col} + \beta_{lan}\varphi_{int}^{lan}\right)}_{\text{Other Gravity Variables}} \tag{21}$$
$$\underbrace{- \left(\eta-1\right)\log\left(P_{iit}\right)}_{\text{Source-Time Fixed Effects}} + \underbrace{\log\left(\left(P_{nt}\right)^{\eta} C_{nt}\right)}_{\text{Destination-Time Fixed Effects}} + \underbrace{\log\left(\frac{\varepsilon_{int}^p}{\left(\eta-1\right)\varepsilon_{int}^\tau}\right)}_{\text{Residuals}}$$

where μ_t is the distance elasticity of trade that satisfies $\mu_t = \delta_t^p + \left(\eta-1\right)\delta_t^\tau$.

Combining Equations 16, 18, 19 and 20 results in the following expression when only changes in δ_t^p and δ_t^τ are considered:

$$d\left(\log C_{nt}\right) = -\frac{d\left(\mu_t\right)}{\eta-1}\sum_i \lambda_{int}\log D_{in} \tag{22}$$

where changes in welfare depend on changes in the distance elasticity of trade (divided by the trade elasticity) together with the *effective* distance measured as the weighted average of log distance measures, where weights are the bilateral expenditure shares.

When the focus is on the changes in welfare through domestic versus international trade, both due to changes in μ_t, Equation 22 can be rewritten as follows:

$$d\left(\log C_{nt}\right) = \underbrace{-\frac{d\left(\mu_t\right)}{\eta-1}\lambda_{nnt}\log D_{nn}}_{\text{Through Domestic Trade}} \underbrace{-\frac{d\left(\mu_t\right)}{\eta-1}\sum_{i\neq n}\lambda_{int}\log D_{in}}_{\text{Through International Trade}} \tag{23}$$

which implies the following expression representing the share of international trade in changes in welfare:

$$\text{Share of International Trade} = \frac{\sum_{i\neq n}\lambda_{int}\log D_{in}}{\sum_{i}\lambda_{int}\log D_{in}} \tag{24}$$

which can be simply calculated by using data on bilateral expenditure shares λ_{int}'s and distance measures D_{in}'s, without any information on μ_t's. We utilize this expression to measure the historical share of international trade in welfare changes due to changes in distance effects over time. Therefore, this measure can be considered as the distance-reducing effects of globalization.

When the focus is on historical changes in welfare due to developments in the distance elasticity of trade over time, cumulative changes in welfare can be calculated as follows according to Equation 22:

$$\text{Cumulative Changes in Welfare} = \underbrace{-\sum_{t=s}^{e}\frac{d\left(\mu_t\right)}{\eta-1}\lambda_{nnt}\log D_{nn}}_{\text{Domestic Trade}} \underbrace{-\sum_{t=s}^{e}\frac{d\left(\mu_t\right)}{\eta-1}\sum_{i\neq n}\lambda_{int}\log D_{in}}_{\text{International Trade}} \tag{25}$$

where s and e represent starting and end time of the investigation. We will use this expression to analyze the historical welfare changes of countries due to the developments in the

distance elasticity of trade over time. On top of λ_{int}'s and D_{in}'s, this expression also requires information on μ_t's, as we estimate them using OLS or PPML, below.

When the focus is on future potential changes in welfare due to removing all distance-related effects on trade, we ask the following question: What would be the changes in welfare if the effects of distance would be reduced to zero? This corresponds to having $d(\mu_t) = -\mu_t$, implying according to Equation 22 that:

$$\text{Potential Changes in Welfare} = \underbrace{\frac{\mu_t}{\eta - 1}\lambda_{nnt} \log D_{nn}}_{\text{Domestic Trade}} + \underbrace{\frac{\mu_t}{\eta - 1}\sum_{i \neq n} \lambda_{int} \log D_{in}}_{\text{International Trade}} \tag{26}$$

which can be calculated for any time t for given values of μ_t's, λ_{int}'s and D_{in}'s for all i, n. We will use this expression to analyze the potential welfare changes of countries due to the potential developments in the distance elasticity of trade in the future.

Unlike Equation 24, calculating the changes in welfare in Equations 25 and 26 requires the knowledge of μ_t's over time, as we obtain next.

3 Estimation Strategy and Data

Based on Equation 21, the estimation requires assumptions on the residuals. When it is assumed that $\log\left(\frac{\varepsilon^p_{int}}{(\eta-1)\varepsilon^\tau_{int}}\right)$'s are distributed normally with zero mean, the estimation of Equation 21 can be achieved by using OLS. We use this assumption and thus estimate Equation 21 by using OLS to show the existence of the distance puzzle. This is achieved by estimating Equation 21 by using data on log bilateral imports, distance, contiguity, colonial relationship, and common language, together with source-time and destination-time fixed effects. In this framework, μ_t's are estimated as the time-varying coefficients in front of distance.

However, OLS estimations are problematic not only due to their inconsistency but also due to zero trade observations being ignored in such estimations. Accordingly, following several studies in the literature, we also consider an alternative estimation by PPML by assuming that $\frac{\varepsilon_{int}^{p}}{(\eta-1)\varepsilon_{int}^{\tau}} = v_{int}$'s represent multiplicative residuals. Further using Equation 21 results in the well-known expression for the PPML estimation:

$$\underbrace{P_{int}C_{int}}_{\text{Bilateral Imports}} = \exp\left(\begin{array}{c} \underbrace{-\mu_t \log\left(D_{in}\right)}_{\text{Distance Effects}} \underbrace{-\left(\eta-1\right)\left(\beta_{con}\varphi_{int}^{con}+\beta_{col}\varphi_{int}^{col}+\beta_{lan}\varphi_{int}^{lan}\right)}_{\text{Other Gravity Variables}} \\ \underbrace{-\left(\eta-1\right)\log\left(P_{iit}\right)}_{\text{Source-Time Fixed Effects}} + \underbrace{\log\left(\left(P_{nt}\right)^{\eta}C_{nt}\right)}_{\text{Destination-Time Fixed Effects}} \end{array}\right) + v_{int} \quad (27)$$

which is estimated by using data on bilateral imports (this time by also including zero trade observations), distance, contiguity, colonial relationship, and common language, together with source-time and destination-time fixed effects. In this framework, μ_t's are again estimated as the time-varying coefficients in front of distance.

The data are borrowed from Fouquin and Hugot (2016), where bilateral imports, distance and gravity variables cover 173 countries for the annual period between 1827 and 2014. One advantage of this data set is that it carefully considers zero trade observations that can be included in the PPML estimation.

All estimations are achieved by also including data on domestic trade represented by $P_{nnt}C_{nnt}$'s as they are essential for the welfare analysis through Equations 24, 25 and 26. For these domestic trade observations, $P_{nnt}C_{nnt}$'s are measured by the gross domestic product minus total exports (already given in the data set) as in studies such as by Yotov (2012), gravity variables of contiguity, colonial relationship and common language are all set to zero, and domestic distance measures are also given in the data set.

Finally, although the trade elasticity of $\eta - 1$ in the welfare calculations through Equations 24, 25 and 26 is nothing more than a scale factor, for the sake of completeness, we follow studies such as by Anderson and Van Wincoop (2003), Head and Mayer (2014) or

Yilmazkuday (2019) to adopt a trade elasticity measure of $\eta - 1 = 5$ in our calculations below.

