Grounded by Gravity: 
A Well-Behaved Trade Model with Industry-Level Economies of Scale

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Abstract

We propose a new quantitative framework to study the positive and normative implications of industry-level external economies of scale in economies open to international trade. In contrast to the textbook model, we find that if the strength of external economies is not too high then our model generates patterns of specialization that are consistent with comparative advantage under frictionless trade, and that the model remains tractable even under positive trade costs and satisfies the gravity equation, making the model useful to examine the quantitative importance of external economies. If the strength of external economies is not too high then all countries gain from trade. The presence of scale economies lowers the gains from trade relative to autarky (conditional on trade flows) except if the country specializes in industries with high scale economies, and they amplify the gains from further trade liberalization except if it leads to specialization in industries with low scale economies. Our quantitative analysis reveals that the presence of scale economies implies on average larger gains from removing all tariffs observed in the data, with gains more than tripling for China and more than doubling for some countries, although gains fall for some countries.

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1. Introduction

For over a century trade economists have struggled to understand the positive and normative implications of localized industry-level external economies of scale — see Marshall (1890), Graham (1923), Chipman (1965) and Ethier (1982). Standard models yielded some discomforting results, including “a bewildering variety of equilibria” (Krugman, 1995) — even ones in which trade patterns do not conform to comparative advantage and lead to losses relative to autarky — that render them useless for quantitative analysis. The root of the problem is a circularity whereby the scale of an industry affects its productivity, while an industry’s productivity affects its scale through the impact on the pattern of trade and specialization.

Grossman and Rossi-Hansberg (2010) proposed a two-country Ricardian model with national industry-level external economies of scale (or Marshallian externalities) that avoids this circularity by moving away from perfect competition and assuming Bertrand competition instead. Since firms in each industry understand the implications of their decisions on industry output and productivity, the equilibrium is unique and similar to that in Dornbusch, Fischer and Samuelson (1977) when trade is frictionless. Unfortunately, as shown by Lyn and Rodríguez-Clare (2013a,b), the framework quickly becomes intractable under trade costs.

In this paper we present a new approach to study the consequences of Marshallian externalities in a trade context. We retain the assumption of perfect competition, as in the standard Ricardian model, but relax the implicit assumption in that model that the whole industry produces a single homogeneous good. Instead, we allow for heterogeneity in productivity across a continuum of differentiated goods within each industry, as in Eaton and Kortum (2002, henceforth EK), and show that the model is well behaved if the strength of Marshallian externalities is not too high. In particular, the equilibrium analysis remains tractable even under positive trade costs and satisfies the gravity equation, making the model useful to examine the quantitative importance of Marshallian externalities.\(^1\)

The multi-industry Ricardian model with Marshallian externalities turns out to be

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\(^1\)Our analysis restricts to the case of Marshallian externalities, which operate inside each industry. An alternative case is the one in which some of the externalities operate across industries, as for example studied in Yatsynovich (2017) for the case with frictionless trade.
isomorphic to a generalized version of the multi-industry Krugman (1980) model of
product differentiation with internal economies of scale, as well as a generalized
version of the multi-industry Melitz (2003) model. The common mathematical struc-
ture that characterizes the equilibrium in all these multi-industry gravity models is
governed by two industry-level elasticities: the elasticity of bilateral trade flows with
respect to bilateral trade costs, commonly referred to as the trade elasticity; and the
elasticity of productivity with respect to industry size, which we will refer to as the scale
elasticity. We show that the equilibrium properties of the model depend critically on
whether the product of these two elasticities is higher or lower than one. If this prod-
uct is higher than one in some particular industry then any pattern of cross-country
specialization in which a non-empty set of countries are the sole suppliers in that in-
dustry is consistent with equilibrium. Otherwise, the pattern of specialization is always
consistent with comparative advantage under frictionless trade, and the model remains
tractable in the presence of trade costs.

In the second half of the paper we use our unified framework to study the impli-
cations of scale economies for the welfare effects of trade. We first establish that all
countries gain from trade relative to autarky as long as the product of the trade and
scale elasticities is weakly lower than one in all industries. This is so even if the scale
elasticity differs across industries, an important finding in light of previous results with
this type of model where countries could lose from opening up to trade.

We extend the “sufficient statistics approach” to the quantification of the gains from
trade (i.e., the negative of the welfare change caused by a move to autarky) in Arkolakis,
Costinot and Rodriguez-Clare (2012) (henceforth ACR) to multi-industry models with
scale economies. The isomorphism that ACR establish across single-industry models
now applies to multi-industry models as well: for the same industry-level trade and
scale elasticities, the models deliver the same gains from trade and the same counter-
factual implications given trade and production data. More generally, given trade and

\[2\text{Abdel-Rahman and Fujita (1990), Allen, Arkolakis and Takahashi (2014) and Redding (2016) explore
similar isomorphisms for spatial equilibrium models in the economic geography literature.}

\[3\text{A similar threshold plays an important role in quantitative economic geography settings such as those
described in Allen and Arkolakis (2014). See Kucheryavyy, Lyn and Rodriguez-Clare (2019) for a detailed
discussion.}

\[4\text{In Section 4 we formalize what we mean by saying that the pattern of specialization is "consistent with
comparative advantage," and discuss results for the more general case with trade costs.}

\[5\text{See, for example, Ethier (1982).}
scale elasticities, we derive a general formula for the gains from trade in terms of the share of industry-level expenditure allocated to domestic goods, as well as the share of a country’s expenditure and revenue allocated to each industry. We use this formula to explore the way in which scale economies affect the gains from trade.

For the simple case in which the scale elasticity is the same across industries, we find that the gains from trade are lower with scale economies than without. This result may seem counterintuitive, but the reader should keep in mind that the gains from trade are defined as conditional on trade shares, so that — as in ACR and Costinot and Rodríguez-Clare (2014) — we can compare the gains from trade implied by different models that are consistent with the same data. Thus, the intuition that scale economies should lead to larger gains from trade through deeper industry-level specialization and larger trade flows is simply not operative here, although as we explain below this intuition is relevant for the gains from trade liberalization, defined as the welfare effects of a counterfactual decline in trade costs starting at the observed equilibrium.

So why do scale economies lead to lower gains from trade? The move back to autarky implies a reallocation of labor across industries that, in the presence of scale economies, leads to productivity gains in expanding industries and productivity losses in contracting industries. Since the industries that expand are those where the country has positive net imports, it must be that they have a high expenditure share or a low employment share. A higher expenditure share implies that a given productivity gain matters more for welfare, whereas a low employment share implies that a given absolute increase in employment leads to a higher proportional expansion and a higher productivity gain. As a result, a move back to autarky generates an expenditure-weighted average productivity improvement, implying lower welfare losses. A corollary of this reasoning is that the decline in the gains from trade from the presence of economies of scale is stronger for economies that exhibit a higher degree of industry-level specialization.

The previous results are specific to the case in which the scale elasticity is the same across industries. If the scale elasticity varies across industries, the implication of economies of scale depends not only on the degree of industry-level specialization, but also on its pattern. Everything else equal, countries that happen to specialize in industries with high scale elasticities will gain more from trade than countries that specialize in
industries with low scale elasticities. Countries that specialize in industries with high scale elasticities may even gain more from trade in the presence of economies of scale compared to the standard model without them.

We next consider two simple cases for which we can analytically characterize the impact of scale economies on the gains from trade liberalization: first, a case of two mirror-image countries, and, second, a case with exogenous wages. In the first case we find that the gains from trade liberalization are higher with scale economies than without, a reflection of the magnified response of industry-level specialization and trade to the decline in trade costs in the presence of economies of scale. In the second case we find that countries lose from unilateral trade liberalization if the product of the trade and scale elasticities is above a threshold value that is a function of industry-level import and export shares, and we argue that this is a straightforward implication of the fact that trade liberalization leads to further specialization in an industry with relatively weak external economies of scale, a generalization of a key result in Venables (1987).

We complement our exploration of the effect of scale economies on the gains from trade and the gains from trade liberalization by applying our framework to data from the World Input Output Database (WIOD, Timmer et al., 2015) in 2008. A key ingredient for this quantitative analysis is a set of values for industry-level trade and scale elasticities. We take those from Bartelme et al. (2018), who set trade elasticities at the median value of recent estimates in the literature, and estimate scale elasticities using an approach motivated by the model we have developed in this paper. The effects of scale economies on the gains from trade discussed above turn out to be quantitatively important. For example, they lead to an increase in the gains from trade for Germany, from 5.9% to 6.6%, and Korea, from 6.9% to 7.5%, but a decrease for Greece, from 5.9% to 4.3%, and most prominently for Russia, from 2.8% to 1.2%.

We also use the model to quantify the welfare implications of removing all tariffs observed in the data. We find that the presence of scale economies implies on average larger gains from the removal of all tariffs, with gains more than tripling for China and more than doubling for some countries. Still, gains from trade liberalization fall for countries that are pushed to specialize in industries with relatively low economies of

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6Lashkaripour and Lugovskyy (2019) have also estimated sector-level trade and scale elasticities in an environment compatible with our model. Reassuringly, the estimates in both of these papers satisfy the condition that the product of the trade and scale elasticities be lower than one in all sectors.
scale. The most dramatic example of this force is for Russia and Mexico, which experience welfare losses that are twice and three times as large with economies of scale than without, respectively.

We end with a quantitative exploration of the effect of scale economies on industry specialization and trade flows. We find that the removal of economies of scale implies a decline in the degree of specialization and total trade, but the effects are small, implying that scale economies are much less important than Ricardian comparative advantage in driving industry-level specialization.

Our welfare analysis is related to that in Costinot and Rodríguez-Clare (2014), who compute both gains from trade and gains from trade liberalization for multi-industry economies under perfect and monopolistic competition. Compared to that paper, we further establish analytically that all countries gain from trade as long as the product of the trade and scale elasticities is weakly lower than one in all industries, we connect a country’s decline in the gains from trade to its degree of industry specialization, we analyze how varying scale elasticities across industries interact with a country’s inter-industry trade pattern to affect its gains from trade, and we connect the results for the gains from trade liberalization to the insights in Venables (1987).

Our paper is also related to Somale (2018), who introduces sector-specific innovation into a multi-sector Eaton and Kortum (2002) model (via mechanisms from Eaton and Kortum, 2001) to quantify its implications for welfare. Interestingly, although the model in Somale (2018) is dynamic, the balanced growth path is also characterized by the same system of equations as all the models that we consider in this paper, and so our results extend to this case as well. Somale (2018) also studies the quantitative importance of scale economies in determining industry-level specialization, but whereas he focuses on the variance of comparative advantage, we compare direct measures of trade and specialization between the data and those that would arise in a counterfactual world where everything is the same except that there are no economies of scale.7

7Our paper is also related to Caliendo et al. (2015), who compute the gains from trade liberalization in a multi-industry Melitz model extended to allow for intermediate goods as in Caliendo and Parro (2015). Our focus is on the theoretical properties of the model, including isomorphisms across different microfoundations for economies of scale as well as understanding the properties of equilibria and the mechanisms through which economies of scale affect gains from trade and gains from trade liberalization.
2. A Ricardian Model with Marshallian Externalities

We extend the multi-industry EK model as in Costinot, Donaldson and Komunjer (2012, henceforth CDK) to allow for Marshallian externalities. Formally, there are $N$ countries indexed by $n$, $i$ and $l$, and $K$ industries or sectors indexed by $k$. Each industry is composed of a continuum of goods or varieties $\omega \in \Omega \equiv [0,1]$. The only factor of production is labor, which is immobile across countries and perfectly mobile across industries within a country. We use $\bar{L}_i$ and $w_i$ to denote the inelastic labor supply and the wage level in country $i$, respectively. Each country has a representative consumer with upper-tier Cobb-Douglas preferences with industry-level expenditure shares $\beta_{i,k} \in \mathbb{R}^K_+$ for all $(i,k)$ with $\sum_{k=1}^K \beta_{i,k} = 1$ for all $i$, and lower-tier CES across varieties within an industry with elasticity of substitution $\sigma_k$. Trade costs are of the standard iceberg type, so that delivering a unit of any industry $k$ good from country $i$ to country $n$ requires shipping $\tau_{ni,k} \geq 1$ units of the good, with $\tau_{ii,k} = 1$ for all $i$ and all $k$ and $\tau_{ni,k} \leq \tau_{ni,k} \tau_{il,k}$ for all $n, l, i$ and $k$ (triangular inequality).

The production technology exhibits constant or increasing returns to scale due to national external economies of scale at the industry level (i.e., Marshallian externalities). In particular, labor productivity for good $\omega$ in industry $(i,k)$ is $z_{i,k}(\omega)L_{i,k}^{\phi_k}$, where $z_{i,k}(\omega)$ is an exogenous productivity parameter, $L_{i,k}$ is the total labor allocated to industry $(i,k)$, and $\phi_k$ is the industry-specific parameter that governs the strength of Marshallian externalities (i.e., the elasticity of industry productivity with respect to industry size), which we refer to as the scale elasticity in industry $k$. We model $z_{i,k}(\omega)$ as in EK: $z_{i,k}(\omega)$ is independently drawn from a Fréchet distribution with shape parameter $\theta_k$ and scale parameter $T_i,k$.

