Deconstructing the Gains from Trade: Selection of Industries vs. Reallocation of Workers

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Abstract

In a Ricardian model with CES preferences and general distributions of industry efficiencies, the sources of the welfare gains from trade can be precisely decomposed into a *selection* and a *reallocation* effect. The former is the change in average efficiency due to the selection of industries that survive international competition. The latter is the rise in the weight of exporting industries in domestic production, due the reallocation of workers away from less-efficient non-exporting industries. This decomposition, which is hard to calculate in the general case, simplifies dramatically if industry efficiencies are Fréchet distributed, providing easy-to-quantify model-based measures of these two effects. Under this assumption, we also show that when the gains from trade are small, it is the selection effect that matters most; as the gains from trade rise and the size of the export sector grows, so does the importance of the reallocation effect.

JEL classification: F10, F11, F40

Keywords: Ricardian model; selection effect; reallocation effect

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1 Introduction

In a very influential paper, Arkolakis, Costinot, and Rodríguez-Clare (2012) have shown that the welfare gains from trade implied by a very large class of models depend on only two sufficient statistics: (*i*) the share of expenditure on domestic goods (which is often called "domestic trade share"); and (*ii*) the elasticity of imports with respect to variable trade costs ("trade elasticity"). This result is remarkable because it applies to frameworks as different as the simple Armington model, in which goods are differentiated by country of origin; the Ricardian model with heterogeneous industries and Fréchet-distributed efficiencies of Eaton and Kortum (2002); the monopolistic competition model of Krugman (1980); as well as variants of the monopolistic competition model of Melitz (2003), with heterogeneous firms and Pareto-distributed efficiencies (such as those developed by Chaney, 2008, and Eaton, Kortum, and Kramarz, 2011). Given their importance for empirical studies, these models are now commonly referred to as "quantitative trade models."

Following this result, the literature appears to be taking two main directions. One analyzes how the measurement of the gains from trade changes when some assumptions of quantitative trade models are relaxed (see Arkolakis, Costinot, Donaldson, and Rodríguez-Clare, 2012, and Melitz and Redding, 2013 and 2014). The other focuses on the empirical implications of the result. In particular, it is now clear that the various models have different implications for the estimated value of the trade elasticity, so that even though the analytical formulation of the gains from trade is the same, the resulting quantification still differs across models (Simonovska and Waugh, 2014a).

In this paper we explore a different route, by focusing on the *sources* of the welfare gains of the open economy with respect to the autarky economy. In particular, we study whether quantitative trade models allow us to quantify not only the overall welfare gains, but also the contribution of the different sources. This is a key issue in both the theoretical and the empirical literature in international trade. The matter is also critical for policy purposes. By understanding what are the most important sources of the welfare gains, countries could design and implement appropriate policies in order to maximize the benefits from trade liberalization and foster economic development.

Answering this question, however, is in general very difficult, because different quantitative models entail different predictions on the sources of the welfare gains. For example, gains from consuming a greater variety of goods are key in Armington and monopolistic competition models, but are absent in Ricardian models. Given these sharp differences, we analyze this question for one specific family of models and investigate whether belonging to the class of quantitative trade models facilitates the measurement of the contribution of the different sources.

The family on which we focus is the Ricardian model with many countries and goods, CES preferences, and general distributions of industry efficiencies. Thus, with respect to Arkolakis, Costinot, and Rodríguez-Clare (2012), although we restrict the attention to only one family of models, we extend the scope of the analysis by providing general results for Ricardian models in which industry efficiencies follow a generic distribution, and not necessarily a Fréchet.

For this general family of models, we show that the welfare gains of the open economy with respect to the autarky economy can always be decomposed into two distinct sources: a *selection* and a *reallocation* effect. The former is the effect on average efficiency of the selection of industries that, thanks to their sufficiently low marginal costs of production relative to foreign industries, survive international competition. Such average efficiency is computed by considering, for the sole industries that survive international competition, the same relative weights in domestic production as the autarky economy. The latter effect, instead, is related to the rise in the weight in domestic production of the exporting industries, which is due to the reallocation of workers away from the less-efficient non-exporting industries to the industries that start servicing the foreign market.

While the model provides very precise theoretical definitions for both effects, their analytical expression is, in general, too cumbersome to be used for empirical purposes. In most applications, in fact, it would require computing several billions of distributions of efficiencies. By contrast, this decomposition simplifies dramatically if we impose that industry efficiencies are Fréchet distributed — the assumption that makes our Ricardian model belong to the class of quantitative trade models. Under this assumption, we can derive exact model-based measures of these two effects, which can be quantified using only data on trade flows and domestic production.

The Fréchet assumption entails this simplification for the following reasons. First, it allows us to easily quantify the gains from trade, as shown by Arkolakis, Costinot, and Rodríguez-Clare (2012). Second, it implies that the selection effect is a measurable share of the overall gains from trade, making it possible to obtain the contribution to welfare of this effect. Third, as a consequence, the reallocation effect (whose quantification is, in the general case, extremely difficult) can be calculated simply as the complement of the selection effect. Therefore, a key insight of our analysis is that quantitative trade models seem to be useful not only to assess the overall welfare gains, but also to properly measure their sources.

Using the Fréchet assumption, we also demonstrate that, when the gains from trade are small and there are still few exporters in the domestic economy, the largest share of the welfare gains is due to the selection effect. As the export sector grows and the gains from trade increase, the importance of the reallocation effect also rises. Because the contribution of the reallocation effect rises with the size of the overall gains from trade, it follows that the factors affecting the former are exactly the same factors affecting the latter. In particular, both the welfare gains and the contribution of the reallocation effect are higher for small, open and very productive economies, located near to markets that are large, rich, and less productive and, therefore, easier to penetrate. Another interesting feature of our result is that the specific value of the trade elasticity, which is key to determine the overall welfare gains, does not affect the shares of the gains pertaining to the selection and the reallocation effect, making their measurement even more straightforward and robust than that of the welfare gains.

A quantification for a sample of 46 advanced and developing economies in the years 2000 and 2005 shows that the selection effect is, on average, somewhat more important than the reallocation effect (accounting for about 60% of the gains from trade). In particular, the selection effect is dominant for large countries: only in the United States and Japan, among the advanced economies, and in Brazil, Russia, India, and China, among the developing countries, does the share of gains pertaining to the selection effect exceeds 80 percent. However, for small open economies such as Denmark, Ireland, the Netherlands, Singapore, Thailand, and Vietnam, it is the reallocation effect that is dominant, as it is responsible for over 70 percent of the gains.