4 Empirical Results

This section depicts the welfare gains from trade due to changes in the distance elasticity of trade. The results are depicted for certain country groups, while country-specific results are summarized in Appendix Table A.1.

4.1 Share of International Trade in Welfare Gains

The results based on Equation 24, which do not require any information on μ_t's, are given in Figure 1 over time, and in Table 1 or Table 2 for the year of 2014. As is evident, the historical share of international trade in welfare gains of the world has increased from about 1% back in 1820s to about 6% in 2014, suggesting that distance-reducing effects of globalization has increased about 6 times over the last two centuries in the world.

Regarding sub-periods, the share of international trade has increased continuously for several (but not all) countries during the 19th century according to Figure 1, confirming the first era of globalization as in studies such as by Bairoch (1974) or Jacks, Meissner, and Novy (2011); this share has increased more during the first than during the second half of the 19th century, also consistent with studies such as by Uebele (2011) who has shown that globalization has accelerated faster in the first than in the second half of the 19th century. After the disruption in trade due to the interwar period, the share of international trade has continued increasing in the world, confirming the second era of globalization as in studies such as by Hummels (2007).

The Organisation for Economic Co-operation and Development (OECD) versus non-OECD countries have experienced similar increases, although their patterns over time are

different. The share of international trade has increased from about 1.5% back in 1820s to only about 3% for the United States (with several disruptions along the way, including those due to the Civil War and the interwar period), whereas it has increased from below 1% to about 8% for the European Union. The share of international trade for China has increased about 5 times, from about 0.8% in 1950s to about 4% in 2014, while it has increased from about 1.5% in 1920s to about 8% for Mexico.

Across all countries in the sample, the share of international trade for the year of 2014 ranges between 2% (for Bhutan) and 19% (for Liberia), suggesting that countries benefit from international trade (due to changes in the distance elasticity of trade over time) in different magnitudes depending on their domestic and international distance measures.

4.2 Cumulative Historical Welfare Gains

Cumulative historical welfare gains based on Equation 25 for $s = 1827$ and $e = 2014$ are given in Figure 2 over time, and in Tables 1-2 for the year of 2014. Since these gains depend on μ_t's and hence the estimation methodology, we provide evidence based on each methodology next.

4.2.1 Results Based on the OLS Estimation

The OLS estimation results in the distance elasticity of trade estimates given in Figure 2. As is evident, while the estimates are mostly stable over time in 1800s, there is evidence for increasing negative effects of distance on trade starting from 1960s. In particular, μ_t estimates have decreased from about 1.8 in 1820s to about 1.2 in 1960s and it has increased to about 2.1 as of 2014. The latter evidence is what the literature calls "the distance puzzle" as the expectation is that the effects of distance are decreasing over time due to improvements in transportation technologies suggested by Hummels (2007) as well as globalization itself (as a factor shifting preferences toward international products over time).

The implications of increasing negative effects of distance on trade (starting from 1960s) are reflected as reductions in the cumulative welfare gains from trade in the world according to Equation 25. In particular, the cumulative gains from international trade are about -65% in the world, whereas those from domestic trade are about -16%, which add up to about 81% of a welfare loss as of 2014. The cumulative loss (as of 2014) is about 54% and 87% for OECD versus non-OECD countries, respectively, whereas it is about 114% for India.

It is implied that the negative welfare implications of the distance puzzle are extremely high. Since these implications are based on inconsistent OLS estimates of μ_t's, where zero trade observations are ignored, they are subject to improvement when such observations will be included in the PPML investigation, as we achieve next.

4.2.2 Results Based on the PPML Estimation

The PPML estimation results in the distance elasticity of trade estimates given in Figure 3. There is evidence for decreasing effects of distance on trade over time, where μ_t measures have gradually decreased from about 3.4 in 1820s to about 2.6 in 1960s and to about 2.1 as of 2014. Hence, the distance puzzle implied by the OLS estimation is solved when zero trade observations are included (as in Felbermayr and Kohler (2006)) in the PPML estimation.

The implications of decreasing negative effects of distance on trade are reflected as gains from trade in the world, except for the interwar period. The corresponding cumulative gains from domestic (international) trade according to Equation 25 are about 11% (47%), adding up to about 58% in the world. These cumulative gains are about 89% versus 51% for OECD and non-OECD countries, respectively, whereas it is about 155% for the United States for which most of the contribution is through international trade.

It is implied that the significant negative welfare implications of the distance puzzle suggested by inconsistent OLS estimates of μ_t's can be understood and the distance puzzle is solved when the PPML estimates of μ_t's are considered.

4.3 Potential Future Welfare Gains

Potential future welfare gains based on Equation 26 are calculated for the year of 2014 (the last year in the sample). Since both the OLS and the PPML estimates of μ_t for the year of 2014 are about 2.1, the corresponding potential future gains given in Tables 1-2 are highly similar to each other.

Potential future welfare gains in the world are about 197% (79%) through domestic (international) trade in the world, which are highly similar across OECD versus non-OECD countries as well. Across countries, potential future gains through international (domestic) trade take their highest value for the United States (Liberia), where the total potential gains for the United States are about 320%. Although it may not be feasible to completely achieve these gains, the results provide useful information about the overall potential in the future.

5 Concluding Remarks and Policy Suggestions

Using the implications of a trade model, this paper has shown that the effects of distance on trade can be connected the welfare gains from trade by using bilateral distance measures and bilateral expenditure shares across countries. This theoretical result has been used to empirically investigate the welfare implications of the distance puzzle.

When zero trade observations are ignored in trade regressions using OLS, it has been shown that the negative effects of distance on trade have been *increasing* over time, suggesting evidence for the distance puzzle. The corresponding welfare implications suggest that the world economy has experienced a cumulative welfare loss (about 81%) due to this puzzle in the last two centuries.

Since OLS estimations are problematic not only due to their inconsistency but also due to zero trade observations being ignored in such estimations, the distance puzzle is solved when zero-trade observations are included in PPML estimations as it is shown that the

negative effects of distance on trade have been *decreasing* over time. The corresponding welfare implications suggest that there are significant welfare gains from trade (about 58%) during the same period.

The implications of the model have also been used to measure the potential future gains from trade. This has been achieved by considering a hypothetical case in which the effects of distance have been set to zero, both within and across countries. The corresponding results have shown that the potential future gains from domestic trade are about 79%, whereas those from international trade are about 197%, suggesting that there is much more to be done to reduce the negative effects of distance on trade.