There is perfect competition, and the positive effect of industry size on productivity, $L_{i,k}^{\phi_k}$, is external to the firm. Thus, firms take as given both prices and unit costs, which are given by $c_{ni,k}(\omega) = \frac{\tau_{ni,k} w_i}{z_{i,k}(\omega)L_{i,k}^{\phi_k}}$. This implies that $p_{ni,k}(\omega) = c_{ni,k}(\omega)$. Since consumers can shop for the best deal around the world, prices must satisfy

$$p_{n,k}(\omega) = \min_{1 \leq i \leq N} \{p_{ni,k}(\omega)\}.$$  

Let $X_{ni,k}$ denote the total expenditure of country $n$ on goods in industry $(i,k)$, and
let \( \lambda_{ni,k} \equiv X_{ni,k}/\sum_{l=1}^{N} X_{nl,k} \) denote industry-level bilateral trade shares. Following the procedure in EK yields

\[
\lambda_{ni,k}(w, L_k) = \frac{T_{i,k}L_{i,k}^\alpha (w_{i, \tau_{ni,k}})^{-\theta_k}}{\sum_i T_{i,k}L_{i,k}^\alpha (w_{i, \tau_{ni,k}})^{-\theta_k}},
\]

where \( w = (w_1, ..., w_N) \) is the vector of wages, \( L_k \equiv (L_{1,k}, ..., L_{N,k}) \) is the vector of labor allocations to industry \( k \) across all countries, and \( \alpha_k \equiv \theta_k \phi_k \). In turn, the price index for industry \( k \) in country \( n \) is

\[
P_{n,k} = \gamma_k \left( \sum_i T_{i,k}L_{i,k}^\alpha (w_{i, \tau_{ni,k}})^{-\theta_k} \right)^{-1/\theta_k},
\]

and the aggregate price index is

\[
P_n = \tilde{\beta}_n \prod_{k=1}^{K} P_{n,k}^{\tilde{n}_{n,k}},
\]

where \( \gamma_k \) and \( \tilde{\beta}_n \) are some constants.\(^8\)

To write down the equilibrium condition for each industry \((i, k)\), it is important to note that Marshallian externalities imply that — in contrast to the CDK model — some industries could have zero labor allocations (i.e., \( L_{i,k} = 0 \)). Therefore, we need to be careful when formulating the market equilibrium conditions in our model. By analogy with the standard Ricardian model, the complementary slackness conditions require the price to be weakly lower than the unit cost, with equality if there is positive production in the industry.\(^9\) Multiplying both the price and the unit cost by labor productivity (adjusted by trade costs), this is the same as requiring that revenue per worker be weakly lower than the wage, with equality if there is positive employment in the industry, i.e.,

\[
G_{i,k}(w, L_k) \equiv w_i - \frac{1}{L_{i,k}} \sum_{n} \lambda_{ni,k}(w, L_k) \beta_{n,k} w_n \tilde{l}_n \geq 0.
\]

The equilibrium labor allocation in industry \((i, k)\) must satisfy the following comple-

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\(^8\)Specifically, \( \gamma_k = \Gamma \left( \frac{1-\sigma_k + \theta_k}{\theta_k} \right)^{1/\sigma_k} \), where \( \Gamma \) is the Gamma function, and \( \tilde{\beta}_n \) is the standard Cobb-Douglas term \( \tilde{\beta}_n = \prod_k \beta_{n,k}^{-1/\theta_k} \).

\(^9\)Formally, we need both the industry-level and good-level complementary slackness conditions. However, the good-level complementary slackness conditions are standard in the solution of the EK-type framework with probabilistic technologies and so we omit them in this paper.
mentary slackness condition:

\[ L_{i,k} \geq 0, \quad G_{i,k}(\mathbf{w}, L_k) \geq 0, \quad L_{i,k}G_{i,k}(\mathbf{w}, L_k) = 0. \] (4)

The last equality is the standard industry clearing condition from CDK. And since in that model the equilibrium labor allocations are strictly positive for all \((i, k)\), the first and second inequalities above are automatically satisfied in any equilibrium.

It is worth emphasizing here that the standard result in the classic Ricardian model with industry-level economies of scale — where zero employment in an industry implies that productivity is zero, which then justifies zero employment — does not necessarily hold in our setting because the productivity of each good within an industry is a random draw from a Fréchet distribution, which is unbounded above. Thus, as the size of the industry becomes vanishingly small, the goods produced would be the ones for which the country’s productivity is infinitely high, and this could overcome the Marshallian forces that push productivity to zero.\(^\text{10}\) This balance of forces is captured by the function \(G_{i,k}(\mathbf{w}, L_k)\), whose range is assumed to include infinity and hence to be well-defined even for \(L_{i,k} = 0\). As we will discuss further below, if the Marshallian force dominates, then \(G_{i,k} = 0\) when \(L_{i,k} = 0\) and such a corner is compatible with equilibrium, whereas if the EK force dominates then \(G_{i,k} = \infty\) when \(L_{i,k} = 0\) and it is not.

Finally, the labor-market clearing condition for any country \(i\) is the same as in CDK:

\[ \sum_k L_{i,k} = \bar{L}_i. \] (5)

Denote by \(\mathbf{L} = (L_1, \ldots, L_k)\) the vector of labor allocations across industries. The equilibrium of the economy is a wage vector and labor allocation \((\mathbf{w}, \mathbf{L})\) such that (4) holds for all \((i, k)\) and (5) holds for all \(i\). Before characterizing the equilibrium for our model with Marshallian externalities, we first show isomorphisms between our model and other workhorse models in trade. A consequence is that our characterization of equilibrium will apply to these other settings as well.

\(^{10}\)The fact that the productivity of goods produced goes to infinity as the industry becomes vanishingly small is a standard trade-driven selection that arises in the multi-industry EK model – see CDK.
3. A Common Framework

In this section we discuss how generalized multi-sector versions of the models in Krugman (1980) and Melitz (2003) lead to the same equilibrium conditions as the model of the previous section, except of course that the trade and scale elasticities correspond to different structural parameters. At the end of the section we introduce new notation for the trade and scale elasticities ($\varepsilon_k$ and $\psi_k$ respectively) that is valid across models with different micro-foundations.\textsuperscript{11,12}

As we discuss below, a multi-sector version of Krugman (1980) would imply that $\alpha_k = 1$ for all $k$. To add flexibility and allow for $\alpha_k \neq 1$, we assume that the elasticity of substitution across varieties from different countries can differ from the elasticity of substitution across varieties from the same country. Specifically, there is a continuum of differentiated varieties within each industry, and preferences are multi-tiered: Cobb-Douglas across industries with weights $\beta_{i,k}$, CES across country bundles within an industry with elasticity of substitution $\eta_k$, and CES across varieties within a country bundle with elasticity of substitution $\sigma_k > 1$.\textsuperscript{13} Everything else is as in the standard Krugman model: labor is the only factor of production and the total labor cost of producing quantity $q$ of any variety in industry $(i, k)$ is $F_{i,k} + q / A_{i,k}$, where labor productivity $A_{i,k}$ and fixed cost $F_{i,k}$ are exogenous but can vary across industry-country pairs.

In Appendix A we show that the expressions for trade shares and industry price indices in this generalized-Krugman model collapse to those in equations (1) and (2) but now with trade and scale elasticities given by $\eta_k - 1$ and $(\sigma_k - 1)^{-1} - 1$, respectively, and $\alpha_k = \eta_k - 1 / (\sigma_k - 1)$. If $\sigma_k = \eta_k$ for all $k$ then this is just the standard multi-industry Krugman model and $\alpha_k = 1$.\textsuperscript{14} See rows 2 and 4 of Table 1.\textsuperscript{15}

\textsuperscript{11} As is customary in the quantitative trade literature, the trade elasticity is defined as the elasticity of bilateral trade flows with respect to bilateral trade costs, holding wages and productivity constant — see Arkolakis \textit{et al.} (2012).

\textsuperscript{12} In a similar spirit, Helpman and Krugman (1985) provide an integrated framework for international trade in the presence of different returns to scale and market structures. While their analysis is theoretical and limited to the case of frictionless trade, we focus on gravity models and the quantitative implications of scale economies for trade flows and welfare.

\textsuperscript{13} Feenstra \textit{et al.} (2014) also consider a multi-industry Melitz-Pareto model with possibly different elasticities of substitution across varieties from different countries and across varieties from the same country.

\textsuperscript{14} Note also that if $\sigma_k \to \infty$, then $(\eta_k - 1) / (\sigma_k - 1) \to 0$ and we obtain the multi-industry Armington model.

\textsuperscript{15} It is straightforward to incorporate Marshallian externalities into the multi-industry Krugman model presented above. For instance, letting $A_{i,k} \equiv A_{i,k} L_{i,k}^\phi$ leads to scale and trade elasticities $(\sigma_k - 1)^{-1} + \phi_k$ and $\eta_k - 1$, respectively.
Now consider the Melitz (2003) model with Pareto distributed productivity and the same preferences as in the Krugman model above. After paying a fixed “entry” cost $F_{i,k}$ in units of labor in country $i$, firms are able to produce a variety in industry $(i,k)$ with labor productivity drawn from a Pareto distribution with shape parameter $\theta_k > \sigma_k - 1$ and location parameter $b_{i,k}$. Firms from $i$ can then pay a fixed “marketing” cost $f_{n,k}$ in units of labor of $n$ to serve that market.\textsuperscript{16,17} As shown in Appendix A, the expressions for trade shares and industry price indices in this model collapse to those in equations (1) and (2) but now with trade and scale elasticities given by $\frac{\theta_k}{1+\theta_k(\frac{1}{\sigma_k-1} - \frac{1}{\sigma_k-1})}$ and $1/\theta_k$, respectively. Again, if $\sigma_k = \eta_k$ for all $k$ then this is just the standard multi-sector Melitz-Pareto model and $\alpha_k = 1$ for all $k$. See rows 3 and 5 in Table 1.

In Appendix A we show that both the generalized multi-sector Krugman and Melitz models lead to an equilibrium system that is equivalent to the one for the model presented in Section 2, except for constants that play no role for equilibrium analysis and comparative statics.\textsuperscript{18} We can then think of a common framework that nests the multi-sector EK model with Marshallian externalities of Section 2 as well as the Krugman and Melitz models presented in the current section. We refer to this common framework in the remainder of the paper, and use notation $\epsilon_k$ and $\psi_k$ to denote the trade and scale elasticities, $S_{i,k}$ to capture industry productivity, and $\mu_{n,k}$ for the constant affecting the price index. With $\alpha_k \equiv \epsilon_k \psi_k$, the expressions for trade shares and price indices are now

\[
\lambda_{ni,k}(w, L_k) = \frac{S_{i,k} L_{i,k}^{\alpha_k} (w_l \tau_{ni,k})^{-\epsilon_k}}{\sum_l S_{l,k} L_{l,k}^{\alpha_k} (w_l \tau_{nl,k})^{-\epsilon_k}} \quad (6)
\]

and

\[
P_{n,k} = \mu_{n,k} \left( \sum_l S_{l,k} L_{l,k}^{\alpha_k} (w_l \tau_{nl,k})^{-\epsilon_k} \right)^{-1/\epsilon_k} \quad (7)
\]

\textsuperscript{16}To simplify the analysis, we assume that the fixed marketing cost to serve destination $n$ does not vary across origins $i$. Allowing these fixed costs to vary across country pairs would not change any of our main conclusions below.

\textsuperscript{17}The assumption that fixed marketing costs are paid in units of labor of the destination country is critical for the result that this model collapses to the general structure introduced above. This is related to the discussion in ACR about how their macro-level restriction R3′ obtains in the Melitz-Pareto model if and only if the fixed cost is paid in units of labor of the destination country.

\textsuperscript{18}This is true in the Melitz model under the balanced trade assumption. If a comparative statics exercise involves changing trade deficits, then the outcome of the Melitz model would not be equivalent to the outcome of the other two models. We ignore this issue in the analysis that follows and recognize that, whenever our comparative static exercises involve changing trade deficits, the results apply only to the Ricardian and Krugman models.
The Krugman and Melitz models provide different ways to micro-found external economies of scale. The source of economies of scale in the Krugman model is the love-of-variety effect: keeping everything else constant, a one log point increase in $L_{i,k}$ leads to a proportional increase in the number of varieties produced in industry $(i, k)$, which has an effect equivalent to an increase in productivity of that industry (in log points) of $1/(\sigma_k - 1)$. The source of economies of scale in the Melitz model is the selection effect: keeping everything else constant, a one log point increase in $L_{i,k}$ leads to a proportional increase in firm entry and an increase in productivity thresholds for industry $(i, k)$ for selling in any market, and an effect equivalent to an increase in productivity of that industry (in log points) of $1/\theta_k$.