These findings have important policy implications. Suppose that the export sector is less similar to other sectors of the economy in terms of, for example, skills that are required to workers, as documented by the empirical literature.[1] This feature of the export sector could make resource reallocation from other industries slower or more difficult. In this case, our theoretical and empirical results suggest that, in the initial stages of trade liberalization (i.e. when trade barriers are still high), these frictions do not prevent to reap the benefits from trade, because most of the gains obtain from the selection effect, that is from the closure of less efficient industries and the reallocation of workers across all the surviving industries, which are mostly non-exporters. Similarly, large countries can expect to enjoy welfare gains almost in full, even in the hypothesis of a cumbersome reallocation to the export sector, thanks to the considerable size of their non-exporting industries. On the other hand, reallocation of workers to the export sector is crucial in small open economies. Therefore, to fully benefit from trade, these countries must be ready to favor resource reallocation to this sector, in particular by enhancing education and training for unskilled workers.

[1] Bernard, Jensen, Redding and Schott (2007) show, in fact, that exporting firms are more skill intensive than their domestic competitors.

Our paper is related to several strands of the literature. Many recent empirical and theoretical studies have focused on one specific source of the welfare gains, that is aggregate productivity. An early example is Pavcnik (2002), who estimates productivity improvements in Chile using firm-level data. This study confirms the importance of the mechanisms described in this paper, as it finds that the exit of plants and the reshuffling of resources from less efficient to more efficient producers are the main sources of the productivity gains. Many other papers, instead, have focused on model-based measures of the "productivity gains from trade," computed as increases in average efficiency.[2] To better grasp the link between these papers and our own, it is worth recalling that, in the Ricardian model, the growth in world-wide aggregate productivity induced by international trade is the basic source of the welfare gains for all countries. In other words, countries benefit from the fact that, by specializing in the production of the goods for which they have a comparative advantage, the world production of the optimal consumption bundle increases. Thus, our paper sheds light on how each individual country, through the mechanisms of selection and reallocation induced by trade liberalization, contributes to the improvement in world-wide aggregate productivity and reaps the benefits of international trade for its own welfare.

Another related strand of the literature is the wave of papers focusing on empirical estimates of the gains from trade, such as Feenstra (1994 and 2010), Broda and Weinstein (2006), Goldberg, Khandelwal, Pavcnik, and Topalova (2009), and many others. These papers use different econometric techniques to quantify either the contribution of specific sources of gains (usually those from consuming new varieties) or the size of the overall welfare gains. Our approach, instead, grounded on the derivation of model-based measures of the welfare gains, follows more closely the one of Eaton and Kortum (2002), Alvarez and Lucas (2007), Arkolakis, Demidova, Klenow, and Rodríguez-Clare (2008), Ravikumar and Waugh (2009), and Arkolakis, Costinot, and Rodríguez-Clare (2012). Unlike those papers, however, we are also able to quantify the contribution of the different sources of gains.[3]

Given that a big chunk of the related literature focuses on welfare gains in mo-

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[2]See, for example, Bernard, Eaton, Jensen, and Kortum (2003), Costinot, Donaldson, and Komunjer (2012), Bolatto (2013), Finicelli, Pagano and Sbracia (2013a and 2013b), and Levchenko and Zhang (2013).

[3]A close relative of our study is also the paper by Demidova and Rodríguez-Clare (2009), who decompose the welfare gains from trade of a small open economy under monopolistic competition into four terms: productivity, terms of trade, number of varieties, and curvature (i.e. the degree of heterogeneity across varieties). Here, instead, we consider a general equilibrium model with perfect competition and, most importantly, we derive a quantifiable expression of the two sources that, in our Ricardian framework, provide the welfare gains.

nopolistic competition models à la Melitz (2003), it is worth clarifying the differences between these frameworks and the Ricardian one. On the production side, the adjustment that takes place after trade liberalization is very similar in the two frameworks. In both models, in fact, domestic production: (i) focuses only on a subset of the goods that were made under autarky (these are the goods that are made more efficiently with monopolistic competition, and those in which the country has a comparative advantage in Ricardo); (ii) becomes tilted towards exporters (who benefit from foreign demand). On the consumption side, according to both models households consume less of those tradeable goods whose production remains domestic; however: (a) in the Ricardian model, households purchase more of the remaining tradeable goods (because imports are cheaper), so that overall consumption increases, even though they do not gain access to more varieties; (b) in the monopolistic competition model, households start consuming a greater variety of goods. For any country, if the trade elasticity implied by the two models were the same, then the gain from consuming a larger quantity of imported goods in the Ricardian model would be the same as the gain from consuming more imported varieties in frameworks à la Melitz (2003). To put it differently, with identical trade elasticities, "Ricardo's intensive margin" would be equal to "Melitz's extensive margin".[4]

The rest of the paper is organized as follows. Section 2 describes the model, which extends Eaton and Kortum (2002) to general distributions of industry efficiencies. Section 3 shows that the welfare gains induced by international trade can be decomposed into two distinct effects, related to the selection of industries and the reallocation of workers. Section 4 introduces the assumption of Fréchet-distributed industry efficiencies, shows that the analytical expressions of the two effects simplify, and quantifies them for a sample of countries and years. Section 5 draws the main conclusions.

[4]We recall, however, the important caveat, established by Simonovska and Waugh (2014a), that different trade models have different implications about the value of the trade elasticity. These authors, in particular, report point estimates of the trade elasticity that are in a range between 4.0 and 4.6 for the Eaton-Kortum model (see their tables 2 and 3) and between 3.6 and 3.7 for the Melitz model (table 4). This result would imply that welfare gains (which are decreasing in the trade elasticity) are somewhat higher in the latter model. Nevertheless, the empirical question concerning the value of the trade elasticities (and, in turn, of the gains from trade) in the two models seems to be still wide open. Other papers, in fact, do find lower values of the trade elasticity for the Eaton-Kortum model, reporting estimates as low as 3.6 (Eaton and Kortum, 2002) and 2.8 (Simonovska and Waugh, 2014b).