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Table 1 - Results Based on OLS Estimates

	Gains from Trade	Cumulative Gains through:		Potential Future Gains through:	
Country	Share of International Trade	International Trade	Domestic Trade	International Trade	Domestic Trade
World	6%	-0.65	-0.16	0.79	1.97
OECD	6%	-0.41	-0.13	0.83	1.99
Non-OECD	6%	-0.71	-0.17	0.78	1.97
United States	3%	-0.39	-0.07	0.47	2.75
European Union	8%	-0.32	-0.17	1.00	1.54
China	4%	-0.59	-0.15	0.59	2.33
Japan	5%	-0.39	-0.07	0.60	2.07
United Kingdom	5%	-0.27	-0.14	0.62	1.77
India	5%	-1.04	-0.10	0.74	2.24
Canada	6%	-0.49	-0.29	0.95	2.21
Mexico	8%	-0.49	-0.14	1.16	1.84

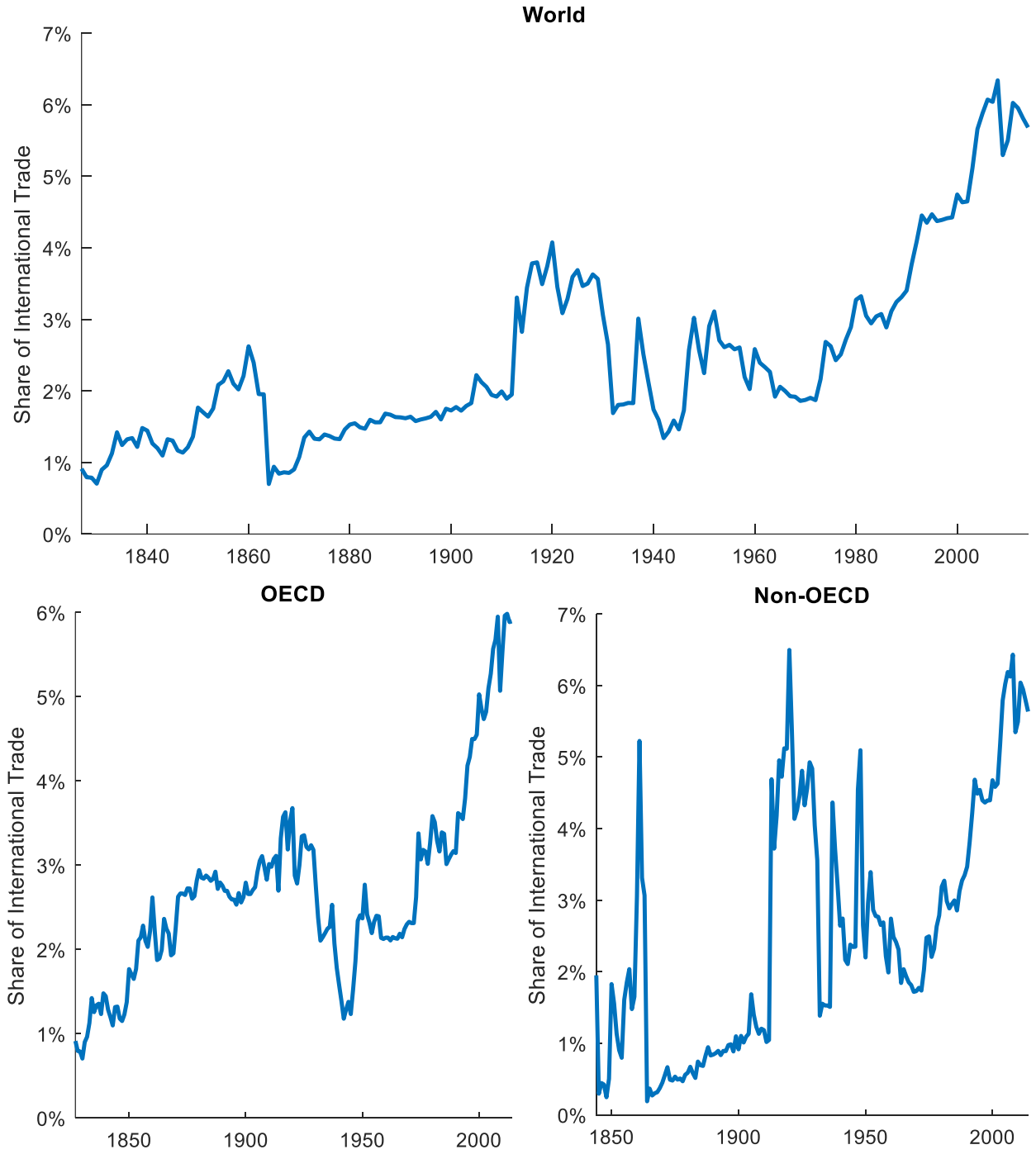
Notes: Share of international trade in welfare gains through distance effects is defined as welfare gains due to international trade divided by the sum of welfare gains due to domestic and international trade. Cumulative welfare gains have been calculated by taking the sum of the changes in welfare gains over the years. Cumulative actual gains are based on the OLS estimation. The numbers represent the values in 2014. Potential future gains represent changes in welfare due to removing all distance-related effects on trade.

Table 2 - Results Based on PPML Estimates

	Gains from Trade	Cumulative Gains through:		Potential Future Gains through:	
Country	Share of International Trade	International Trade	Domestic Trade	International Trade	Domestic Trade
World	6%	0.47	0.11	0.79	1.97
OECD	6%	0.73	0.16	0.83	1.98
Non-OECD	6%	0.41	0.10	0.78	1.96
United States	3%	1.37	0.18	0.47	2.74
European Union	8%	0.59	0.16	1.00	1.54
China	4%	0.57	0.11	0.59	2.33
Japan	5%	0.55	0.02	0.60	2.07
United Kingdom	5%	0.83	0.27	0.62	1.77
India	5%	0.49	0.04	0.73	2.24
Canada	6%	0.35	0.24	0.94	2.20
Mexico	8%	0.26	0.13	1.15	1.84