### Table 1: Mapping to Different Models

<table>
<thead>
<tr>
<th>Model</th>
<th>Trade elasticity, $\varepsilon_k$</th>
<th>Scale elasticity, $\psi_k$</th>
<th>$\alpha_k = \varepsilon_k \psi_k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDK with ME</td>
<td>$\theta_k$</td>
<td>$\phi_k$</td>
<td>$\theta_k \phi_k$</td>
</tr>
<tr>
<td>Multi-Sector Krugman</td>
<td>$\sigma_k - 1$</td>
<td>$\frac{1}{\sigma_k - 1}$</td>
<td>1</td>
</tr>
<tr>
<td>Multi-Sector Melitz-Pareto Model</td>
<td>$\theta_k$</td>
<td>$\frac{1}{\theta_k}$</td>
<td>1</td>
</tr>
<tr>
<td>Generalized Multi-Sector Krugman</td>
<td>$\eta_k - 1$</td>
<td>$\frac{1}{\eta_k - 1}$</td>
<td>$\frac{\eta_k - 1}{\sigma_k - 1}$</td>
</tr>
<tr>
<td>Generalized Multi-Sector Melitz-Pareto</td>
<td>$\frac{\theta_k}{1 + \theta_k \left( \frac{1}{\eta_k - 1} - \frac{1}{\sigma_k - 1} \right)}$</td>
<td>$\frac{1}{\theta_k}$</td>
<td>$\frac{1}{1 + \theta_k \left( \frac{1}{\eta_k - 1} - \frac{1}{\sigma_k - 1} \right)}$</td>
</tr>
</tbody>
</table>

### 4. Characterizing Equilibrium

We now turn to characterizing the equilibrium of the multi-sector gravity model with industry-level economies of scale. The analysis proceeds in two steps: we first characterize the equilibrium labor allocations given wages, and then we characterize wages that satisfy labor market clearing given the corresponding equilibrium labor allocations. This proves convenient because our stronger result is for labor allocation given wages, where we have a sharp necessary and sufficient condition for uniqueness that includes both the Krugman and Melitz-Pareto type models, and also this is where we characterize intuitive parameter restrictions for whether the equilibrium exhibits cor-
ners or not.

**Two-Step Equilibrium Definition.** The equilibrium labor allocations for some wage vector \( w \) are given by \( L \) that satisfy (4) for all \((i,k)\). Let \( \mathcal{L}(w) \) be the set of such equilibrium allocations. A wage vector \( w \) is an equilibrium wage vector if there exists an element \( L \in \mathcal{L}(w) \) such that \( L \) also satisfies (5) for all \( i \).

Note that given wages, for each industry \( k \) we have a system of \( N \) nonlinear complementary slackness conditions in \( L_{i,k} \) for \( i = 1,...,N \) specified by (4). For the first step we exploit the fact that this system is independent across \( k \).

We now introduce some additional notation and definitions.

**Interior, Corner and Complete Specialization Allocations.** An allocation \( L_k \) is an interior allocation if \( L_{i,k} > 0 \) for all \( i \); an allocation \( L_k \) is a corner allocation if \( L_{i,k} = 0 \) for at least one \( i \); and an allocation \( L_k \) is a complete specialization allocation if there is a unique \( i^*(k) \) such that \( L_{i,k} = 0 \) for all \( i \neq i^*(k) \).

**Industry-Level Equilibrium Labor Allocations.** Given wage \( w \), \( \mathcal{L}_k(w) \) denotes the set of equilibrium labor allocations in industry \( k \), i.e., for any \( L_k \in \mathcal{L}_k(w) \), \( L_k \) satisfies complementary slackness conditions (4) for industry \( k \).

### 4.1. Step 1: Equilibrium Labor Allocations

Given the previous definitions, we are now ready to state our first Proposition. The formal proof is provided in Appendix B.

**Proposition 1.** If either (a) \( 0 \leq \alpha_k < 1 \), or (b) \( \alpha_k = 1 \) and the matrix \( \{\tau_{ni,k}^{-\epsilon k} \}_{n,i} \) is non-singular, then the set \( \mathcal{L}_k(w) \) is a singleton; if \( \alpha_k > 1 \), then the set \( \mathcal{L}_k(w) \) contains multiple allocations, including (but not necessarily limited to) one for each complete specialization allocation. Moreover, the unique allocation in \( \mathcal{L}_k(w) \) is an interior allocation if \( 0 \leq \alpha_k < 1 \), while it may be an interior or a corner allocation if \( \alpha_k = 1 \).

We now provide some intuition for this result, focusing for concreteness on the Ricardian specification. We can think of a battle between two forces that are activated

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\(^{19}\)The assumption of upper-tier Cobb-Douglas preferences plays an important role in allowing the system to be independent across industries. More generally, industry-level expenditure shares, \( \beta_{n,k} \), in (3) need not be fixed and would be a function of prices across all sectors, thereby, breaking the independence property. As is well known, with upper-tier CES preferences and a high-enough elasticity of substitution, there would be multiple equilibria even in autarky.
as the labor allocation to an industry vanishes. The first is intra-industry Fréchet heterogeneity — a force for cross-country industry diversification with strength \(1/\theta_k\) — which implies that labor productivity increases to infinity as fewer and fewer goods are produced in an industry. The second is Marshallian externalities — a force for cross-country industry specialization with strength \(\phi_k\) — which implies that productivity falls to zero as industry employment falls to zero. For \(\alpha_k \in (0,1)\) we have that \(1/\theta_k > \phi_k\) and the force for diversification dominates the one for specialization, implying a unique and strictly positive equilibrium labor allocation across countries.\(^{20}\) For \(\alpha_k > 1\) we have that \(1/\theta_k < \phi_k\) and the converse holds, implying multiple equilibria since now complete specialization in any country is an equilibrium.\(^{21}\) Finally, for \(\alpha_k = 1\) the two forces are in balance so uniqueness requires an additional force of industry diversification in the form of strictly positive trade costs, as guaranteed by the assumption that the matrix \(\{\tau_{ni,k}\}_{n,i}\) is non-singular.\(^{22}\)

### 4.2. Step 2: Equilibrium Wages

In the Online Appendix we show formally that an equilibrium always exists.\(^{23}\) There we also show that \(\alpha_k \leq 1\) for all \(k\) is a necessary condition for unique equilibrium wages, a direct consequence of Proposition 1. We next provide a Proposition that characterizes sufficient conditions for a unique equilibrium in the absence of trade costs, and then provide a brief description of results for the more general case with trade costs. All proofs are provided in the Online Appendix.

**Proposition 2.** If \(0 \leq \alpha_k \leq 1\) and trade is frictionless in all industries, then there is a unique wage equilibrium.

Combined with Proposition 1, this result implies that the labor allocation is unique

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\(^{20}\)Two assumptions in the EK framework are important here: first, that the Fréchet distribution is unbounded above — this is critical to have labor productivity grow to infinity as the industry shrinks; and second, that there is a continuum of goods within each industry is also of consequence — with a finite number of goods the maximum productivity would be finite, and there would be multiple equilibria.

\(^{21}\)An important example of this obtains when \(1/\theta_k \rightarrow 0\), which leads to a degenerate productivity distribution across goods within an industry, and our model collapses to the classic Ricardian model with Marshallian externalities.

\(^{22}\)In the Online Appendix we comment on the role of this assumption and discuss sufficient conditions under which it holds.

\(^{23}\)See Somale (2018) for related existence results in a dynamic version of the multi-industry EK model (with dynamics via mechanisms from Eaton and Kortum, 2001) whose balanced growth path is also characterized by the same system of equations as all the models that we consider in this paper.
in industries with $\alpha_k < 1$. If there are two or more industries with $\alpha_k = 1$ then there can be a continuum of labor allocations in knife-edge cases when $S_{i,k} w_i^{-\varepsilon_k - 1}$ is the same for two or more countries, just as in the standard Ricardian model. Regardless of whether labor allocations are unique or not, however, the pattern of specialization is always compatible with comparative advantage.24

In a setting with trade frictions, we show formally that the condition $\alpha_k \leq 1$ for all $k$ also guarantees that the equilibrium is unique in two special cases: that of a small open economy, and that of two countries, with the latter requiring the additional regularity condition on trade costs in Proposition 1 for the case with $\alpha_k = 1$. Despite extensive simulation analysis, we have never encountered an instance of multiple equilibria even with more than two countries.25 We take this as evidence that the model is well-behaved under these parameter restrictions. For the formal propositions, proofs and a more detailed discussion we refer the reader to the Online Appendix.

5. Scale Economies and the Gains from Trade Relative to Autarky

In this section we explore the implications of scale economies for the gains from trade, defined as in ACR as the negative of the percentage change in real income as we move from the observed equilibrium to autarky. We first do so at a theoretical level and then use the World Input-Output Dataset (WIOD) to quantify the effects. In Section 6 we turn to the related but distinct question of how scale economies affect the gains from trade liberalization, defined as the welfare effects of a counterfactual decline in tariffs

24To see this, consider the case with $\alpha_k = \alpha$ and $\varepsilon_k = \varepsilon$. If $\alpha < 1$ then $\ln \left( \frac{L_{i,k}}{L_{j,k}} \right) = \frac{1}{1 - \alpha} \ln \left( \frac{S_{i,k}}{S_{j,k}} \right)$, a generalization of the result in Costinot et al. (2012) to the case with $\alpha > 0$ – economies of scale simply amplify the effect of comparative advantage on the pattern of specialization by the factor $1/(1 - \alpha)$. If $\alpha = 1$ then $S_{i,k}/S_{i,s} > S_{j,k}/S_{j,s}$ implies that $L_{i,s} L_{j,k} = 0$, so that for any two countries and any two industries, both countries cannot have positive employment in their industries of comparative disadvantage. We prove this by showing that if $L_{i,s} > 0$ then $L_{j,k} = 0$, with the converse proven similarly. In particular, if $L_{i,s} > 0$ then $S_{i,s} w_i^{-\varepsilon - 1} = S_{i,s} w_i^{-\varepsilon - 1}$ for all $l$ and so we have $S_{i,s} w_i^{-\varepsilon - 1} \geq S_{j,s} w_j^{-\varepsilon - 1} > S_{j,k} w_j^{-\varepsilon - 1}$, implying that $L_{j,k} = 0$.

25There are two papers that study the question of uniqueness of equilibrium in the multi-industry Krugman model: Hanson and Xiang (2004) consider the case of two countries and a continuum of industries, while Behrens et al. (2009) consider the case of many countries, one industry and exogenous wages. They both show uniqueness under the assumption that there are no corner allocations. We extend their result to a more general environment, introduce the key condition that the product of the trade and scale elasticities is weakly lower than one in all industries, and allow for corner allocations.
or trade costs starting at the observed equilibrium.

5.1. Theoretical Analysis

In principle, countries that specialize in industries with weak economies of scale could even lose from trade — the premise of Frank Graham’s argument for protection. It turns out, however, that this cannot happen if $0 \leq \alpha_k \leq 1$ for all $k$. A simple argument establishes this result for an industry-country pair $(i,k)$ with $L_{i,k} > 0$. Using equations (6) and (7) and setting $w_i = 1$ by choice of numeraire, the industry-level price index is

$$P_{i,k} = \mu_{i,k} S_{i,k}^{-1/\varepsilon_k} L_{i,k}^{-\psi_k} \lambda_{i,k}^{1/\varepsilon_k}.$$  

Since autarky employment levels are $L_{i,k}^A = \beta_{i,k} \bar{L}_i$, autarky price indices are then

$$P_{i,k}^A = \mu_{i,k} S_{i,k}^{-1/\varepsilon_k} (\beta_{i,k} \bar{L}_i)^{-\psi_k}.$$  

We can then write

$$P_{i,k} = P_{i,k}^A (\lambda_{i,k}^{1/\varepsilon_k}) \left( \frac{L_{i,k}}{\beta_{i,k} \bar{L}_i} \right)^{-\psi_k}. \tag{8}$$

From (8) it is now evident that in the presence of scale economies there are two potentially countervailing forces acting on price indices: the standard gains from trade captured by $(\lambda_{i,k}^{1/\varepsilon_k})$, and the potentially negative scale effect arising from a contraction in employment relative to autarky, which is captured by $L_{i,k} / (\beta_{i,k} \bar{L}_i)^{-\psi_k}$. Note, however, that in an equilibrium with $L_{i,k} > 0$ we must have $L_{i,k} > \lambda_{i,k} \beta_{i,k} \bar{L}_i$, since the RHS is just total employment associated with domestic sales. This implies that $P_{i,k} < P_{i,k}^A (\lambda_{i,k}^{1/\varepsilon_k} - \psi_k)$, and hence $\psi_k \leq 1/\varepsilon_k$ (or $\alpha_k \equiv \varepsilon_k \psi_k \leq 1$) implies that $P_{i,k} < P_{i,k}^A$. In Appendix C.1 we show that this strict inequality also holds in the case in which $L_{i,k} = 0$, thus establishing the following result.