2 The model

We consider a continuum of tradable goods, indexed by $j \in [0, +\infty)$, that can potentially be produced in any of the N countries of the world economy. Each good j can be produced in country i with an efficiency $z_i(j)$ that, in turn, is defined as the amount of output that can be produced with one unit of input — where both output and input are measured in units of constant quality. Any country has a fixed labor endowment L_i. Inputs include labor as well as a bundle of intermediates goods, which comprises the full set of tradable goods j.[5] Technology is described by a Cobb-Douglas production function with constant returns to scale, in which labor has a constant share $\beta \leq 1$ for all industries and countries; namely:

$$q_i(j) = z_i(j)\, L_i^{\beta}(j)\, I_i^{1-\beta}(j) \ , \tag{1}$$

where $q_i(j)$ is the quantity of output j in country i, $L_i(j)$ is the number of workers, and $I_i(j)$ is the quantity of the bundle of intermediate goods.

Consumer preferences are the same across countries. The representative consumer in country i purchases individual goods in amounts $c_i(j)$ in order to maximize a CES utility function:

$$U_i = \left[\int [c_i(j)]^{\frac{\sigma-1}{\sigma}} dj\right]^{\frac{\sigma}{\sigma-1}} \ ,$$

where $\sigma > 0$ is the elasticity of substitution. While the model allows us to deal with both inelastic ($\sigma \leq 1$) and elastic demand ($\sigma > 1$), we will focus on the latter case, because the goods that we consider are all tradable and, in this setting, the typical calibration is $\sigma > 1$.[6]

Consumers maximize their utility function subject to a standard budget constraint. Because we assume that trade is balanced in the open economy, income available for consumption is $Y_i = w_i L_i$, where w_i is the (nominal) wage.

International trade is constrained by barriers, which are modeled using the standard assumption of iceberg costs; i.e., delivering one unit of a good from country i to country n requires shipping d_{ni} units, with $d_{ni} > 1$ for $i \neq n$ and $d_{ii} = 1$ for any i. By arbitrage, trade barriers obey the triangle inequality, so that $d_{ni} \leq d_{nk} \cdot d_{ki}$ for any n, i and k.

Perfect competition implies that the price of one unit of good j produced by

[5] We can ignore physical capital in the production function because the model is static and, then, intermediate inputs play a very similar role.

[6] For an extension of the model that encompasses both tradable and non-tradable goods, see Di Nino, Eichengreen, and Sbracia (2013).

country n and delivered to country i is:

$$p_{in}(j) = \frac{c_n d_{in}}{z_n(j)} \ ,$$

where $c_n = w_n^{\beta} p_n^{1-\beta}$ is the cost of one unit of input in the source country n, with p_n being the unit price of the optimal bundle of intermediate goods, which is the same as the unit price of the optimal bundle of final goods (see equation (3) below). In other words, we assume (as Eaton and Kortum, 2002) that producers combine intermediate goods using the same CES aggregator that consumers use to combine final goods.

Consumers purchase each good from the country that can supply it at the lowest price; therefore, the price of good j in country i is:

$$p_i(j) = \min_n \left(\frac{c_n d_{in}}{z_n(j)} \right) \ .$$

We assume that, in each country i, industry efficiencies $z_i(j)$ are the realizations of a random variable Z_i, with a country-specific cumulative distribution function (c.d.f.) F_i. Because the $z_i(j)$ represent industry efficiencies and there is a continuum of goods, it is natural to assume that Z_i is non-negative and absolutely continuous for each country i. These are the only conditions that we impose, in this and in the following section, on the Z_i's (in Section 4, instead, we assume that the Z_i are Fréchet distributed). As the expert reader may have noticed, we do not impose the standard restriction that the Z_i are mutually independent across countries, but we allow for dependent (correlated) variables.

The continuum-of-goods assumption and the conventional application of the law of large numbers imply that the share of goods for which country i's efficiency is below any real number z is the probability $\Pr(Z_i < z) = F_i(z)$. It is worth noting that, in the autarky economy, all goods are made at home and, then, Z_i is the efficiency distribution of the closed economy.

Given the cost of inputs, the distribution of industry efficiencies translates into a distribution of good prices. More formally, let us denote with P_i the random variable that describes the distribution of good prices in country i; this random variable is defined as:

$$P_i = \min_n \left(\frac{c_n d_{in}}{Z_n} \right) = \left[\max_n \left(\frac{Z_n}{c_n d_{in}} \right) \right]^{-1} \ . \tag{2}$$

The price index in country i, p_i, computed using the correct CES aggregator, is simply the moment of order $1-\sigma$ of the random variable P_i, at the $1/(1-\sigma)$ power; that is:

$$p_i = \left[E\left(P_i^{1-\sigma} \right) \right]^{1/(1-\sigma)} \ . \tag{3}$$

After a simple manipulation of equations (2) and (3), we obtain:

$$\begin{aligned} p_i &= c_i \cdot \left[E\left(M_i^{\sigma-1}\right)\right]^{1/(1-\sigma)} \quad , \\ \text{where } M_i &= \max_n \left(\frac{c_i}{c_n}\frac{Z_n}{d_{in}}\right) \quad , \end{aligned} \tag{4}$$

that leads to the real wage, which measures welfare:[7]

$$\frac{w_i}{p_i} = \left[E\left(M_i^{\sigma-1}\right)\right]^{1/\beta(\sigma-1)} \quad . \tag{5}$$

The welfare gain from trade can be obtained by comparing the real wage of the open and the closed economy, where the latter can be obtained from the former, letting $d_{in} \to +\infty$ for $i \neq n$ (using equations (4) and (5)). In this case, we have $M_i \to Z_i$ and the real wage is $\left[E\left(Z_i^{\sigma-1}\right)\right]^{1/\beta(\sigma-1)}$. Hence, the gain from trade for country i is:

$$g_i = \left[\frac{E\left(M_i^{\sigma-1}\right)}{E\left(Z_i^{\sigma-1}\right)}\right]^{1/\beta(\sigma-1)} \quad . \tag{6}$$

Equation (6) shows that the welfare gain arises from the transformation, that occurs in the open economy, of the "source of the production efficiencies" (efficiencies that, in turn, determine good prices) from Z_i to M_i. Note, in particular, that the latter random variable is a maximum between a set of random variables that includes also Z_i. Because the maximum of a set of random variables first-order stochastically dominates any variable included in the set, then $M_i \succeq Z_i$, so that $g_i \geq 1$.[8] In other words, the real wage is higher in the open economy. Thus, the result that trade is welfare improving is here proven using the language of probability, rather than the tools of general equilibrium.[9]

3 Welfare decomposition

Let us now focus on how labor units are reallocated after opening to trade. To foster intuition, we start by considering the case of two countries, say i and n, before generalizing the result to N countries.