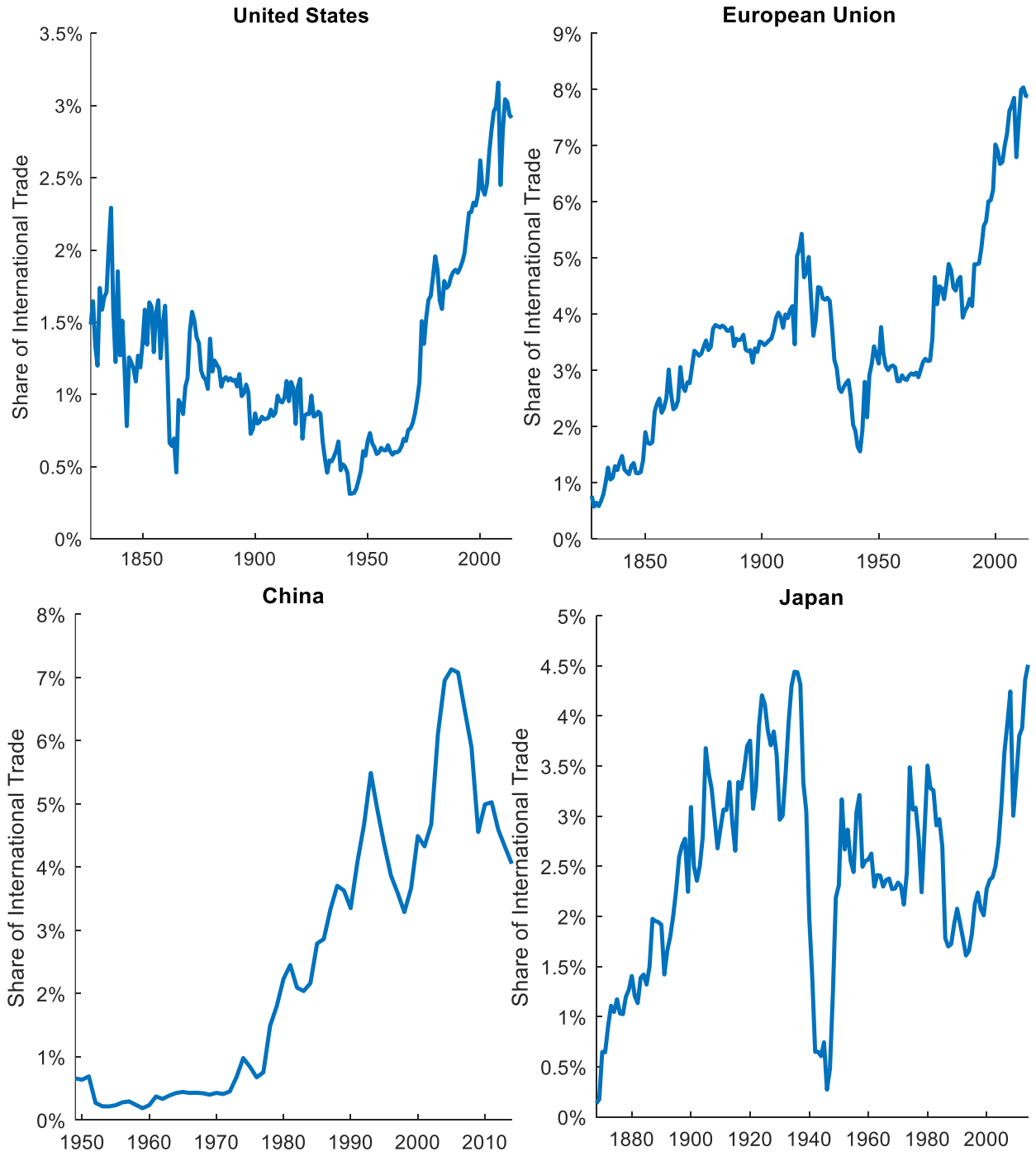
Notes: Share of international trade in welfare gains through distance effects is defined as welfare gains due to international trade divided by the sum of welfare gains due to domestic and international trade. Cumulative welfare gains have been calculated by taking the sum of the changes in welfare gains over the years. Cumulative actual gains are based on the PPML estimation. The numbers represent the values in 2014. Potential future gains represent changes in welfare due to removing all distance-related effects on trade.

Figure 1a – Share of International Trade in Welfare Gains through Distance Effects



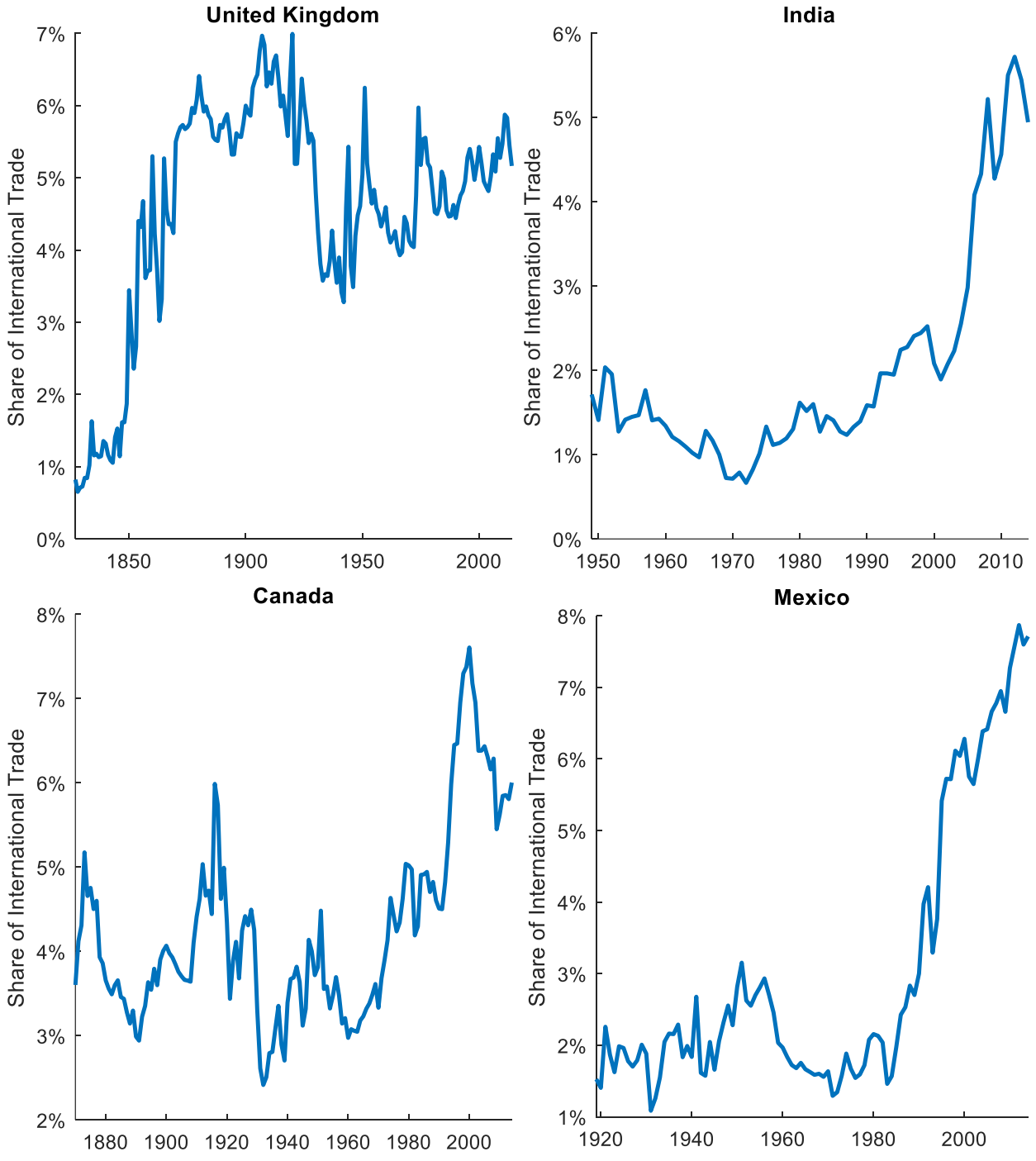
Notes: Share of international trade in welfare gains through distance effects is defined as welfare gains due to international trade divided by the sum of welfare gains due to domestic and international trade. The results have been calculated by using the weighted average of country-specific results, where weights are income shares of countries.

Figure 1b – Share of International Trade in Welfare Gains through Distance Effects



Notes: Share of international trade in welfare gains through distance effects is defined as welfare gains due to international trade divided by the sum of welfare gains due to domestic and international trade. The results have been calculated by using the weighted average of country-specific results, where weights are income shares of countries.