**Proposition 3.** If $0 \leq \alpha_k \leq 1$ for all $k$ then all countries gain from trade.

Intuitively, the strength of the standard gains from trade is regulated by the inverse of the trade elasticity, $1/\varepsilon_k$, while the strength of the potentially negative scale effect is regulated by $\psi_k$. For $\alpha_k \leq 1$ the standard gains from trade always neutralize any potentially opposing scale effects that could lead to higher prices with trade than in autarky. On the contrary, if $\alpha_k > 1$, then one could have higher prices in some industries with trade than without, leading to the possibility of losses from trade.

Proposition 3 can be seen as a generalization of Proposition 1 in Venables (1987), which states that in a Krugman (1980) model with an “outside good” all countries gain
from trade. Formally, the model in Venables (1987) is isomorphic to ours when we consider two countries and two industries, one having no trade costs, no scale economies, and an infinite trade elasticity (the “outside good”), and the other having trade costs, scale economies, and a finite trade elasticity, with $\alpha_k = 1$. Proposition 3 shows that this generalizes to a case without an outside good (i.e., with endogenous wages), with multiple sectors and microfoundations different than Krugman (e.g., Ricardian plus Marshallian externalities), and arbitrary scale economies as long as $\alpha_k \leq 1$ for all $k$.

To further explore the implications of scale economies for the magnitude of the gains from trade, we assume that the equilibrium is interior so that all trade shares and labor allocations are strictly positive. This allows us to derive an expression for the gains from trade as a function of industry-level data and the trade and scale elasticities that extend the multi-sector expressions in ACR.26

Equations (6) and (7) together with $P_n = \tilde{\beta}_n \prod_{k=1}^{K} \beta_{n,k}$ imply that

$$W_n \equiv \frac{w_n}{P_n} = \tilde{\beta}_n^{-1} \prod_k \left( \mu_{n,k}^{-1} \left( \sum_{k} \right) \right)^{\beta_{n,k}/\varepsilon_k}.$$  

Using hat notation, $\hat{x} = x'/x$, a foreign shock (i.e., a shock that does not affect the exogenous variables in country $n$) induces a change in welfare in country $n$ equal to

$$\hat{W}_n = \prod_k \hat{\lambda}_{n,k}^{-\beta_{n,k}/\varepsilon_k} \cdot \prod_k \hat{\beta}_{n,k} \psi_{n,k}.$$  

(9)

The first term on the RHS of this expression is the standard multi-industry formula for gains from trade (with upper-tier Cobb-Douglas preferences), while the second term is an adjustment for scale economies.

To better understand this expression, we can use the fact that the welfare effect of an infinitesimally small change in wages and prices is $d \ln W_n = d \ln w_n - \sum_k \beta_{n,k} d \ln P_{n,k}$. Log-differentiating $\lambda_{n,k} = (\mu_{n,k} S_{n,k}^{-1} L_{n,k}^{-\varepsilon_k} \psi_{n,k} \frac{w_n}{P_{n,k}})^{-\varepsilon_k}$ with respect to $L_{n,k}$, $w_n$ and $P_{n,k}$ and substituting into the previous equation yields

$$d \ln W_n = -\sum_k \beta_{n,k} \frac{d \ln \lambda_{n,k}}{\varepsilon_k} + \sum_k \beta_{n,k} \psi_{n,k} d \ln L_{n,k}.$$  

(10)

26Given Proposition 1, the assumption that labor allocations are strictly positive is not restrictive for the case with $0 \leq \alpha_k < 1$ for all $k$. 
The first term on the right hand side captures the welfare effect of an infinitesimally small foreign shock taking home productivity as given, while the second term captures the welfare effect of that shock through home productivity changes caused by changing industry employment levels in the presence of scale effects. Integrating the first term over some discrete shock yields \( \prod_k \hat{\lambda}_{nn,k}^{\beta_{n,k}/\epsilon_k} \), while integrating the second term yields \( \prod_k \hat{L}_{n,k}^{\beta_{n,k} \psi_k} \)\(^{27}\).

Following ACR, we define the gains from trade as the negative of the percentage change in real income as we move from the observed equilibrium to autarky,

\[
GT_n \equiv \frac{W_n - W_n^A}{W_n}.
\]

We compute \( GT_n \) by applying (9) and noting that for the move back to autarky we have \( \hat{\lambda}_{nn,k} = 1/\lambda_{nn,k} \), and \( \hat{L}_{n,k} = \beta_{n,k}/r_{n,k} \), where \( r_{n,k} \equiv L_{n,k}/\bar{L}_n \) denotes the industry revenue (or employment) shares in the observed equilibrium. Using \( e_{n,k} \equiv X_{n,k}/X_n \) for observed industry expenditure shares (of course, \( e_{n,k} = \beta_{n,k} \) in the model), this leads to a formula for the gains from trade that depends only on the country’s observables \( \lambda_{nn,k}, e_{n,k} \) and \( r_{n,k} \) as well as the trade and scale elasticities, \( \epsilon_k \) and \( \psi_k \),

\[
GT_n = 1 - \Delta_n \prod_k e_{n,k}^{\epsilon_k/\epsilon_k} \lambda_{nn,k}^{\beta_{n,k}/\epsilon_k},
\]

where \( \Delta_n \equiv \prod_k (e_{n,k}/r_{n,k})^{\epsilon_k/\epsilon_k} \). The expression for the gains from trade in the standard perfectly competitive model with no scale economies obtains from (11) by setting \( \psi_k = 0 \) for all \( k \), which leads to \( \Delta_n = 1 \). The effect of scale economies on the gains from trade then depends on whether \( \Delta_n \) is higher or lower than 1.

\(^{27}\)It is interesting to compare the formula in (10) to the one that would obtain if instead of external economies of scale we had wedges affecting the allocation of labor across sectors, as in Krueger and Summers (1986) and Baqaee and Farhi (2017). The corresponding equation would be

\[
d\ln W_n = -\sum_k \beta_{n,k} \frac{d\ln \lambda_{nn,k}}{\epsilon_k} + \sum_k \frac{L_{n,k}}{\bar{L}_n} \frac{w_{n,k}}{\bar{w}_n} d\ln L_{n,k},
\]

where \( \bar{w}_n = \sum_k w_{n,k} L_{n,k}/\bar{L}_n \) is the average wage. Here \( L_{n,k}/\bar{L}_n \) and \( w_{n,k}/\bar{w}_n \) play the role of \( \beta_{n,k} \) and \( \psi_{n,k} \) in (10). Whereas \( w_{n,k} = w_n \) for all \( k \) implies \( d\ln W_n = -\sum_k \beta_{n,k} \frac{d\ln \lambda_{nn,k}}{\epsilon_k} \) in the case of wedges, this would not be true if \( \psi_k = \psi \) for all \( k \) in (10), except if \( \beta_{n,k} = L_{n,k}/L_n \), which will generally not hold with trade. Another difference is that while we can be sure that all countries gain from trade in the case of scale economies if the necessary condition for uniqueness holds, no such clear result emerges under wedges. Finally, note that this is just comparing first-order effects; higher-order effects are different with economies of scale relative to the case with wedges.
Consider first the case in which the scale elasticity is the same across industries ($\psi_k = \psi$ for all $k$) and note that $\Delta_n^{1/\psi} = \exp D_{KL}(e_n \parallel r_n)$, where $r_n \equiv (r_{n1}, ..., r_{nK})$, $e_n \equiv (e_{n1}, ..., e_{nK})$, and

$$D_{KL}(e_n \parallel r_n) \equiv \sum_k e_{n,k} \ln(e_{n,k} / r_{n,k}) \quad (12)$$

is the Kullback-Leibler divergence of $r_n$ from $e_n$. We can think of $D_{KL}(e_n \parallel r_n)$ as a measure of industry specialization in country $n$ — in autarky we would have $r_n = e_n$ and $D_{KL}(e_n \parallel r_n) = 0$, while if $r_n \neq e_n$ then $D_{KL}(e_n \parallel r_n) > 0$. This implies that $\Delta_n > 1$ (except if $r_n = e_n$, in which case $\Delta_n = 1$) so that, given trade shares, scale economies actually reduce the gains from trade, with a larger decline for higher values of $\psi$ and for countries that exhibit higher levels of specialization.\footnote{In the information theory literature, this measure is also called relative entropy of $e_n$ with respect to $r_n$.}

We can gain intuition about this result by going back to equation (10) and noting that if $\psi_k = \psi$ for all $k$ then the second term on the RHS of that equation can be written as $\psi \sum_k e_{n,k} \frac{dL_{n,k}}{L_{n,k}}$. A move back to autarky implies the expansion of industries with net imports and hence a high expenditure share or low employment. In either case, the expenditure-weighted productivity gain in expanding industries will be on average higher than the expenditure-weighted productivity loss in contracting industries, and hence $\psi \sum_k e_{n,k} \frac{dL_{n,k}}{L_{n,k}} > 0$. After integration, this leads to $\Delta_n > 1$.

Readers may be surprised by the result that the gains from trade are lower with economies of scale (i.e., $0 < \alpha < 1$) than without (i.e., $\alpha = 0$). As we mentioned above, this is because we are following the ACR approach of taking trade flows as data that is held fixed as we compare different models. The intuition that scale economies should lead to larger gains from trade through deeper industry-level specialization and larger trade flows is not operative here, although as we illustrate in Section 6 this intuition is relevant for the gains from trade liberalization.\footnote{The opposite result would hold if instead of economies of scale we had diseconomies of scale. For example, in a setting with $\psi = 0$ and worker-level heterogeneity, Galle et al. (2017) show that $GT_n = 1 - \prod_k \lambda e_{n,k} / (e_{n,k} / r_{n,k})^{-e_{n,k}/\kappa}$, where $\kappa$ is a parameter that determines the degree of heterogeneity. The argument above now implies that the gains from trade are higher than in the case with no scale economies, which obtains here in the limit as $\kappa \to \infty$, and corresponds to the case in which workers are homogeneous. We discuss this more formally in the Online Appendix.}

Turning now to the more general case in which $\psi_k$ varies across $k$, $\Delta_n$ can be rewrit-
ten as

\[ \Delta_n = \exp \{ \bar{\psi} [DS_n - PS_n] \}, \]

(13)

where \( DS_n \equiv D_{KL}(e_n \parallel r_n) \) and

\[ PS_n = \sum_k \frac{\psi_k - \bar{\psi}}{\bar{\psi}} \ln \left( \frac{r_{n,k}}{e_{n,k}} \right)^{e_{n,k}}, \]

(14)

with \( \bar{\psi} \equiv (1/K) \sum_k \psi_k \). Expression (13) makes it clear that in general there are two (possibly competing) forces: the first measures the degree of specialization (DS) in country \( n \), while the second measures the pattern of specialization (PS), i.e., the tendency of country \( n \) to specialize in industries with either higher or lower than average scale economies. Since DS always pushes towards lower gains relative to the case with no scale economies, the overall effect of scale economies on gains from trade depends on the direction and magnitude of PS. Countries that tend to specialize in industries with lower than average scale economies — so that PS is negative — gain less from trade with scale economies than without. However, in countries that tend to specialize in industries with higher than average scale economies — so that PS is positive — the effect of scale economies on the gains from trade is ambiguous. If a country’s PS is strong enough to overcome its DS, then such a country could have higher gains with than without scale economies.