[7] Recall that, in the competitive equilibrium of both the open and the closed economy, welfare is $w_i L_i / p_i$, where L_i is exogenous.

[8] We remind the reader that the random variable X first-order stochastically dominates the random variable Y, and we write $X \succeq Y$, if and only if $F_X(z) \leq F_Y(z)$ for any $z \in \mathbb{R}$, where F_X and F_Y are the c.d.f. of, respectively, X and Y. If this condition holds, then $E\left(X^k\right) \geq E\left(Y^k\right)$, for any $k > 0$.

[9] The finding that $g_i \geq 1$ for any i, proven using basic probability theory, generalizes a result of Finicelli, Pagano, and Sbracia (2013a), extending it to a framework in which there are also intermediate goods.

3.1 A 2-country example

The first-order conditions (FOCs) of the consumer's problem imply that the consumption of good j in country i is:

$$c_i(j) = \left[\frac{p_i(j)}{p_i}\right]^{-\sigma} \cdot U_i \ , \tag{7}$$

where $U_i = w_i L_i / p_i$ is the level of utility achieved by country i.

The FOCs of the producer's problem, on the other hand, imply that the quantities of labor and intermediate goods used to produce good j in country i are chosen according to the following proportions:

$$I_i(j) = \frac{1-\beta}{\beta}\frac{w_i}{p_i} L_i(j) \ . \tag{8}$$

By aggregating across industries both sides of equation (8), we find that the overall amount of intermediate goods used in country i is $I_i = \frac{1-\beta}{\beta} \cdot (w_i/p_i) \cdot L_i$.

The assumption that intermediate goods are combined using the same CES aggregator used to combine final goods implies that, for any country i, the demand for j as intermediate good, $m_i(j)$, is proportional to the demand as consumption good, $c_i(j)$; that is: $c_i(j)/U_i = m_i(j)/I_i$. Because $I_i/U_i = (1-\beta)/\beta$, it follows that, in country i, the demand for good j as an intermediate input is $m_i(j) = (1-\beta) \cdot c_i(j)/\beta$. Hence, in any country i, the overall demand for good j is $c_i(j)/\beta$.

In the two-country model that we are examining, each good can either be produced abroad and imported at home; or be produced at home and sold only in the domestic market; or be produced at home and sold both in the domestic and the foreign market. Therefore, the resource constraint for country i requires that:

$$q_i(j) = \begin{cases} 0 & \text{if } j \in O_{i,z} \\ \frac{1}{\beta} c_i(j) & \text{if } j \in O_{i,d} \\ \frac{1}{\beta}\left[c_i(j) + c_n(j)\, d_{ni}\right] & \text{if } j \in O_{i,e}^n \end{cases} , \tag{9}$$

for any j, where $O_{i,z}$ denotes the set of "zombie" industries of country i, i.e. those industries that shut down right after trade liberalization;[10] $O_{i,d}$ is the set of industries that sell their goods only on the domestic market; and $O_{i,e}^n$ is the set of industries that sell both at home and in country n.[11] By construction, the sets $O_{i,z}$, $O_{i,d}$, and

[10] We borrow the terminology "zombie industries" from Caballero, Hoshi, and Kashyap (2008), who use it to refer to industries that are kept alive only by misdirected or subsidized bank lending. In the context of our model, instead, these industries would be kept alive by trade protectionist policies.

[11] In the two-country model, these sets are defined as follows: $O_{i,z} = \left\{j : \frac{z_i(j)}{c_i} > \frac{z_n(j)}{c_n d_{in}}\right\}$, $O_{i,d} = \left\{j : \frac{z_n(j)}{c_n d_{in}} \leq \frac{z_i(j)}{c_i} > \frac{z_n(j) d_{ni}}{c_n}\right\}$, and $O_{i,e}^n = \left\{j : \frac{z_i(j)}{c_i} \geq \frac{z_n(j) d_{ni}}{c_n}\right\}$.

$O_{i,e}^{n}$ form a partition of the set of tradable goods; hence, the intersection between any subset of them is empty and their union spans the whole set of tradable goods. The set $O_{i,o} \equiv O_{i,d} \cup O_{i,e}^{n}$, on the other hand, includes the sole industries that survive international competition.[12]

By plugging equations (1) and (7) into equation (9) (using also equation (8)), and solving the resource constraint for the number of workers in industry j, we obtain:

$$L_i(j) = \begin{cases} 0 & \text{if } j \in O_{i,z} \\ z_i^{\sigma-1}(j) \cdot \left(\frac{w_i}{p_i}\right)^{\beta(1-\sigma)} L_i & \text{if } j \in O_{i,d} \\ z_i^{\sigma-1}(j) \cdot \left(\frac{w_i}{p_i}\right)^{\beta(1-\sigma)} L_i \cdot (1+k_{ni}) & \text{if } j \in O_{i,e}^{n} \end{cases}, \tag{10}$$

where:

$$k_{ni} = \frac{w_n L_n}{w_i L_i} \left(\frac{p_i d_{ni}}{p_n}\right)^{1-\sigma} . \tag{11}$$

The term k_{ni} measures the rise in the weight of the exporting relative to non-exporting industries. It is related to the demand that comes from country n, since it depends positively on the size of this country in terms of relative GDP, and negatively on the iceberg cost between countries i and n, and their relative price levels.

In the autarky economy, $O_{i,z} = O_{i,e}^{n} = \varnothing$ and the resource constraint returns, for any good j, $L_i(j) = z_i^{\sigma-1}(j) \cdot (w_i/p_i)^{\beta(1-\sigma)} L_i$. Let us consider, then, how labor is reallocated after trade liberalization. With respect to the autarky economy, in the open economy the number of workers in the zombie industries goes to zero. The number of workers in the industries that produce goods that are sold only domestically declines (provided that $\sigma > 1$), because these industries face a tougher competition, due to the fact that imported goods are cheaper than those that were made at home under the autarky regime.[13] The number of workers in the exporting industries rises, absorbing all the workers "in excess" from the other domestic industries. More specifically, these industries sell less in the domestic market (as international competition brings in cheaper imported goods), so they would need less workers to serve this market, but foreign demand allows them not only to keep their workers, but also to hire new ones in order to produce more goods to be sold abroad.[14]

[12] The term $c_n(j)\, d_{ni}/\beta$ in equation (9) represents the foreign demand that benefits only the exporting industries. In particular, the representative consumer of country n demands the quantity $c_n(j)/\beta$, but iceberg costs imply that d_{ni} units must be shipped from country i to deliver one unit of good to country n. Thus, the overall quantity produced to serve the latter market is $c_n(j)\, d_{ni}/\beta$.