Figure 1c – Share of International Trade in Welfare Gains through Distance Effects

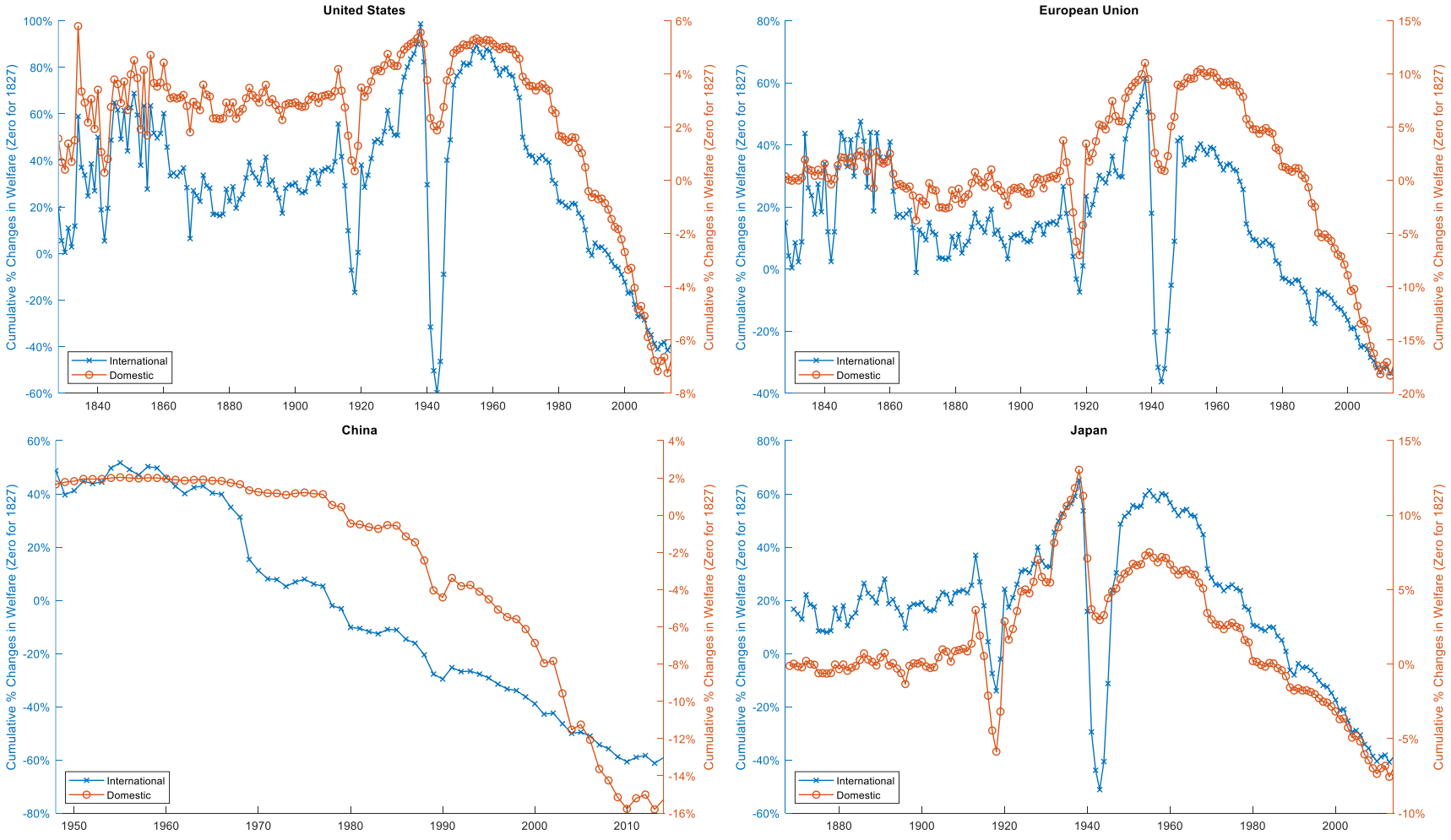


Notes: Share of international trade in welfare gains through distance effects is defined as welfare gains due to international trade divided by the sum of welfare gains due to domestic and international trade. The results have been calculated by using the weighted average of country-specific results, where weights are income shares of countries.

Figure 2a – Cumulative Welfare Gains through Changes in the Distance Elasticity of Trade Costs based on OLS Estimates

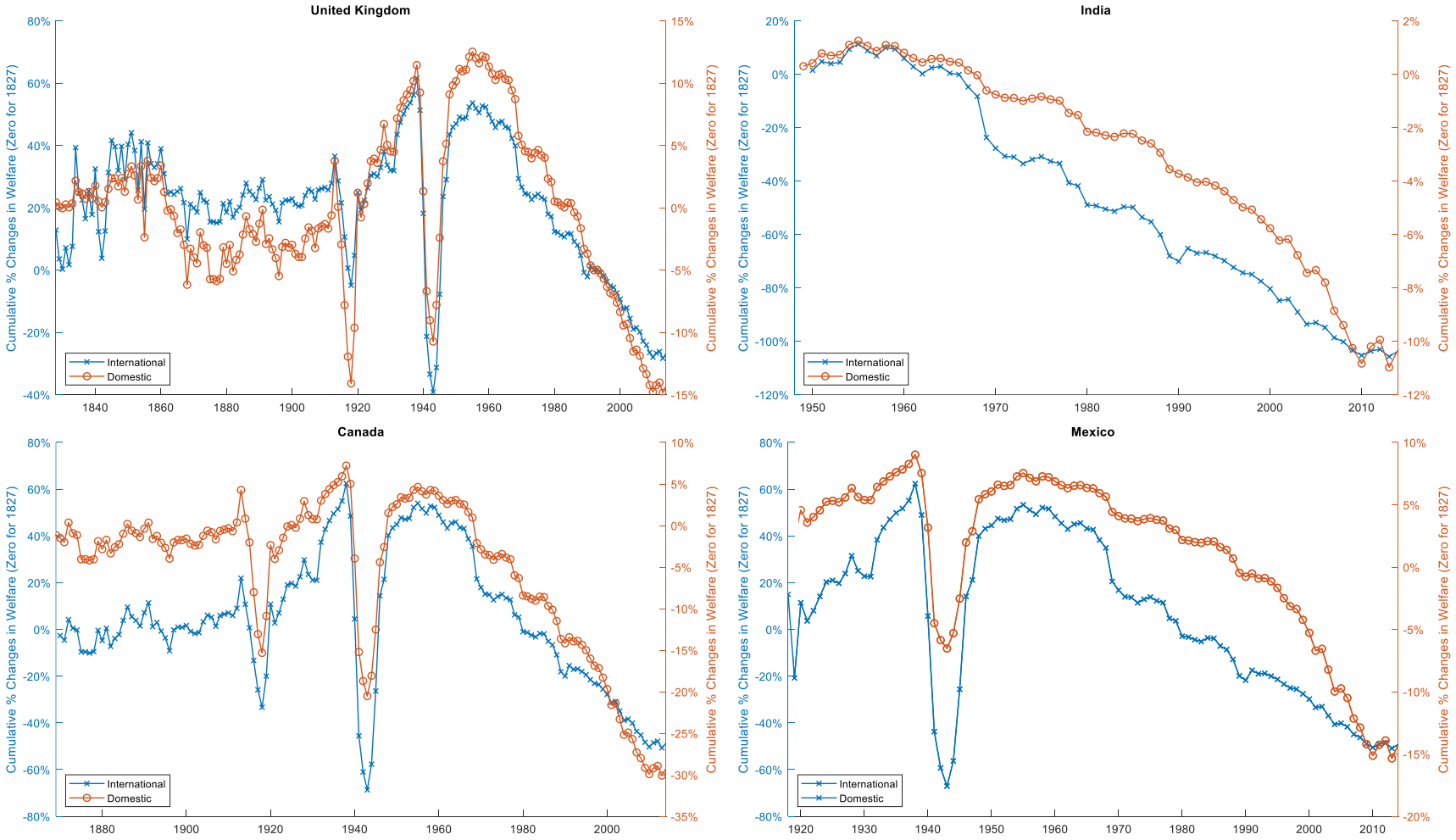
Notes: The results for country groups have been calculated by using the weighted average of country-specific results, where weights are income shares of countries. Welfare gains in 1827 are set equal to zero. Cumulative welfare gains have been calculated by taking the sum of the changes in welfare gains over the years.