5.2. Quantitative Analysis

We now explore the quantitative implications of the previous observations by computing the gains from trade using actual data combined with Equation (11). A critical input for the analysis is a set of values for the sector-level trade and scale elasticities. We take those from Bartelme, Costinot, Donaldson and Rodriguez-Clare (2018, henceforth BCDR), who in turn take trade elasticities from the median value of recent estimates in the literature, and estimate scale elasticities using an approach that is motivated by the model we have developed in this paper.\(^{30,31}\) These elasticities satisfy the condi-
tion $\alpha_k \leq 1$ for all $k$ and are listed in Table 6 of Appendix C.2. We follow Costinot and Rodriguez-Clare (2014) and compute measures of $\lambda_{nn,k}, \epsilon_{n,k}$, and $r_{n,k}$ employing data on 31 sectors and 33 countries (plus the rest of the world aggregate) from the WIOD in 2008.\footnote{Equation (11) ignores trade deficits. As discussed in Costinot and Rodriguez-Clare (2014), this implies that our results in this subsection capture the change in real income rather than the change in real expenditure caused by shutting down trade and closing any trade deficits that exist in the data.}

We present the results of this exercise in Table 2. Column 1 reports the gains from trade when setting all scale economies to zero while column 2 sets them to the values

\begin{table}[h]
\centering
\begin{tabular}{lcccccc}
\hline
\textbf{Country} & \textbf{(1)} & \textbf{(2)} & \textbf{(3)} & \textbf{(4)} & \textbf{Country} & \textbf{(1)} & \textbf{(2)} & \textbf{(3)} & \textbf{(4)} \\
\hline
AUS & 2.79 & 2.13 & 3.57 & -8.74 & IRL & 10.95 & 11.29 & 6.90 & 13.95 \\
AUT & 8.40 & 8.48 & 1.54 & 3.21 & ITA & 3.81 & 3.96 & 2.60 & 5.47 \\
BEL & 14.51 & 14.82 & 7.24 & 13.83 & JPN & 2.61 & 2.91 & 4.05 & 9.78 \\
BRA & 1.62 & 1.56 & 0.38 & -0.70 & KOR & 6.94 & 7.45 & 13.25 & 23.31 \\
CAN & 4.78 & 4.36 & 2.41 & -5.69 & MEX & 3.77 & 3.04 & 1.75 & -12.29 \\
CHN & 2.86 & 3.01 & 1.59 & 4.46 & NLD & 10.07 & 10.49 & 1.98 & 10.74 \\
CZE & 7.42 & 7.56 & 1.43 & 4.29 & POL & 5.67 & 5.52 & 0.86 & -2.04 \\
DEU & 5.91 & 6.55 & 3.27 & 15.90 & PRT & 6.29 & 5.77 & 3.16 & -6.95 \\
DNK & 9.27 & 9.00 & 8.96 & 3.54 & ROM & 5.70 & 4.83 & 2.04 & -14.83 \\
ESP & 4.05 & 3.97 & 2.26 & 0.77 & RUS & 2.84 & 1.23 & 7.65 & -22.59 \\
FIN & 5.48 & 5.88 & 3.63 & 11.40 & SVK & 10.72 & 10.80 & 3.81 & 5.48 \\
FRA & 4.00 & 4.15 & 1.97 & 4.76 & SVN & 11.06 & 10.37 & 11.22 & -3.00 \\
GBR & 4.43 & 4.20 & 0.77 & -3.58 & SWE & 6.68 & 6.99 & 1.90 & 8.10 \\
GRC & 5.85 & 4.30 & 10.97 & -19.04 & TUR & 3.82 & 3.77 & 1.77 & 0.80 \\
IDN & 3.23 & 3.06 & 1.27 & -1.96 & USA & 1.97 & 1.76 & 0.72 & -3.31 \\
IND & 3.40 & 3.35 & 1.32 & 0.28 & ROW & 6.49 & 5.74 & 4.99 & -9.55 \\
\hline
\textbf{Average} & 6.09 & 5.94 & 3.98 & 1.10 & \\
\hline
\end{tabular}
\caption{Gains from Trade, Degree and Pattern of Specialization}
\end{table}
estimated in BCDR. Column 3 reports the degree of industry specialization, $DS$, and column 4 reports the pattern of specialization, $PS$. From the theoretical analysis above we know that, given the average scale elasticity $\bar{\psi} \equiv (1/K) \sum_k \psi_k$, $DS$ and $PS$ are sufficient statistics for the effect of economies of scale on the gains from trade (relative to the ACR formula): $(GT - GT_{ACR})/(1 - GT_{ACR}) \approx -\bar{\psi} (DS - PS)$.  

Notes: $DS$ and $PS$ are calculated according to expressions (12) and (14), correspondingly. The numbers in parentheses are, respectively, the standard ACR gains, $GT_{ACR}$, and the gains from trade in the presence of economies of scale, $GT_{scale}$, both calculated according to (11). $PS$, $GT_{ACR}$ and $GT_{scale}$ are calculated by setting $\epsilon_k$ for manufacturing industries based on estimates from BCDR, and setting $\epsilon_k = 0$ for non-manufacturing industries. For $GT_{ACR}$, $\psi_k = 0$ for all $k$. For $PS$ and $GT_{scale}$, $\psi_k$ for manufacturing industries are set based on estimates from BCDR, and $\psi_k = 0$ for non-manufacturing industries. The straight line is the 45 degree line. To avoid cluttering, some country labels are dropped.

Figure 1: Degree of Specialization, Pattern of Specialization and Gains from Trade in the Presence of Economies of Scale

Consistent with Proposition 3, gains from trade are positive for all countries even when there are scale economies. On average, the gains from trade with and without

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33This is an approximation. We start with $GT - GT_{ACR} = (1 - \Delta) (1 - GT_{ACR})$. Combined with $1 - \Delta = 1 - \exp(\bar{\psi} (DS - PS)) \approx -\bar{\psi} (DS - PS)$, the result in the text follows immediately.
scale economies are very similar, but there are significant differences for certain countries. For example, allowing for economies of scale leads to an increase in the gains from trade for Germany, from 5.9% to 6.6%, and Korea, from 6.9% to 7.5%, but a decrease for Greece, from 5.9% to 4.3%, and most prominently for Russia, from 2.8% to 1.2%. Scale economies lead to lower gains from trade for Greece and Russia because these countries happen to be specialized in industries with relatively weak economies of scale, as revealed by a negative PS. In contrast, the pattern of specialization in Germany and Korea is such that PS is positive and dominates the negative effect of DS, thus leading to higher gains from trade with economies of scale.

The role of DS and PS in affecting the gains from trade is illustrated in Figure 1. The figure is a scatter diagram of DS (on the horizontal axis) against PS (on the vertical axis) for all countries in our sample, with most points also indicating the name of the country and the gains from trade without and with economies of scale as in columns 1 and 2 of Table 2. More than half of the countries lie below the 45 degree line, indicating that PS < DS, so that economies of scale decrease the gains from trade. However, in addition to Germany and South Korea, there are a few countries (for example, Belgium, China, Finland, Japan and Sweden) with PS > DS, implying higher gains from trade with economies of scale than without thanks to a pattern of specialization tilted in favor of sectors with relatively high scale elasticities.

6. Scale Economies and the Gains from Trade Liberalization

Whereas the previous section was devoted to the gains from trade using autarky as the counterfactual, we now study the gains from a decline in trade barriers, focusing on how these gains are affected by scale economies. We again split the section in two parts: theory and quantitative analysis.

6.1. Theoretical Analysis

We consider two simple cases for which we can derive analytical results for the gains from a decline in trade costs. Both cases consist of two countries and two industries under conditions implying that relative wages are not affected by the trade shock.
6.1.1. Mirror-Image Countries

With two mirror-image countries the wage is equalized, and we can normalize both wages to one. For ease of exposition we index countries by $i = H, F$, where $H$ and $F$ represent Home and Foreign, respectively. Let $L = 2$, $\beta_{i,k} = 1/2$ for all $(i, k)$, and let $S_{H,1} = S_{F,2} = 2$ and $S_{H,2} = S_{F,1} = 1$. Hence, Home has the comparative advantage in industry 1, and Foreign in industry 2. We assume that $\varepsilon_k = \varepsilon$ and $\psi_k = \psi$ for $k = 1, 2$.

To establish a link with the results of Section 5, we first illustrate that the gains from trade are decreasing in $\psi$. We then show that the conclusion is reversed once we consider a trade liberalization exercise in which trade shares respond endogenously as we lower trade costs. There we find that the gains from trade liberalization are increasing in $\psi$.

Home’s gains from trade are simply

$$GT_H = 1 - \left( \frac{1/2}{r_{H,1}} \cdot \frac{1/2}{1 - r_{H,1}} \right)^{\psi/2} \left( \lambda_{HH,1}^{1/2} \cdot \lambda_{HH,2}^{1/2} \right).$$

The term $\left( \frac{1/2}{r_{H,1}} \cdot \frac{1/2}{1 - r_{H,1}} \right)^{\psi/2}$ corresponds to $\Delta_H$ in Equation (11) and is higher than one as long as there is industry-level specialization.\(^{34}\) Thus, given trade shares, gains are lower with scale effects ($\psi > 0$) than without ($\psi = 0$). It is also easy to see that these gains are decreasing in $\psi$.

Next we study the gains from trade liberalization, allowing for endogenous responses of trade shares to trade costs.\(^{35}\) We use the autarky economy (i.e., the economy with $\tau = \infty$) as the baseline case and define gains from trade liberalization as welfare changes resulting from the move from autarky to an economy with a finite level of trade costs. We set $\varepsilon = 5$ and, consistently with the exercises of Section 5, $\psi \in \{0, 0.14, 0.2\}$, which corresponds to $\alpha \in \{0, 0.7, 1\}$. In all these cases $L_{i,k} = 1$ for all $(i, k)$ under autarky. As $\tau$ falls from $\infty$, country $H$ specializes in industry 1 and country $F$ specializes in industry 2, but the extent of specialization will be stronger with $\psi = 0.2$ than $\psi = 0.14$, and with $\psi = 0.14$ than $\psi = 0$, as illustrated in Figure 2a. Figure 2b shows the implications for the gains.

\(^{34}\)The term $\frac{1/2}{r_{H,1}} \cdot \frac{1/2}{1 - r_{H,1}}$ is minimized at $r_{H,1} = 1/2$, and specialization according to comparative advantage implies $r_{H,1} > 1/2$, hence we must have $\left( \frac{1/2}{r_{H,1}} \cdot \frac{1/2}{1 - r_{H,1}} \right)^{\psi/2} > 1$.

\(^{35}\)In the terminology of ACR, this corresponds to an “ex-ante analysis” whereas the results for the gains from trade above correspond to an “ex-post analysis”.

from trade liberalization for each of these three cases. We see that the gains from trade liberalization increase with $\psi$. The intuition is simple: countries gain by specializing according to comparative advantage, and the concentration of production also allows for a greater exploitation of scale economies, which, in turn, generates additional efficiency gains.\footnote{To understand this further, note that the gains from trade liberalization can be seen as the increase in welfare $W_H = 1/(1 - GT_H) = \left(\frac{1/2}{\tau_{H,1}} \cdot \frac{1/2}{1-\tau_{H,1}}\right)^{-\psi/2} \left(\lambda^{-1/2}\cdot \lambda^{-1/2}\right)$ as $\tau$ falls. The decline in $\tau$ leads to deeper industry-level specialization, as captured by a higher $r_{H,1}$, and this decreases $\left(\frac{1/2}{\tau_{H,1}} \cdot \frac{1/2}{1-\tau_{H,1}}\right)^{-\psi/2}$ and decreases $W_H$. But there is also a change in trade shares, and this increases $\lambda^{-1/2} \cdot \lambda^{-1/2}$, which more than offsets the previous effect.}

### 6.1.2. Freely Traded Outside Good

The result established in Proposition 3 that, if the product of the trade and scale elasticities is weakly lower than one in all industries, countries always gain from trade does not necessarily imply that there are always gains from further trade liberalization. In fact, our model nests the one in Venables (1987), and so we know that a unilateral decline in inward trade costs may decrease welfare. To see this more explicitly, consider a case with two countries and two industries, with $\varepsilon_1 = \infty > \varepsilon_2$, $\psi_1 = 0 < \psi_2 \leq 1/\varepsilon_2$ (so that $\alpha_2 \leq 1$), and with no trade costs in industry 1 (i.e., $\tau_{12,1} = \tau_{21,1} = 1$). If we start with an interior equilibrium (i.e., $L_{i,k} > 0$ for $i = 1, 2$ and $k = 1, 2$) then wages are pinned down

\[ \lambda_{H \cdot H} = \left(\frac{1/2}{\tau_{H,1}} \cdot \frac{1/2}{1-\tau_{H,1}}\right)^{-\psi/2} \left(\lambda^{-1/2}\cdot \lambda^{-1/2}\right) \]

This decrease in $W_H$ leads to a reduction in trade shares, and this increases $\lambda^{-1/2} \cdot \lambda^{-1/2}$, which more than offsets the previous effect.
by (exogenous) productivities in industry 1 (the outside good), and — suppressing the industry sub-index — the labor allocation in industry 2 is given by \((L_1, L_2)\) that solves

\[
w_i L_i = \sum_n S_i L_i^\alpha (w_i \tau_{ni})^{-\varepsilon} P_n^\epsilon \beta_n w_n \bar{L}_n,
\]

for \(i = 1, 2\), with \(P_n^{-\varepsilon} = \sum_j S_j L_j^\alpha (w_j \tau_{nj})^{-\varepsilon}\). The case considered by Venables (1987) entails \(\alpha = 1\), in which case the previous system can be rewritten as a system in \((P_1, P_2)\),

\[
w_i = \sum_n S_i (w_i \tau_{ni})^{-\varepsilon} P_n^\epsilon \beta_n w_n \bar{L}_n.
\]

In this case it is easy to see that a decline in \(\tau_{12}\) leads to an increase in \(P_1\) and a decrease in \(P_2\), exactly as in Venables (1987). Of course, if \(\alpha = 0\) then \(P_n^{-\varepsilon} = \sum_j S_j L_j^\alpha (w_j \tau_{nj})^{-\varepsilon}\), and so \(P_1\) would decrease while there would be no change in \(P_2\) implying further gains from unilateral trade liberalization. More generally, we can prove the following proposition (see the Online Appendix for the details):

**Proposition 4.** Assume there are two countries and two industries, with industry 1 playing the role of an outside good (i.e., \(\varepsilon_1 = \infty\), \(\psi_1 = 0\) and \(\tau_{12,1} = \tau_{21,1} = 1\)) and industry 2 having scale economies with \(\alpha > 0\). Assume that the initial equilibrium is interior (i.e., \(L_{i,k} > 0\) for \(i = 1, 2\) and \(k = 1, 2\)). There exists a threshold \(\tilde{\alpha}^{n,\tau} \in (0, 1) — \text{depending on import and export shares} — \text{such that country } n \text{ loses from a small unilateral trade liberalization in industry } 2 \text{ if and only if } \alpha \in (\tilde{\alpha}^{n,\tau}, 1)\).\(^{37}\)

This Proposition generalizes the result of immiserizing inward trade liberalization in Venables (1987) in two ways. First, the result holds outside of the Krugman model – what is needed is that the scale economies vary across sectors, but the source of such economies (for example, love of variety or Marshallian externalities) is irrelevant. Second, the results are a manifestation of the more general idea that a shock that pushes a country to specialize in an industry with weak economies of scale (here the outside good) may lower the gains from trade. Using the notion of the pattern of specialization \((PS)\) introduced in the previous section, we can restate this as implying that if a shock leads to a decline in a country’s \(PS\) then the gains from trade liberalization may be lower with economies of scale than without.