[13] If $\sigma < 1$ ($\sigma = 1$), industries producing goods that are sold only at home would employ more (the same number of) workers.

[14] For $j \in O_{i,e}^{n}$, the two terms of equation (10) represent exactly these factors: the number of workers

Notice that, in any industry, the number of workers is proportional to the efficiency of this industry, at the $\sigma - 1$ power (i.e. to $z_i^{\sigma-1}(j)$). By aggregating across industries both sides of equation (10), we can derive the following decomposition of the real wage (which is proven in Appendix A for the general N-country case):

$$\frac{w_i}{p_i} = \left[\underbrace{\lambda_{i,o} \cdot E\left(Z_{i,o}^{\sigma-1}\right)}_{\text{selection}} + \underbrace{\lambda_{i,e} \cdot k_{ni} \cdot E\left(Z_{i,e;n}^{\sigma-1}\right)}_{\text{reallocation}} \right]^{1/\beta(\sigma-1)}, \tag{12}$$

where $\lambda_{i,o}$ is the probability that an industry of country i survives international competition; $\lambda_{i,e}$ is the probability that it is also an exporter (with $\lambda_{i,e} \leq \lambda_{i,o}$);[15] $Z_{i,o}$ is the random variable that describes the efficiencies of the surviving industries; and $Z_{i,e;n}$ describes the efficiencies of the industries that export in country n.

Equation (12) shows — together with equation (10), from which it is derived — the two sources of welfare gains in this model. The first one comes from impact of the *selection* of industries due to international competition, that transforms the average efficiency of the economy from $E(Z_i^{\sigma-1})$ into $E(Z_{i,o}^{\sigma-1})$. The second one comes from the *reallocation* of workers to the exporting industries, which provides a contribution to welfare that is separate and additional to the previous one (measured by the second term inside the square brackets on the right-hand side of (12)).[16] This contribution depends on the strength of foreign demand (as measured by k_{ni}) and is key to the result that trade is welfare improving. In fact, although the real wage always rises after trade openness, the average efficiency does not necessarily rise.[17] Hence, economies in which average efficiency is lower under trade openness, still benefit from trade thanks to this additional reallocation effect. Under broad conditions about the distribution of industry efficiencies, however, also the selection effect provides a positive contribution to welfare and, in the next section, we discuss and quantify both effects for one specific model that fulfils those conditions.[18]

in the exporting industry that serve the domestic market (which declines after trade liberalization) and the number of workers hired to start servicing the foreign market.

[15] The triangle inequality implies that if an industry is an exporter, then it must necessarily sell its goods also in its domestic market.

[16] The efficiencies of the exporting industries are included also in $Z_{i,o}$ (that describes the efficiency of all the surviving industries, including the exporters). Therefore, the contribution of the reallocation effect is distinct from the one that comes from the selection effect.

[17] In other words, the result that $M_i \succeq Z_i$ implies that $E\left(M_i^{\sigma-1}\right) \geq E\left(Z_i^{\sigma-1}\right)$ (i.e. welfare rises after trade openness), even though $E\left(Z_i^{\sigma-1}\right)$ can be either larger of smaller that $E\left(Z_{i,o}^{\sigma-1}\right)$ (average efficiency does not necessarily rise).

[18] Finicelli, Pagano, and Sbracia (2013a) examine the theoretical conditions under which average efficiency across industries rises after opening to trade. In particular, they show that it always rises

Before turning to the quantification, however, let us show how the result generalizes to the case of many countries ($N \geq 2$).

3.2 The N-country case

For the general multi-country framework, in Appendix A we prove that the real wage in each country i has still two components, the selection effect (SE_i) and the reallocation effect (RE_i):

$$\frac{w_i}{p_i} = (SE_i + RE_i)^{1/\beta(\sigma-1)} \quad . \tag{13}$$

The first term inside the brackets of the right hand side of (13) has the same expression as the corresponding term of the two-country case:

$$SE_i = \lambda_{i,o} \cdot E\left(Z_{i,o}^{\sigma-1}\right) \quad . \tag{14}$$

The second term is now more cumbersome:

$$\begin{aligned} RE_i \; = \; & \sum_{n \neq i} \lambda_{i,e;n} \cdot k_{ni} \cdot E\left(Z_{i,e;n}^{\sigma-1}\right) + \\ & + \sum_{n \neq i, h \neq i, n \neq h} \lambda_{i,e;n,h} \cdot (k_{ni} + k_{hi}) \cdot E\left(Z_{i,e;n,h}^{\sigma-1}\right) + \\ & + ... + \lambda_{i,e;1,...,N} \cdot (k_{1i} + ... + k_{Ni}) \cdot E\left(Z_{i,e;1,...,N}^{\sigma-1}\right) \quad , \end{aligned} \tag{15}$$

where $\lambda_{i,e;n,h,...,k}$ is the probability that an industry of country i exports in (and only) countries n, h, ..., and k; while $Z_{i,e;n,h,...,k}$ is the distribution of the efficiencies of these industries.

As shown by equations (12) and (15), in both the cases $N = 2$ and $N > 2$ the magnitude of the reallocation effect is governed by k_{ni} (equation (11)). In particular, k_{ni} and the size of the reallocation effect are larger if country i is relatively more productive (p_i/p_n is low), and if the destination market n is rich (w_n/w_i high), large (L_n is high relative to L_i) and not too far away (d_{ni} low). Thus, geography, which is key in the Ricardian model as shown by Eaton and Kortum (2002), exerts its effects mostly through the reallocation of workers to the export sector.