Figure 2b – Cumulative Welfare Gains through Changes in the Distance Elasticity of Trade Costs based on OLS Estimates



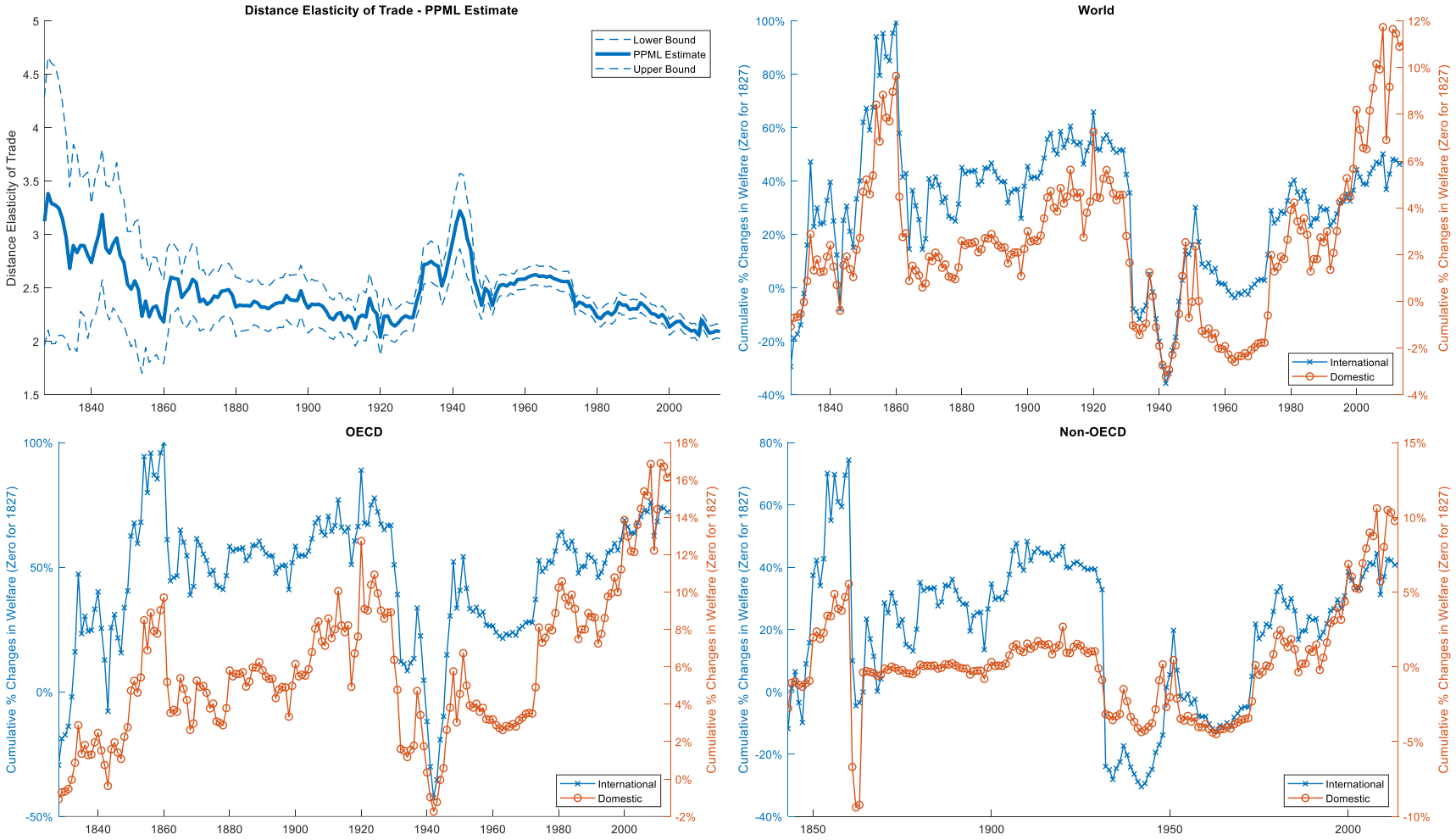
Notes: The results for country groups have been calculated by using the weighted average of country-specific results, where weights are income shares of countries. Welfare gains in 1827 are set equal to zero. Cumulative welfare gains have been calculated by taking the sum of the changes in welfare gains over the years.

Figure 2c – Cumulative Welfare Gains through Changes in the Distance Elasticity of Trade Costs based on OLS Estimates



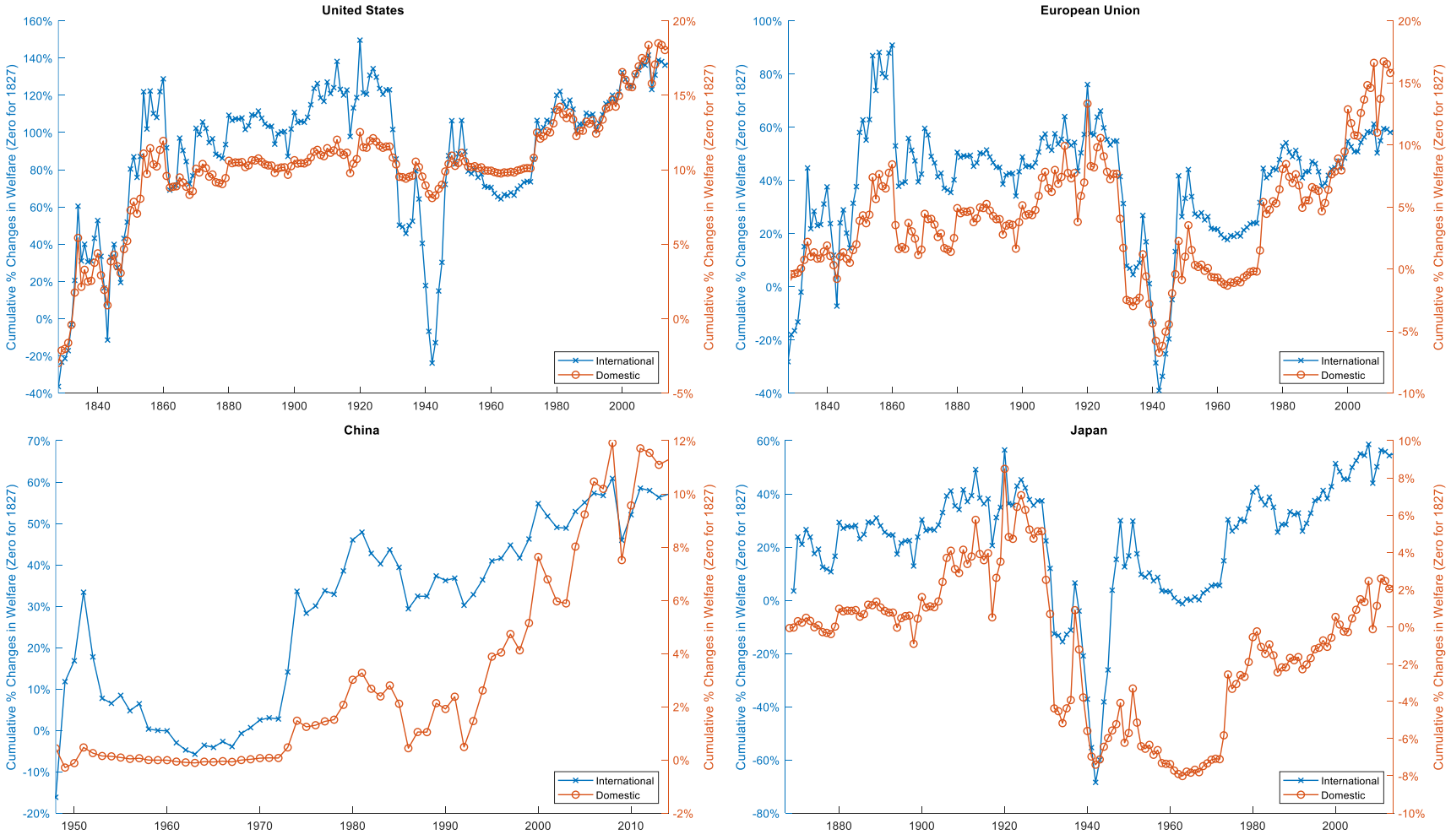
Notes: Welfare gains in 1827 are set equal to zero. Cumulative welfare gains have been calculated by taking the sum of the changes in welfare gains over the years.