\(^{37}\)In the Online Appendix we also show that there exists a threshold \(\tilde{\alpha}^{n,S} \in (0, 1) \text{ such that country } n \text{ loses from a small foreign productivity improvement in industry } 2 \text{ if and only if } \alpha \in (\tilde{\alpha}^{n,S}, 1)\).
6.2. Quantitative Analysis

The results of the previous subsection imply that scale economies tend to increase the gains from trade liberalization except if they lead to a decline in the pattern of specialization. We illustrate the relevance of this finding by quantifying the welfare effects of removing all observed tariffs across the countries and sectors in the WIOD for the year 2008. We use data on *ad-valorem* tariffs for the year 2008 from the United Nations Statistical Division, Trade Analysis and Information System (UNCTAD-TRAINS), as described in detail in Appendix C.2. As in Section 5, we take the trade and scale elasticities from BCDR. To solve for counterfactual equilibria, we use the exact hat algebra approach popularized by Dekle, Eaton and Kortum (2008) but extended here to allow for complementary slackness conditions, as described in the Online Appendix.

The results of this exercise are presented in Table 3. Columns 1 and 2 report the welfare gains for the case without and with economies of scale. Welfare gains in these columns are calculated explicitly as the change in real income, which is given by the sum of labor income and tariff revenues deflated by the price index. Comparing columns 1 and 2 reveals that multilateral liberalization tends to generate larger gains with economies of scale than without: average gains increase from 0.17% to 0.24%. However, there are large differences, with some countries more than doubling the gains (for example, China, the UK and Greece) and others exhibiting significantly lower gains (for example, Brazil, Mexico and Russia).

There are two main forces behind these results. The first one is that, as discussed in Section 6.1.1, the presence of economies of scale tends to amplify the effect of trade liberalization on specialization and trade, leading to larger gains from trade. We capture this force by computing the difference in the gains from trade liberalization with and without economies of scale using the ex-post ACR welfare formula, \( \prod_k \lambda_{nn,k}^{\hat{\beta}_{n,k} \epsilon_k} - 1 \). This ignores tariff revenues and the role of scale economies on domestic productivity, and isolates the effect of changes in domestic trade shares on welfare. The results are shown in column 3. On average, economies of scale lead to an increase in the gains from trade liberalization by 0.35 percentage points.

The second force is that, because of scale economies, the expansion and contraction of industries induced by trade liberalization affects productivity and hence welfare. As explained in Section 5.1, we capture this by the change in \( DS \) and \( PS \). In fact, a very
<table>
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<tr>
<th>Country</th>
<th>Gains from Elimination of Tariffs, %</th>
<th>ACR GTL diff., p.p.</th>
<th>$\bar{D}S$, %</th>
<th>$\bar{P}S$, %</th>
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<th>ACR GTL diff., p.p.</th>
<th>$\bar{D}S$, %</th>
<th>$\bar{P}S$, %</th>
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</table>

**Average** | 0.17 | 0.24 | 0.35 | 2.82 | -2.19 |

**Notes:** Each of the columns 1 and 2 presents results on welfare gains of a separate counterfactual exercise that removes all tariffs observed in the data. For columns 1 and 2, values of $\epsilon_k$ for manufacturing industries are set based on values provided by BCDR, and for non-manufacturing industries $\epsilon_k = 4$. For column 1, $\psi_k = 0$ for all $k$. For column 2, $\psi_k$ for manufacturing industries are set based on estimates from BCDR, and for non-manufacturing industries $\psi_k = 0$. BCDR-based values of $\epsilon_k$ and $\psi_k$ are provided in Table 6. Column 3 shows the difference in percentage points of ACR welfare gains between the cases in columns 2 and 1, correspondingly. $\bar{P}S$ in column 4 are calculated for the exercises in column 2. Average values in the last row are calculated based on the full set of countries.

Table 3: Effects of Multilateral Elimination of Tariffs

A good approximation of the difference in the gains from trade liberalization in columns 1 and 2 is given by the value in column 3 minus the average scale elasticity $\bar{\psi}$ times the difference of columns 4 and 5: $c2 - c1 \approx c3 - \bar{\psi}(c4 - c5)$, with $\bar{\psi} = 0.05$. Thus, for example, the gains from trade liberalization in Brazil are lower once we allow for scale economies in spite of a large positive value in column 3 — which by itself would imply that those gains would be 0.15% higher — because of the large increase in $DS$ and decline in $PS$, with $0.15 - 0.05(1.78 + 1.73) = -0.03$, which is close to the difference between columns 1 and 2. The same forces explain lower gains from trade liberalization in Canada, India,
Mexico, Russia, and Taiwan.

7. Scale Economies and Trade Flows

In this section we quantify the role of scale economies in determining industry-level specialization and trade flows. In particular, we ask how these variables would change if we shut down scale economies but leave all other exogenous variables unchanged.

We rely on the fact that if $L$ is an equilibrium of the actual economy with scale economies then it is also an equilibrium of the economy with no scale economies given by

$$w_i L_{i,k} = \sum_{n=1}^{N} T_{i,k} \left( w_i \tau_{n,l,k} \right)^{-\epsilon_k} \beta_{n,k} \left( w_n \bar{L}_n + D_n \right)$$

(16)

and

$$\sum_{k=1}^{K} L_{i,k} = \bar{L}_i,$$

(17)

where $T_{i,k} = S_{i,k} L_{i,k}^{\alpha_k}$ and where $D_n$ are trade deficits satisfying $\sum_n D_n = 0$. Thus, if we want to know the counterfactual allocation for the economy with $\alpha_k = 0$ for all $k$ but everything else equal, we can use the exact hat algebra approach in the economy with no scale effects subjected to a shock to productivities $T_{i,k}$ given by $\hat{T}_{i,k} = S_{i,k} L_{i,k}^{\alpha_k}$. To focus on the interaction between specialization and scale economies, we assume that $\hat{S}_{i,k}$ is such that if country $i$ was in autarky then the shock would have no effect on productivity. Since in autarky $L_{i,k} = \beta_{i,k} \bar{L}_i$, this requires $\hat{S}_{i,k} = (\beta_{i,k} \bar{L}_i)^{\alpha_k}$. Using $L_{i,k} = r_{i,k} \hat{L}_i$ and measuring $\beta_{i,k}$ by $e_{i,k}$, this implies that $\hat{T}_{i,k} = (e_{i,k} / r_{i,k})^{\alpha_k}$. Using (16) and (17) we can derive a system in wage changes. The solution for $\hat{w}_i$ can then be used to get the implied changes in labor allocations $\hat{L}_{i,k}$, and by extension the implied changes in trade flows $\hat{X}_{ni,k}$. The details of this derivation are in the Online Appendix.

Table 4 presents results of this exercise. For this exercise, we again take the values of trade and scale elasticities from BCDR. Columns 1 and 2 report the implied change in DS and in total exports for each country in the model. As expected, the removal of economies of scale implies a decline in the degree of specialization and total trade, but

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We can ignore corner solutions because the data has no zeros at the industry level (i.e., $r_{i,k} > 0$ for all $i,k$) and the shock that we consider moves us away from corners.

In order to solve for $\hat{w}_i$, we only need to work with the model for $\alpha_k = 0$ for all $k$ (the standard multi-sector Eaton and Kortum, 2002), and so for this case the algorithm that solves for $\hat{w}_i$ is just a straightforward extension of the Alvarez and Lucas (2007) algorithm to multiple sectors.
### Table 4: Scale and Trade Flows

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<th>Country</th>
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<th>$\hat{EX}$, %</th>
<th>Country</th>
<th>$\hat{DS}$, %</th>
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<td>POL</td>
<td>-0.42</td>
<td>-1.07</td>
<td></td>
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</tr>
</tbody>
</table>

Average: $-1.28$, $-2.59$

Notes: Columns 1 and 2 present results of an exercise in which it assumed that the data is generated by the model with $\varepsilon_k$ and $\psi_k$ for manufacturing industries based on estimates from BCDR (provided in Table 6), and $\varepsilon_k = 4$ and $\psi_k = 0$ for non-manufacturing industries. In the exercise, $\psi_k$ for all $k$ are set to zero, and all productivities are adjusted so that in autarky the changes in $\psi_k$ would have no effect. All other parameters are held unchanged. $\hat{DS}$ and $\hat{ES}$ are the implied changes in the degree of specialization and total exports in terms of the world GDP. Average values in the last row are calculated based on the full set of countries.

The effects are small. Without economies of scale amplifying Ricardian comparative advantage, industry-level specialization would be on average 1.3% smaller than what we observe in the data, implying that scale economies are much less important than Ricardian comparative advantage in driving industry-level specialization. In addition, without economies of scale total world exports would be about 3% lower than what we see in the data (this number is close to the simple average decline in exports of 2.6% provided in Table 4).

### 8. Concluding Remarks

For over a century since Alfred Marshall’s initial exposition, economists have been intrigued with the implications of industry-level external economies of scale for trading economies. Despite such interest, however, the discomfort with the plethora of equilib-
ria and counter-intuitive implications in early work implied that Marshallian external-
ities were mostly ignored in the recent trade literature. By leveraging the emergence of
the Eaton and Kortum (2002) Ricardian framework as a workhorse model we show how
one can tractably model Marshallian externalities and put it to work within a quan-
titative setting. The resulting model has exactly the same mathematical structure as
generalized versions of the multi-industry Krugman and Melitz-Pareto models and so
our results apply to these well-known models as well. The condition for the model to
be well-behaved is simple and intuitive: the scale elasticity must be weakly lower than
the inverse of the trade elasticity for all industries.

The model is rich in welfare implications. Most importantly, if the product of
the trade and scale elasticities is weakly lower than one in all industries then all coun-
tries gain from trade. Economies of scale tend to make gains from trade lower and
gains from trade liberalization higher relative to models without scale economies, with
results more positive for countries that specialize in industries with stronger than aver-
age scale economies.

Motivated by the multi-industry gravity model with scale economies developed in
this paper, Bartelme et al. (2018) have proposed a way to estimate industry-level scale
elasticities and to quantify the consequences for industrial policy. Their estimates in-
dicate that scale economies are positive but lower than the inverse of the trade elastic-
ity, with substantial variation across manufacturing industries. We have explored the
implications of these estimated elasticities for the gains from trade relative to autarky
and for the gains from removal of all tariffs observed in the data for the countries in the
WIOD. We find that the presence of economies of scale implies on average slightly lower
gains from trade relative to autarky and significantly larger gains from the removal of
all tariffs, which more than double for several countries, while falling for others.

We also found that while economies of scale do play a role in explaining trade flows
and industry-level specialization in the data, they pale in comparison to the impor-
tance of Ricardian comparative advantage: shutting down economies of scale would
imply a decline in industry-level specialization of about 1.3%, with an implied fall in
world exports of 3%.
References


Appendices

A. A Common Framework

In this appendix we derive expressions for price indices and trade shares for the multi-industry versions of Krugman (1980) and Melitz (2003) models. The derivations show that both Krugman and Melitz-Pareto models lead to equilibrium conditions that are almost identical to the ones for the Ricardian model.