In principle, quantifying the expressions of (14) and (15) is not an impossible task, although it may be rather daunting. Given the joint distribution of $(Z_1, ..., Z_N)$, in fact,

under very broad assumptions about the country distributions of industry efficiencies; namely: (*i*) if the distributions of efficiencies are independent across countries; (*ii*) for many types of distributions, if their correlations are sufficiently low; (*iii*) regardless of cross-country correlations, if industry efficiencies belong to families of distributions that are widely used in the literature, such as the Fréchet, Pareto and Lognormal.

one can always derive the distribution of any of the $Z_{i,e;n,h,\ldots,k}$, which are just univariate conditional distributions (see Appendix A). However, in empirical applications their number might be extremely large, making their computation a very challenging task. With N countries, one has to compute the distributions of the efficiencies for the industries that export in each of the $N-1$ foreign countries, those for the industries that export in all the possible $N(N-1)/2$ couples of countries, etc.. For instance, in the 46-country application that we consider in the next section, one should have to compute a total of more than 35,000 billions of different distributions (that is $2^{N-1}-1$). In the next section, instead, we show that, by introducing an assumption that transform our general Ricardian model into one of the quantitative trade models of Arkolakis, Costinot, and Rodríguez-Clare (2012), the quantification of the two effects simplifies dramatically.

4 Fréchet-distributed efficiencies

We now assume that, in any country i, industry efficiencies are Fréchet distributed, with parameters T_i and θ;[19] hence, the probability that an industry of country i has an efficiency lower that a positive real number z is $F_i(z) = \exp\left\{-T_i z^{-\theta}\right\}$. For the sake of simplicity, we also assume that these distributions are mutually independent across countries.[20]

The moment of order k of Z_i is:

$$E\left(Z_i^k\right) = T_i^{k/\theta} \cdot \Gamma\left(\frac{\theta - k}{\theta}\right) \ , \tag{16}$$

which exists if and only if $\theta > k$, where Γ is Euler's Gamma function. Because welfare is related to the moment of order $\sigma - 1$ of Z_i, we assume $\theta > \sigma - 1$. The parameter T_i, usually defined as the "state of technology" of country i, captures country i's absolute advantage: an increase in T_i relative to T_n implies an increase in the share of goods that country i produces more efficiently than country n. The shape parameter θ,

[19] Kortum (1997) and Eaton and Kortum (2009) show that the Fréchet distribution emerges from a dynamic model of innovation in which, at each point in time: (i) the number of ideas that arrive about how to produce a good follows a Poisson distribution; (ii) the efficiency conveyed by each idea is a random variable with a Pareto distribution; (iii) firms produce goods using always the best idea that has arrived to them.

[20] The key assumption is that industry efficiencies are Fréchet distributed, while independence can easily be relaxed. In particular, Eaton and Kortum (2002) propose a multivariate Fréchet distribution for industry efficiencies that allows for correlation across countries, and Finicelli, Pagano and Sbracia (2013a) use it to compute the "productivity gains from trade" for different degrees of correlation.

common to all countries, is inversely related to the dispersion of Z_i. It is related to the concept of comparative advantage because, in the Ricardian model, gains from trade depend on the heterogeneity in efficiencies. In this model, a decrease in θ (i.e. higher heterogeneity), coupled with mutual independence, generates larger gains from trade for all countries.

An important property of the model with Fréchet-distributed efficiencies is that the price distribution in country i for the goods imported from country n is the same for any n (and equal to P_i). Thus, for example, source countries with a higher state of technology or lower iceberg costs exploit these advantages by selling a wider range of goods to that country but, in the equilibrium, the price distributions of the goods that the various foreign sources supply to the destination market i are identical (see Eaton and Kortum, 2002, and Arkolakis, Costinot, and Rodríguez-Clare, 2012). A related key property is that, in the open economy: $M_i = Z_{i,o}$.[21] Hence, equation (5) becomes:

$$\frac{w_i}{p_i} = \left[E\left(Z_{i,o}^{\sigma-1}\right)\right]^{1/\beta(\sigma-1)} \quad . \tag{17}$$

We now show how the analytical decomposition of welfare simplifies and how its sources can be quantified under the Fréchet assumption. Combining equation (17) with (13) and using equation (14), it turns out that:

$$RE_i = (1-\lambda_{i,o}) \cdot E\left(Z_{i,o}^{\sigma-1}\right) \ , \tag{18}$$

while it is still $SE_i = \lambda_{i,o} \cdot E\left(Z_{i,o}^{\sigma-1}\right)$.

The welfare gain induced by trade openness (equation (6)) becomes:

$$g_i = \left[\frac{E\left(Z_{i,o}^{\sigma-1}\right)}{E\left(Z_i^{\sigma-1}\right)}\right]^{1/\beta(\sigma-1)} \quad ,$$

that, in turn, can be decomposed as:

$$g_i = \left[\underbrace{\lambda_{i,o} \cdot \frac{E\left(Z_{i,o}^{\sigma-1}\right)}{E\left(Z_i^{\sigma-1}\right)}}_{\text{selection}} + \underbrace{(1-\lambda_{i,o}) \cdot \frac{E\left(Z_{i,o}^{\sigma-1}\right)}{E\left(Z_i^{\sigma-1}\right)}}_{\text{reallocation}}\right]^{1/\beta(\sigma-1)} \quad .$$

In other words, given the overall gain from trade g_i, a share $\lambda_{i,o}$ of the gain is due to the selection effect, while its complement, $1-\lambda_{i,o}$, is due to the reallocation effect.[22]

[21] If the random variables $X \sim Fréchet\,(\xi,\theta)$ and $Y \sim Fréchet\,(\lambda,\theta)$ are independent, then $\max(X,Y) \sim X|X \geq Y \sim Fréchet\,(\xi+\lambda,\theta)$.

[22] In interpreting the shares of the welfare gain due to the selection and the reallocation effect, we can

We can now turn to the measurement. The properties of the Fréchet distribution imply that $Z_{i,o}$ is still a Fréchet, with parameters Λ_i and θ, where:[23]

$$\Lambda_i = T_i + \sum_{i \neq k} T_k \left(\frac{c_k d_{ik}}{c_i} \right)^{-\theta} .$$

It follows that:[24]

$$\frac{E\left(Z_{i,o}^{\sigma-1}\right)}{E\left(Z_i^{\sigma-1}\right)} = \left(\frac{\Lambda_i}{T_i}\right)^{(\sigma-1)/\theta} .$$

To quantify g_i, we borrow from Finicelli, Pagano and Sbracia (2013a, Proposition 5) the result that:

$$\begin{aligned} \Lambda_i &= T_i \cdot \Omega_i \\ \text{where } \Omega_i &\equiv 1 + \frac{IMP_i}{PRO_i - EXP_i} , \end{aligned} \tag{19}$$

in which IMP_i is the value of country i's aggregate imports, PRO_i is the value of its production, and EXP_i is the value of aggregate exports. Thus:

$$g_i = (\Omega_i)^{1/\beta\theta} . \tag{20}$$

This is the same result established by Arkolakis, Costinot, and Rodríguez-Clare (2012) for the larger class of quantitative trade models. In fact, Ω_i^{-1}, which is equal to one minus the import penetration ratio, is the so-called "trade domestic share" (i.e. the share of expenditure on domestic goods), while in this Ricardian model the trade elasticity is $\beta\theta$.