Figure 3a – Cumulative Welfare Gains through Changes in the Distance Elasticity of Trade Costs based on PPML Estimates



Notes: The results for country groups have been calculated by using the weighted average of country-specific results, where weights are income shares of countries. Welfare gains in 1827 are set equal to zero. Cumulative welfare gains have been calculated by taking the sum of the changes in welfare gains over the years.

Figure 3b – Cumulative Welfare Gains through Changes in the Distance Elasticity of Trade Costs based on PPML Estimates



Notes: The results for country groups have been calculated by using the weighted average of country-specific results, where weights are income shares of countries. Welfare gains in 1827 are set equal to zero. Cumulative welfare gains have been calculated by taking the sum of the changes in welfare gains over the years.

Figure 3c – Cumulative Welfare Gains through Changes in the Distance Elasticity of Trade Costs based on PPML Estimates

Notes: Welfare gains in 1827 are set equal to zero. Cumulative welfare gains have been calculated by taking the sum of the changes in welfare gains over the years.

Appendix Table A.1 - Country-Specific Results

	Gains from Trade	Cumulative Gains (PPML Estimates)		Potential Future Gains through:	
Country	Share of International Trade	International Trade	Domestic Trade	International Trade	Domestic Trade
Afghanistan	7%	0.41	0.05	0.94	1.66
Angola	8%	0.16	0.23	1.13	1.67
Albania	9%	0.18	0.06	0.90	1.22
United Arab Emirates	18%	0.21	0.36	2.99	0.24
Argentina	3%	0.25	0.12	0.44	2.31
Armenia	9%	0.13	0.13	1.00	1.21
Antigua and Barbuda	14%	0.08	0.20	1.75	0.69
Australia	4%	0.95	0.54	0.62	2.43
Austria	10%	0.01	0.10	1.15	1.24
Azerbaijan	5%	0.16	0.10	0.50	1.55
Burundi	3%	0.38	0.07	0.30	1.55
Belgium	18%	0.37	0.56	2.45	0.25
Benin	9%	0.38	0.09	0.81	1.06
Burkina Faso	5%	0.43	0.11	0.63	1.70
Bangladesh	6%	0.39	0.10	0.69	1.58
Bulgaria	13%	0.28	-0.99	1.63	0.98
Bahamas, The	16%	0.15	0.86	2.39	0.58
Bosnia and Herzegovina	10%	0.09	0.09	1.13	1.14
Belarus	12%	0.11	0.19	1.53	1.12
Belize	13%	0.20	0.42	1.61	0.94
Bolivia	9%	0.32	0.09	1.24	1.60
Brazil	3%	0.37	0.01	0.39	2.65
Barbados	11%	0.20	0.34	1.11	0.90
Brunei	13%	0.17	0.50	1.63	0.84
Bhutan	2%	0.08	0.04	0.10	1.19
Botswana	10%	0.28	0.08	1.23	1.17
Central African Republic	5%	0.43	0.15	0.55	1.78
Canada	6%	0.35	0.24	0.94	2.20
Switzerland	9%	0.11	0.15	0.91	1.20
Chile	7%	1.13	0.40	1.04	1.86
China	4%	0.57	0.11	0.59	2.33
Cote d'Ivoire	9%	0.34	0.26	1.16	1.45
Cameroon	6%	0.42	0.14	0.81	1.93
Congo, Democratic Republic of the	5%	0.43	0.09	0.77	2.18
Congo, Republic of the	14%	0.23	0.32	2.15	0.94
Colombia	4%	0.75	0.13	0.59	2.05
Comoros	9%	0.08	0.11	1.13	1.27
Cape Verde	9%	0.17	0.13	1.13	1.42
Costa Rica	13%	0.31	0.30	1.70	0.85
Cyprus	8%	0.14	0.23	0.65	1.05
Czech Republic	17%	0.11	0.19	2.29	0.38
Germany	8%	0.44	0.08	0.97	1.59
Djibouti	18%	0.07	0.23	2.75	0.28
Dominica	16%	0.05	0.17	2.21	0.47
Denmark	7%	0.48	0.17	0.81	1.39
Dominican Republic	8%	0.25	0.13	0.86	1.39
Algeria	7%	0.31	0.16	0.93	1.75
Ecuador	8%	0.61	0.13	0.97	1.58
Egypt, Arab Rep.	6%	0.12	0.11	0.68	1.65
Spain	6%	1.15	0.11	0.81	1.93
Estonia	14%	0.03	0.20	1.56	0.63
Ethiopia (excludes Eritrea)	5%	0.36	0.08	0.56	1.73
Finland	7%	0.05	0.12	0.85	1.57
Fiji	12%	0.18	0.36	1.51	1.06
France	5%	1.08	0.16	0.68	1.93
Gabon	9%	0.27	0.32	1.13	1.50
United Kingdom	5%	0.83	0.27	0.62	1.77
Georgia	10%	0.17	0.09	1.19	1.23
Ghana	10%	0.25	0.21	1.32	1.38
Guinea	12%	0.33	0.17	1.27	0.86
Gambia, The	15%	0.25	0.35	2.27	0.67
Guinea-Bissau	10%	0.24	0.26	1.09	1.07
Equatorial Guinea	13%	0.30	0.27	1.96	0.99
Greece	7%	0.54	0.09	0.76	1.56
Grenada	12%	0.08	0.15	1.06	0.71
Greenland	8%	0.31	0.40	1.17	1.71
Guatemala	9%	-0.01	0.16	0.93	1.23
Guyana	13%	0.09	0.63	1.68	0.89
Honduras	12%	-0.14	0.24	1.41	1.01
Croatia	8%	0.11	0.10	0.91	1.39
Haiti	11%	0.49	0.15	1.13	1.01
Hungary	17%	-0.11	0.17	2.22	0.46
Indonesia	5%	0.16	-0.41	0.69	2.17
India	5%	0.49	0.04	0.73	2.24
Ireland	10%	-0.02	0.24	1.12	1.12
Iran	5%	0.39	0.11	0.72	2.02
Iraq	7%	0.27	-0.02	0.83	1.64
Iceland	9%	0.24	0.13	1.06	1.24
Israel	7%	0.19	0.12	0.67	1.27
Italy	5%	0.29	0.12	0.66	1.93
Jamaica	10%	0.03	0.14	1.06	1.12
Jordan	12%	0.16	0.23	1.46	0.89
Japan	5%	0.55	0.02	0.60	2.07
Kazakhstan	5%	0.20	0.10	0.71	2.21
Kenya	7%	0.33	0.22	0.89	1.71
Kyrgyzstan	15%	0.16	0.10	2.11	0.80
Cambodia	17%	0.29	0.23	2.21	0.46
Kiribati	15%	0.37	0.27	2.40	0.82
Saint Kitts and Nevis	10%	0.32	0.01	1.61	1.48
Korea, South	10%	0.06	0.17	1.33	1.29
Kuwait	11%	0.18	0.31	1.07	0.80
Laos	12%	0.35	0.19	1.55	1.14
Lebanon	10%	0.19	0.21	1.09	1.09
Liberia	19%	-0.05	0.57	3.60	0.15
Libya	11%	0.39	0.21	1.52	1.37