A.1. A Krugman Model with Two-Tier CES preferences

There is a continuum of differentiated varieties within each industry. Preferences are multi-tiered: Cobb-Douglas across industries with weights $\beta_{i,k}$, CES across country bundles within an industry with elasticity $\eta_k$, and CES across varieties within a country bundle with elasticity of substitution $\sigma_k > 1$.

Let $A_{i,k}$ be the exogenous productivity in $(i,k)$ which is common across firms in that industry, let $F_{i,k}$ denote the fixed cost (in terms of labor) associated with the production of any variety in $(i,k)$, and let $M_{i,k}$ the measure of goods produced in $(i,k)$. There is monopolistic competition and trade shares are $\lambda_{ni,k} = \left(\frac{P_{ni,k}}{P_{n,k}}\right)^{1-\eta_k}$, where $P_{ni,k} = M_{i,k}^{-1/(1-\sigma_k)} \left(\bar{\sigma}_k \frac{w_i \tau_{ni,k}}{A_{i,k}}\right)$ is the price index in country $n$ of country $i$ varieties of industry $k$, $\bar{\sigma}_k \equiv \frac{\sigma_k}{(\sigma_k - 1)}$ is the mark-up, and $P_{n,k} = \left(\frac{\sum_i P_{ni,k}^{1-\eta_k}}{1-\eta_k}\right)^{1/(1-\eta_k)}$.

We now solve for equilibrium variety $M_{i,k}$ as a function of industry employment $L_{i,k}$ and then use the result to derive an expression for trade shares for this model. Variable profits in $(i,k)$ are simply total industry revenues divided by $\sigma_k$. Letting $\Pi_{i,k}$ be total profits net of fixed costs in industry $(i,k)$, we then have $\Pi_{i,k} = \sum_n \lambda_{ni,k} X_{n,k} / \sigma_k - w_i M_{i,k} F_{i,k}$. If $L_{i,k} > 0$, then free entry implies zero profits, so total revenues must equal total wage payments in industry $(i,k)$, $\sum_n \lambda_{ni,k} X_{n,k} = w_i L_{i,k}$. Combined with $\Pi_{i,k} = 0$ we then have $M_{i,k} = L_{i,k} / (\sigma_k F_{i,k})$. Trade shares are then

$$\lambda_{ni,k} = \frac{A_{i,k}^{\eta_k-1} F_{i,k}^{-\frac{\eta_k-1}{\sigma_k-1}} L_{i,k}^\frac{\eta_k-1}{\sigma_k-1} \left(w_i \tau_{ni,k}\right)^{-(\eta_k-1)}}{\sum_l A_{l,k}^{\eta_k-1} F_{l,k}^{-\frac{\eta_k-1}{\sigma_k-1}} L_{l,k}^\frac{\eta_k-1}{\sigma_k-1} \left(w_l \tau_{nl,k}\right)^{-(\eta_k-1)}}$$
with price indices given by

\[ P_{n,k} = \mu_k^{Krug} \left( \sum_l A_{n,l,k}^{-\frac{\eta_k-1}{\sigma_k-1}} F_{n,l,k}^{-\frac{\eta_k-1}{\sigma_k-1}} L_{n,l,k}^{-\frac{\eta_k-1}{\sigma_k-1}} \left( \omega_l \tau_{n,l,k} \right)^{-\frac{\eta_k-1}{\sigma_k-1}} \right)^{-1/(\eta_k-1)}, \]

where \( \mu_k^{Krug} = \sigma_k^{-\frac{1}{\sigma_k-1}}. \)

It is then immediately evident that the expressions for trade shares and industry price indexes in this Krugman model collapses to those in equations (6) and (7) by setting \( \mu_n,k = \mu_k^{Krug}, \ S_{i,k} = A_{i,k}^{-\frac{\eta_k-1}{\sigma_k-1}}, \ \psi_k = (\sigma_k - 1)^{-1}, \ \text{and} \ \epsilon_k = (\eta_k - 1). \) Note also that if we set \( \sigma_k = \eta_k \) for all \( k, \) then this is just the standard multi-industry Krugman model, while if \( \sigma_k \to \infty, \) then \( (\eta_k - 1)/(\sigma_k - 1) \to 0 \) and we obtain the multi-industry Armington model. See rows 2 and 4 of Table 1.

Given the expressions for the price indices and trade shares derived above, the equilibrium conditions are given by the same expressions as in the Ricardian model: goods market clearing conditions (3)-(4) and labor market clearing conditions (5).

A.2. A Melitz-Pareto Model with Two-Tier Preferences

We now present a model à la Melitz (2003) with Pareto-distributed productivity.

After paying a fixed “entry” cost \( F_{i,k} \) in units of labor in country \( i, \) firms are able to produce a variety in industry \((i,k)\) with labor productivity drawn from a Pareto distribution with shape parameter \( \theta_k > \sigma_k - 1 \) and location parameter \( b_{i,k}. \) Firms from \( i \) can then pay a fixed “marketing” cost \( f_{n,k} \) in units of labor of \( n \) to serve that market.

Let \( \Omega_{n,i,k} \) denote the set of varieties that \( i \) sells to \( n \) in industry \( k. \) The price index of these goods is \( P_{n,i,k} = \left( \int_{\omega \in \Omega_{n,i,k}} p_{n,i,k}(\omega)^{1-\sigma_k} \, d\omega \right)^{-\frac{1}{\sigma_k}}. \) Let \( M_{i,k} \) denote total entry in industry \((i,k)\) and \( \phi_{n,i,k}^* \) denote the cutoff productivity such that \( i \) exports to \( n \) all goods with productivity higher than \( \phi_{n,i,k}^*. \) We have

\[
\begin{align*}
\int_{\phi_{n,i,k}^*}^{\infty} \left( \frac{\sigma_k}{\sigma_k - 1} \omega_l \tau_{n,i,k} \right)^{1-\sigma_k} \phi_{n,i,k} dG_{i,k}(\phi) &= \theta_k b_{i,k}^{\theta_k} M_{i,k} \left( \frac{\sigma_k}{\sigma_k - 1} \omega_l \tau_{n,i,k} \right)^{1-\sigma_k} \int_{\phi_{n,i,k}^*}^{\infty} \phi_{n,i,k}^{\sigma_k - \theta_k - 2} \, d\phi \\
&= \frac{\theta_k b_{i,k}^{\theta_k}}{\theta_k - \sigma_k + 1} M_{i,k} \left( \frac{\sigma_k}{\sigma_k - 1} \omega_l \tau_{n,i,k} \right)^{1-\sigma_k} \left( \phi_{n,i,k}^* \right)^{\sigma_k - \theta_k - 1}. 
\end{align*}
\]
The condition that determines the cutoff \( \phi_{ni,k}^* \) is

\[
\frac{1}{\sigma_k} \left( \frac{\sigma_k}{\sigma_k - 1} \cdot \frac{\omega_i \tau_{ni,k}}{X_{ni,k}} \right)^{1-\sigma_k} \left( \frac{P_{ni,k}}{P_{n,k}} \right)^{1-\eta_k} X_{n,k} = w_n f_{n,k}.
\]

This implies that\(^{40}\)

\[
\phi_{ni,k}^* = \sigma_k \left( \frac{\sigma_k}{\sigma_k - 1} \cdot \frac{\omega_i \tau_{ni,k}}{X_{ni,k}} \right)^{1-\sigma_k} \left( \frac{P_{ni,k}}{P_{n,k}} \right)^{1-\eta_k}.
\]

Using the well-known result that marketing costs associated with sales \( X_{ni,k} \) are \( v_kX_{ni,k} \) with \( v_k = \frac{\theta_k - (\sigma_k - 1)}{\sigma_k \theta_k} \), we get that the profits associated with sales \( X_{ni,k} \) (net of production and marketing costs) are \( (1/\sigma_k - v_k)X_{ni,k} \). Letting \( L_{i,k} \) represent total labor used for production and entry by industry \((i, k)\) (so that \( w_i L_{i,k} = (1 - v_k) \sum X_{ni,k} \)), then the free entry condition is \( (1/\sigma_k - v_k) w_i L_{i,k} = w_i F_i M_{i,k} \), which implies that \( M_{i,k} = \frac{1}{1+\theta_k} \frac{L_{i,k}}{P_{n,k}} \).

Plugging expressions for \( \phi_{ni,k}^* \) and \( M_{i,k} \) into the expression for \( P_{ni,k} \) above, using \( X_{n,k} = \beta_n \nu L_n \), and solving for \( P_{ni,k} \), yields

\[
P_{ni,k}^{1-\eta_k} = \left[ \mu_{n,k}^{Mel} \right]^{-\theta_k \xi_k} \left[ \frac{\theta_k}{\theta_k - \sigma_k + 1} \cdot \frac{1}{1+\theta_k} \right]^{-\frac{1}{\sigma_k} \left( \frac{\sigma_k f_{ni,k}}{\beta_{ni,k} L_n} \right)^{1-\frac{1}{\sigma_k}}},
\]

where \( \xi_k \equiv \frac{1}{\frac{1}{\sigma_k} - \frac{1}{\eta_k}} \), and

\[
\mu_{n,k}^{Mel} \equiv \frac{\sigma_k}{\sigma_k - 1} \left[ \frac{\theta_k}{\theta_k - \sigma_k + 1} \cdot \frac{1}{1+\theta_k} \right]^{-\frac{1}{\sigma_k} \left( \frac{\sigma_k f_{ni,k}}{\beta_{ni,k} L_n} \right)^{1-\frac{1}{\sigma_k}}}.\]

The expression for trade shares can then be derived by using \( P_{ni,k}^{1-\eta_k} = \sum_i P_{ni,k}^{1-\eta_k} \) together with \( \lambda_{ni,k} = \left( \frac{P_{ni,k}}{P_{n,k}} \right)^{1-\eta_k} \). This gives

\[
\lambda_{ni,k} = \frac{\sum_i \theta_k \xi_k \sum_i \xi_k \left( w_i \tau_{ni,k} \right)^{-\theta_k \xi_k}}{\sum_i \theta_k \xi_k \sum_i \xi_k \left( w_i \tau_{ni,k} \right)^{-\theta_k \xi_k}}.
\]

\(^{40}\)This expression is valid as long as \( \phi_{ni,k}^* \geq b_{i,k} \). We assume that this inequality holds for all \( n, i, \) and \( k \).

\(^{41}\)Note that \( M_{i,k} \) is the measure of entering firms, i.e., both operating and non-operating. Letting \( M_{ni,k} \) be the measure of firms from \( i \) in industry \( k \) that serve market \( n \), it is straightforward to show that \( M_{ni,k} = M_{i,k} \left( b_{i,k} \theta_i \phi_{ni,k}^* \right)^{\theta_i} \).
Finally, combining $P_{n,k}^{1-\eta_k} = \sum_i P_{ni,k}^{1-\eta_i}$ with the result above for $P_{ni,k}$ yields price indices

$$P_{n,k} = \mu_{n,k}^{Mel} \left( \sum_i b_i^{\theta_i \xi_k} F_{i,k}^{-\xi_k} L_{i,k}^{\xi_k} \left( w_i \tau_{ni,k} \right)^{-\theta_i \xi_k} \right)^{-\frac{1}{\eta_k \xi_k}}.$$ 

Note that if we set $\sigma_k = \eta_k$ for all $k$ then $\xi_k = 1$ and this model is just a multi-industry version of the Melitz-Pareto model in Arkolakis et al. (2008).

We get expressions (6) and (7) for trade shares and price indices by setting $\mu_{n,k} = \mu_{n,k}^{Mel}$, $S_{i,k} = b_i^{\theta_i \xi_k} F_{i,k}^{-\xi_k}$, $\psi_k = 1/\theta_k$, and $\epsilon_k = \theta_k \xi_k$. The goods market clearing conditions are then given by (3)-(4). The labor market clearing conditions need to take into account that labor is used not only for production and entry (which is all included in $L_{i,k}$), but also for paying marketing costs (which is not part of $L_{i,k}$ according to our definition above):

$$\sum_k L_{i,k} = \left[ 1 - \sum_k \beta_{i,k} \psi_k \right] \bar{L}_i.$$ 

This expression differs from the labor market clearing condition (5) in the Ricardian model by the constant $\sum_k \beta_{i,k} \psi_k$. This difference is inconsequential for equilibrium analysis and comparative statics, therefore, in the analysis pertaining to the general model we ignore this term.

The above derivations for the Melitz model rely on the balanced trade assumption. Without this assumption, the multiplicative term for the price index and the term on the right-hand side of the labor market clearing condition would depend on trade deficits. This has implications for the comparative statics exercises that involve changing trade deficits. At the same time, the derivations for the Ricardian model with Marshallian externalities and for the Krugman model do not depend on the balanced trade assumption.