The quantification of the selection and the reallocation effect can be completed once that we derive $\lambda_{i,o}$, which is the probability that an industry of country i survives international competition. Using the properties of the Fréchet distribution, it is easy to find that:

$$\lambda_{i,o} = \frac{T_i (c_i)^{-\theta}}{\sum_k T_k (c_k d_{ik})^{-\theta}} = \frac{1}{\Omega_i} \tag{21}$$

---

safely ignore the complication due to the exponent $1/\beta(\sigma-1)$. In fact, a monotone transformation of the utility function, such as the one that can be obtained by taking U_i at the $\beta(\sigma-1)$ power, would yield the same equilibrium quantities and relative prices. In this transformed model, then, welfare would be the same as in the original model, but at the $\beta(\sigma-1)$ power, making the exponent of the gain from trade equal to 1 (while leaving the base unchanged).

[23] The result follows immediately from the property described in footnote 22 and the fact that if $X \sim Fréchet(\xi, \theta)$ and $a > 0$, then $aX \sim Fréchet(a^{\theta}\xi, \theta)$.

[24] Note that $\Lambda_i > T_i$. In other words, if industry efficiencies are Fréchet distributed, then the average efficiency of the surviving industries is always higher than that of the whole set of domestic industries (i.e. of the set that includes also the industries that shut down after trade liberalization). This feature of the "quantitative Ricardian trade model" is both consistent with the available empirical evidence and it is shared by a large class of Ricardian models (see footnote 15).

Note that, because welfare gains are increasing in Ω_i, it follows that, when gains are larger, the selection effect is less important and the reallocation effect is more important. This result can be readily explained. When gains from trade are small, the selection effect matters mostly because there are few exporters in the domestic economy and, then, the possibilities of reallocating workers in these industries are fewer. On the other hand, as the export sector grows and the gains from trade increase, the importance of the reallocation effect also rises because exporting industries (which are on average more productive) absorb more workers.

What does real data show about the size of these two effects? Table 1 provides a quantification of the welfare gains from trade as well as the contribution of the selection and reallocation effect for a sample of 46 advanced and developing countries in two different years, 2000 and 2005. Gains are computed using equation (20), taking the value of the main parameters from literature. In particular, we assume that the shape parameter is $\theta = 4$, as advocated by Simonovska and Waugh (2014b), and the share of intermediate goods in production is $\beta = 0.33$, a conventional measure of the share of value added in total output. The share of the gains from trade pertaining to the selection and reallocation effects, respectively equal to $\lambda_{i,o}$ and $1 - \lambda_{i,o}$, are computed using equation (21).

Given that the Ricardian theory laid out in this paper best describes trade in manufactures, rather than in natural resources or primary goods, we follow the literature and consider data on the values of domestic production, exports and imports — which is all is needed to compute the gains from trade as well as the contribution of their sources — all referred to the manufacturing sector. In addition, given that the model assumes that trade is balanced, in the application we impose that exports are identical to imports (equal to their average).

For each year, Table 1 shows the percentage increase in welfare due to international trade and the shares (in percentage) due to the selection and the reallocation effect. Results show that gains from trade are considerable (for the cross-country average welfare is almost 60 and 70 percent higher than in autarky in 2000 and 2005). As it is well known, the size of the gains is quite sensitive to the assumptions about the value of the shape parameter and the share of intermediate goods in production. For instance, by taking $\theta = 6.66$ instead of $\theta = 4$ (as Alvarez and Lucas, 2007), the gains would be about 60 percent of those reported in Table 1. By the same token, in the model without intermediate goods ($\beta = 1$), gains from trade would be about one third of those reported in the table.

Overall, the size of the selection effect is somewhat more important than the reallocation effect in our sample of countries (it is close to 60 percent in the year 2000 and

Table 1: Gains from trade and their sources (1)

	Year 2000			Year 2005		
	Welfare gain (%)	Selection effect (%)	Reallocation effect (%)	Welfare gain (%)	Selection effect (%)	Reallocation effect (%)
OECD countries						
Australia	30	70	30	40	64	36
Austria	111	37	63	147	30	70
Belgium-Luxembourg	70	50	50	94	43	57
Canada	87	44	56	74	48	52
Chile	30	70	30	27	73	27
Czech Republic	73	48	52	90	43	57
Denmark	129	33	67	163	28	72
Estonia	n.a.	n.a.	n.a.	242	20	80
Finland	49	59	41	57	55	45
France	44	62	38	49	59	41
Germany	50	59	41	59	54	46
Greece	63	52	48	63	53	47
Hungary	116	36	64	137	32	68
Ireland	133	33	67	151	30	70
Israel	65	52	48	81	46	54
Italy	28	72	28	29	72	28
Japan	11	87	13	13	86	14
Korea	29	72	28	23	76	24
Mexico	45	61	39	47	60	40
Netherlands	226	21	79	n.a.	n.a	n.a.
New Zealand	49	59	41	53	57	43
Norway	66	51	49	68	50	50
Poland	40	64	36	53	57	43
Portugal	56	56	44	67	51	49
Slovak Republic	95	41	59	136	32	68
Slovenia	108	38	62	150	30	70
Spain	37	66	34	41	63	37
Sweden	65	52	48	73	49	51
Switzerland	102	39	61	118	36	64
Turkey	30	71	29	24	75	25
United Kigdom	49	59	41	72	49	51
United States	17	81	19	23	76	24
Non-OECD countries						
Argentina	24	76	25	27	73	27
Brazil	10	88	12	11	87	13
Bulgaria	44	62	38	63	53	47
China	12	87	13	16	83	17
Taiwan	46	60	40	58	55	45
India	13	85	15	23	76	24
Indonesia	32	69	31	24	75	25
Malaysia	55	56	44	56	56	44
Romania	50	59	41	68	50	50
Russian Federation	17	81	19	23	77	24
Singapore	24	36	64	n.a.	n.a.	n.a.
South Africa	25	75	25	26	74	26
Thailand	n.a.	n.a.	n.a.	50	59	41
Vietnam	61	53	47	n.a.	n.a.	n.a.
mean	57	59	41	68	56	44
median	49	59	41	57	55	45
max	226	88	79	242	87	80
min	10	21	12	11	20	13

Source: authors' calculations on OECD STAN data.