Appendix Table A.1 - Country-Specific Results

	Gains from Trade	Cumulative Gains (PPML Estimates)		Potential Future Gains through:	
Country	Share of International Trade	International Trade	Domestic Trade	International Trade	Domestic Trade
Saint Lucia	17%	0.07	0.14	2.31	0.42
Sri Lanka	6%	0.27	0.18	0.73	1.62
Lesotho	13%	0.20	0.06	1.13	0.65
Lithuania	15%	0.07	0.16	2.02	0.64
Latvia	12%	0.06	0.11	1.02	0.69
Macao	15%	0.02	-0.02	0.64	0.21
Morocco	9%	0.29	0.09	1.16	1.49
Moldova	12%	0.08	0.18	1.37	0.86
Madagascar	7%	0.33	0.13	0.99	1.69
Maldives	9%	0.06	0.14	1.28	1.45
Mexico	8%	0.26	0.13	1.15	1.84
Macedonia	13%	0.11	0.14	1.40	0.82
Mali	5%	0.41	0.15	0.61	1.76
Myanmar	9%	0.46	0.00	1.20	1.49
Mongolia	11%	0.13	0.19	1.53	1.32
Mozambique	11%	0.24	0.12	1.73	1.31
Mauritania	13%	0.33	0.31	1.97	0.97
Mauritius	12%	0.06	0.24	1.29	0.79
Malawi	7%	0.36	0.24	0.74	1.39
Malaysia	17%	0.10	0.56	2.70	0.43
Namibia	11%	0.12	0.04	1.45	1.29
Niger	6%	0.48	0.16	0.77	1.89
Nigeria	3%	0.35	0.15	0.39	2.22
Nicaragua	13%	0.24	0.17	1.63	0.93
Netherlands	16%	0.58	0.65	2.10	0.47
Norway	5%	1.06	0.22	0.63	1.91
Nepal	8%	0.47	0.11	1.01	1.59
New Zealand	6%	0.19	0.28	0.80	1.97
Oman	12%	0.22	2.74	1.61	1.12
Pakistan	5%	0.40	0.11	0.73	2.07
Panama	6%	0.18	0.17	0.38	0.91
Peru	6%	1.17	0.23	0.81	2.00
Philippines	6%	0.33	0.89	0.76	1.61
Palau	7%	0.05	0.02	0.42	0.81
Papua New Guinea	15%	0.28	0.51	2.31	0.77
Poland	9%	0.30	0.15	1.10	1.37
Portugal	8%	0.84	0.22	0.98	1.53
Paraguay	10%	0.26	0.13	1.31	1.28
Qatar	10%	0.20	0.27	0.96	0.99
Romania	9%	0.37	0.18	1.12	1.45
Russia	3%	0.32	0.06	0.53	2.55
Rwanda	6%	0.33	0.12	0.50	1.30
Saudi Arabia	7%	0.48	-0.06	1.03	1.89
Sudan	4%	0.43	0.11	0.51	2.22
Senegal	9%	0.33	0.21	1.03	1.25
Solomon Islands	13%	0.30	0.26	1.70	0.94
Sierra Leone	9%	0.32	0.26	1.14	1.34
El Salvador	10%	0.50	0.15	1.11	1.02
Sao Tome and Principe	10%	0.07	0.08	0.96	1.03
Suriname	9%	0.15	0.51	1.17	1.55
Slovakia	17%	0.12	0.19	2.26	0.39
Slovenia	16%	0.06	0.15	1.94	0.50
Sweden	7%	1.10	0.25	0.85	1.68
Swaziland	11%	0.16	0.10	1.30	0.97
Seychelles	16%	0.16	0.35	1.83	0.53
Chad	4%	0.48	0.07	0.39	1.76
Togo	16%	0.33	0.20	1.89	0.42
Thailand	14%	0.32	0.32	1.96	0.90
Tajikistan	11%	0.05	0.27	1.36	1.21
Turkmenistan	6%	0.08	0.23	0.83	1.84
Tonga	10%	0.16	0.13	1.21	1.20
Trinidad and Tobago	13%	0.02	0.47	1.65	0.79
Tunisia	11%	0.32	0.26	1.43	1.15
Turkey	6%	0.42	0.08	0.86	1.85
Tuvalu	17%	0.13	0.13	2.70	0.47
Tanzania	7%	0.38	0.21	0.92	1.90
Uganda	5%	0.38	0.12	0.52	1.73
Ukraine	10%	0.13	0.15	1.32	1.39
Uruguay	6%	0.22	0.39	0.69	1.64
United States	3%	1.37	0.18	0.47	2.74
Uzbekistan	6%	0.19	0.09	0.77	1.87
Saint Vincent and the Grenadines	14%	0.14	0.16	1.60	0.68
Vietnam	17%	0.29	0.29	2.38	0.36
Vanuatu	12%	0.05	0.28	1.72	1.07
Samoa	12%	0.09	0.22	1.39	0.91
South Africa	8%	0.06	0.21	1.20	1.80
Zambia	9%	0.48	0.30	1.15	1.50
Zimbabwe	8%	0.06	-0.08	0.96	1.52
Average	10%	0.29	0.20	1.21	1.30
Median	9%	0.25	0.16	1.11	1.29
Minimum	2%	-0.14	-0.99	0.10	0.15
Maximum	19%	1.37	2.74	3.60	2.74

Notes: Share of international trade in welfare gains through distance effects is defined as welfare gains due to international trade divided by the sum of welfare gains due to domestic and international trade. Cumulative welfare gains have been calculated by taking the sum of the changes in welfare gains over the years. Cumulative actual gains are based on the PPML estimation. The numbers represent the values in 2014. Potential future gains represent changes in welfare due to removing all distance-related effects on trade.