(1) Real wage relative to the autarky economy (values of $(g_i - 1)\%$) and contributions of the selection and the reallocation effect (in percentage).

around 55 per cent in 2005). It is worth noting that, *unlike the gains from trade, the two shares remain unchanged irrespectively of the exact value of θ and β.* Unsurprisingly, the reallocation effect is more important in small open economies, such as Denmark, Estonia, Ireland, the Netherlands, Slovenia, Singapore, Thailand, and Vietnam. For these countries, the share of the welfare gains pertaining to the reallocation effect is above 70 percent in at least one year. On the other hand, for large and relatively more closed countries, it is the selection effect that it is dominant. For instance, among the OECD economies, only the United States and Japan record a share of the welfare gains pertaining to the selection effect above 80 percent in at least one year. Among non-OECD economies, only the BRIC countries (Brazil, Russia, India, and China) show the same record as the United States and Japan.

5 Conclusion

This paper provides a deconstruction of the sources of the welfare gains from trade in a Ricardian model. Under general distributions of industry efficiencies, welfare gains arise from two distinct sources. The former is an effect due to the selection of industries that survive international competition. The latter is related to the reallocation of workers away from the industries that shut down, as well as from those selling only in the domestic market, to the industries that start servicing the foreign market. If industry efficiencies are Fréchet distributed, so that the model becomes one of the quantitative trade models of Arkolakis, Costinot and Rodríguez-Clare (2012), these two effects can be easily measured.

Our results also show that the share of the welfare gains due the reallocation effect is larger, the larger is the welfare gain. Thus, countries that can potentially gain more from trade — i.e. small open economies that are close to large, rich, and less efficient markets — would gain mostly from the reallocation effect. Therefore, to fully reap the benefits from international trade, they must be ready to favor the reallocation of resources towards exporting industries, for example supporting workers' education and training.

The key insight from our analysis, however, is that quantitative trade models seem to be useful not only in order to assess the overall welfare gains, but also to properly measure their sources — an issue that deserves to be further explored in future studies tackling other models in this class. The route taken in this paper of using quantitative trade models to measure not only the overall welfare gains from trade, but also the contribution of their sources, appears to be a promising area for theoretical and empirical research.

Appendix

A Welfare decomposition with many countries

In order to prove equation (13), let us start by generalizing the resource constraint (9) to a context with more than just two countries. As in the two-country case, we still have: $q_i(j) = 0$, if $j \in O_{i,z}$ and $q_i(j) = c_i(j)/\beta$, if $j \in O_{i,d}$. Now consider the set of industries of country i that export in (and only) the countries n, h, ..., and k, for any $\{n, h, ..., k\} \in \{1, ..., N\} \setminus \{i\}$, and denote this set by $O_{i,e}^{n,h,...,k}$;[25] the resource constraint for these industries becomes:

$$q_i(j) = \frac{1}{\beta}\left[c_i(j) + c_n(j)\, d_{ni} + c_h(j)\, d_{hi} + ... + c_k(j)\, d_{ki}\right] .$$

Solving the resource constraint for the number of workers in industry j, we obtain:

$$L_i(j) = \begin{cases} 0 & \text{if } j \in O_{i,z} \\ z_i^{\sigma-1}(j) \cdot \left(\frac{w_i}{p_i}\right)^{\beta(1-\sigma)} L_i & \text{if } j \in O_{i,d} \\ z_i^{\sigma-1}(j) \cdot \left(\frac{w_i}{p_i}\right)^{\beta(1-\sigma)} L_i \cdot (1 + k_{ni} + k_{hi} + ... + k_{ki}) & \text{if } j \in O_{i,e}^{n,h,...,k} \end{cases} , \quad (22)$$

where the terms k_{li} are defined as in equation (11), for any destination market l.

Note that the sets $O_{i,z}$, $O_{i,d}$, $O_{i,e}^{n,h,...,k}$ (for any $\{n, h, ..., k\}$ as above) form a partition of the set of tradable goods. By aggregating across industries both sides of equation (22), we obtain the following:

$$\left(\frac{w_i}{p_i}\right)^{\beta(\sigma-1)} = \lambda_{i,d} \cdot E\left(Z_{i,d}^{\sigma-1}\right) + ... + \lambda_{i,e;n,h,...,k} \cdot (1 + k_{ni} + k_{hi} + ... + k_{ki}) \cdot E\left(Z_{i,e;n,h,...,k}^{\sigma-1}\right) + ... \quad (23)$$

where $\lambda_{i,d}$ is the probability that an industry of country i survives international competition and serves only the domestic market (i.e. $\lambda_{i,d} = \Pr(Z_i \in O_{i,d})$); $\lambda_{i,e;n,h,...,k}$ is the probability that an industry of country i exports in (and only) countries n, h, ..., and k (i.e. $\lambda_{i,e;n,h,...,k} = \Pr(Z_i \in O_{i,e}^{n,h,...,k})$); $Z_{i,e;n,h,...,k}$ is the distribution of the efficiencies of these industries (i.e. $Z_{i,e;n,h,...,k} = Z_i | Z_i \in O_{i,e}^{n,h,...,k}$). Considering that:

$$\lambda_{i,o} \cdot E\left(Z_{i,o}^{\sigma-1}\right) = \lambda_{i,d} \cdot E\left(Z_{i,d}^{\sigma-1}\right) + ... + \lambda_{i,e;n,h,...,k} \cdot E\left(Z_{i,e;n,h,...,k}^{\sigma-1}\right) + ... ,$$

[25] The analytical definition of $O_{i,e}^{n,h,...,k}$ is as follows: this set includes all the industries that export in countries n, h, ..., and k, i.e. those for which $z_i(j)/c_i > z_l(j)\, d_{li}/c_l$, for $l = n, h, ..., k$; and excludes those that export in countries different from n, h, ..., and k, i.e. those for which $z_i(j)/c_i < z_l(j)\, d_{li}/c_l$ for $l \neq n, h, ..., k$.

we can conveniently rearrange the right-hand side of equation (23) into the sum of two terms, given by equations (14) and (15). By taking the $1/\beta\,(\sigma - 1)$ power of both sides, we finally obtain equation (13).

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