**B. Proof of Proposition 1**

As it is mentioned in the main text, the case with $\alpha_k = 0$ is trivial: given wages, labor allocations are explicitly obtained from the conditions $L_{i,k} G_{i,k}(w, L_k) = 0$. Below we focus on the case with $\alpha_k \in (0, 1]$. 
For brevity of notation suppress the sub-index $k$ and let $a_{ni} \equiv S_i (w_i r_{ni})^{-\theta} w_i^{-\alpha}$ and $b_n \equiv \beta_n w_n \bar{L}_n$. Combining equations (1) and (3) we then have

$$
\frac{G_i (w, L)}{w_i} = 1 - \frac{1}{w_i L_i} \sum_n a_{ni} (w_i L_i)^{\alpha} b_n.
$$

Transforming variables with $x_i \equiv w_i L_i$, letting $x \equiv (x_1, \ldots, x_N)$, and with a slight abuse of notation, we can write

$$
G_i (x) = 1 - \sum_n a_{ni} x_i^{\alpha - 1} b_n.
$$

The system in (4) can now be written as a non-linear complementarity problem (NCP) in $x$:

$$
x_i \geq 0, \quad G_i (x) \geq 0, \quad x_i G_i (x) = 0, \quad i = 1, \ldots, N.
$$

(18)

Note that if $x$ solves (18) then $\sum_i x_i G_i (x) = 0$ and hence $\sum_i x_i = \sum_i b_i$. This implies that the solution to (18) satisfies $x \in \Gamma \equiv \{ x \in \mathbb{R}^N | x_i \geq 0, i = 1, \ldots, N; \sum_i x_i = \sum_i b_i \}$.

To prove Proposition 1 we follow a popular approach in the economics literature that consists of characterizing equilibria of general equilibrium models as solutions to optimization problems.\[^{43}\] Doing this is possible if, for example, the function $G(x) \equiv (G_1 (x), \ldots, G_N (x))$ has a Jacobian that is symmetric at all points in its domain, since in this case the function $G$ is the gradient of some other function $F$ that we can use in the optimization problem.\[^{44}\] Fortunately, our function $G$ satisfies this symmetry condition. In fact, it is easy to see that $G$ is the gradient of function $F : \mathbb{R}_+^N \setminus \{0\} \rightarrow \mathbb{R}$ defined by

$$
F(x) \equiv \alpha n x_n - \sum_n b_n \ln \left( \sum_i a_{ni} x_i^{\alpha} \right).
$$

(19)

As we establish formally below, this makes it possible to solve the NCP in (18) by way of solving $\text{arg min}_{x \in \Gamma} F(x)$, where $\Gamma$ is the compact set defined above.\[^{45}\]

---

\[^{42}\] Analogously to our treatment of the original functions $G_{i,k} (w, L_k)$ and $L_{i,k} G_{i} (w L_k)$ at $L_{i,k} = 0$ (see the Online Appendix), we define values of $G_i (x)$ and $x_i G_i (x)$ at $x_i = 0$ by their limits.

\[^{43}\] Negishi (1960) is probably the most well-known example of this approach in which market equilibria are characterized as solutions to a social planner's problem. Kehoe, Levine and Romer (1992) describe a more general framework in which the optimization problem does not necessarily have an economic interpretation. Our case fits into their general framework.

\[^{44}\] A classical result in mathematics states that a vector function is a gradient map if and only if its Jacobian is symmetric in the domain of the function (see, for example, Theorem 4.1.16 on page 95 in Ortega and Rheinboldt, 2000).

\[^{45}\] We thank Anca Ciurte and Ioan Rasa for pointing us in this direction.
In Lemmas 1 and 2 below we characterize the optimization problem \( \arg\min_{x \in \Gamma} F(x) \). After that, in Lemma 3, we establish the connection between this problem and the NCP (18).

**Lemma 1.** If either (a) \( 0 < \alpha < 1 \), or (b) \( \alpha = 1 \) and the matrix \( \{ \tau_{ni,k}^{-\epsilon} \}_{n,i} \) is non-singular, then \( F(\cdot) \) defined in (19) has a unique global minimum on \( \Gamma \).

**Proof.** Observe that \( F(\cdot) \) is a continuous function on \( \Gamma \), and \( \Gamma \) is a compact set. Hence, \( F(\cdot) \) has a global minimum on \( \Gamma \). Below we show that function \( F(\cdot) \) is strictly convex on \( \Gamma \). Then, given that \( \Gamma \) is a convex set, \( F(\cdot) \) has at most one global minimum on \( \Gamma \).

If \( 0 < \alpha < 1 \), then for any \( n \) function \( \sum_i a_{ni} x_i^\alpha \) is a strictly concave function. And since the logarithm is a strictly concave function, \( F(\cdot) \) is strictly convex.

If \( \alpha = 1 \), then we need to make sure that for any two vectors \( x \neq y \) we cannot have that \( \sum_i a_{ni} x_i = \sum_i a_{ni} y_i \) for all \( n \). Otherwise, we would have \( F(\gamma x + (1 - \gamma) y) = \gamma F(x) + (1 - \gamma) F(y) \) for any \( \gamma \in [0, 1] \) and strict convexity would be violated. The assumption that the matrix \( \{ \tau_{ni,k}^{-\epsilon} \}_{n,i} \) is non-singular guarantees that matrix \( A = (a_{ni}) \) is also non-singular. Hence, for any \( x \neq y \) we have \( \sum_i a_{ni} x_i \neq \sum_i a_{ni} y_i \) for at least one \( n \). Hence, in case of \( \alpha = 1 \), \( F(\cdot) \) is also strictly convex under the regularity assumption on the matrix of trade costs. Note that without this assumption the function \( F(\cdot) \) is just convex, but not necessarily strictly convex. \( \square \)

**Lemma 2.** Let \( x^* \) be the unique global minimum of \( F(\cdot) \) on \( \Gamma \). If \( 0 < \alpha < 1 \), then \( x^*_i > 0 \) for all \( i = 1, \ldots, N \).

**Proof.** Suppose, without loss of generality, that \( x^*_1 = 0 \). Since \( \sum_n x_n^* = \sum_n b_n > 0 \), we can also suppose without loss of generality that \( x^*_2 \neq 0 \). Consider the vector \( x(\epsilon) = (\epsilon, x^*_2 - \epsilon, x^*_3, \ldots, x^*_N) \), where \( \epsilon \in [0, x^*_2] \). Clearly, \( x(\epsilon) \in \Gamma \). Define

\[
\tilde{F}(\epsilon) \equiv F(x(\epsilon)) = \sum_n x_n^* - \sum_n b_n \ln \left( a_{n1} \epsilon^\alpha + a_{n2} (x^*_2 - \epsilon)^\alpha + \sum_{i=2}^N a_{ni} (x^*_i)^\alpha \right).
\]

We now show that \( \tilde{F}(\epsilon) < \tilde{F}(0) \) for small enough \( \epsilon > 0 \). We have

\[
\frac{\partial}{\partial \epsilon} \left( a_{j1} \epsilon^\alpha + a_{j2} (x^*_2 - \epsilon)^\alpha \right) = a a_{j1} \epsilon^{\alpha-1} - a a_{j2} (x^*_2 - \epsilon)^{\alpha-1},
\]
which, given \( \alpha \in (0, 1) \), is positive for small enough \( \epsilon \). This implies that 
\[
\sum_{i=2}^{N} a_{ji} (x_{i}^{*})^{\alpha} + \sum_{i=2}^{N} a_{ji} (x_{i}^{*})^{\alpha} > a_{j2} (x_{2}^{*})^{\alpha} + \sum_{i=2}^{N} a_{ji} (x_{i}^{*})^{\alpha}
\]
for small enough \( \epsilon \). Since \( \ln(\cdot) \) is a strictly increasing function, we then get that \( \tilde{F}(\epsilon) < \tilde{F}(0) \) for small enough \( \epsilon \), a contradiction. This implies that \( x^{*} \) cannot be a global minimum of \( F(\cdot) \) on \( \Gamma \). Hence, in the case of \( \alpha \in (0, 1) \) we must have \( x_{i}^{*} > 0 \) for all \( i \).

**Lemma 3.** If \( 0 < \alpha \leq 1 \), then \( x^{*} \) is a global minimum of \( F(\cdot) \) on \( \Gamma \) if and only if \( x^{*} \) is a solution to (18).

**Proof.** The proof of this lemma is almost trivial, because the conditions in (18) are just the first-order conditions for the minimization of \( F(\cdot) \) on \( \Gamma \). The only complication is that, to invoke the first-order conditions, we need to have differentiability of \( F(\cdot) \) on \( \Gamma \), which is understood as differentiability of \( F(\cdot) \) on some open set containing \( \Gamma \). In case of \( \alpha < 1 \) any such open set necessarily includes points \( x \) with \( x_{i} \leq 0 \), at which \( F(\cdot) \) is not differentiable. The proof below formally deals with this complication.

Let us start with the simpler case of \( \alpha = 1 \). We can take the set 
\[
D = \{ x \in \mathbb{R}^{N} | \sum_{i} a_{ni} x_{i} > 0 \quad \text{for all} \quad n \}
\]
as the domain of \( F(\cdot) \) and use \( \Gamma \) as the constraint set. Clearly, \( \Gamma \subset D \cap \{ x \in \mathbb{R}^{N} | \sum_{i} x_{i} = \sum_{i} b_{i} \} \) and \( F(\cdot) \) is differentiable on \( D \) for \( \alpha = 1 \). Consider the minimization problem

\[
\begin{align*}
\min_{x \in D} F(x) \\
\text{s.t.} \\
x_{i} \geq 0, \quad i = 1, \ldots, N; \\
\sum_{i} x_{i} = \sum_{i} b_{i}.
\end{align*}
\]

(20)

Its first-order conditions, after some manipulations, can be written as

\[
\begin{align*}
x_{i} \geq 0, \quad \frac{\partial F(x)}{\partial x_{i}} \geq 0, \quad x_{i} \frac{\partial F(x)}{\partial x_{i}} = 0, \quad i = 1, \ldots, N, \\
\sum_{i} x_{i} = \sum_{i} b_{i}.
\end{align*}
\]

These conditions are also sufficient, because \( F(\cdot) \) is convex and the set that satisfies the constraints of the minimization problem is a convex set. Then, since \( G_{i}(x) = \frac{\partial F(x)}{\partial x_{i}} \), we get that any solution of the minimization problem (20) is also a solution of the NCP in (18) and vice versa.
Let us now turn to the case with $0 < \alpha < 1$. Let $x^*$ be a minimum of $F(\cdot)$ on $\Gamma$. By Lemma 2, $x^*_i > 0$ for all $i$. Let $\delta > 0$ be some number such that $\delta \leq x^*_i$ for all $i = 1, \ldots, N$. Define the domain of $F$ by $D = \{x \in \mathbb{R}^N | x_i > \delta/2, i = 1, \ldots, N\}$. Consider the minimization problem:

$$\min_{x \in D} F(x)$$

s.t. $\sum_i x_i = \sum_i b_i$. (21)

Since $\tilde{D} \cap \{x \in \mathbb{R}^N | \sum_i x_i = \sum_i b_i\} \subset \Gamma$, if $x^*$ minimizes $F$ on $\Gamma$, it also solves the minimization problem (21). Since $x^*_i > \delta/2$ for all $i$, the first-order conditions for (21) are given by

$$\frac{\partial F(x^*)}{\partial x_i} = 0, i = 1, \ldots, N,$$

and $\sum_i x^*_i = \sum_i b_i$. (22)

Hence, $x^*$ solves NCP in (18). Conversely, if $x^*$ solves NCP, then $x^*_i > 0$ for all $i$ because the condition $G_i(x^*) \geq 0$ cannot be satisfied for $x^*_i = 0$ if $0 < \alpha < 1$. Hence, $x^*$ satisfies conditions (22), which are the first order conditions for an interior solution of (21) with an appropriately chosen $\delta > 0$. Since these first-order conditions are also sufficient, $x^*$ solves (21). Now, suppose by contradiction that the minimum of $F(\cdot)$ on $\Gamma$ is some $x^{**} \neq x^*$. Then, by Lemma 2, $x^{**}_i > 0$ for all $i$. Therefore we can extend the open set on which $F(\cdot)$ is differentiable to include both $x^*$ and $x^{**}$. Then both $x^*$ and $x^{**}$ satisfy the first-order conditions (22), which gives a contradiction given that $F(\cdot)$ is strictly convex and the constraint set is convex. Hence, $x^*$ is the minimum of $F(\cdot)$ on $\Gamma$. \[\square\]

Combing the results from Lemmas 1-3, we get a proof of the part of Proposition 1 concerning the case of $0 < \alpha \leq 1$.

### C. Scale Economies, Welfare and Trade Flows

#### C.1. Proof of Proposition 3

The argument just above Proposition 3 has already established that, setting $w_l = 1$ by choice of numeraire, if $L_{i,k} > 0$ then $P_{i,k} < P^A_{i,k}$ and so there are strictly positive gains from trade in industry $k$ for country $i$. Let’s now consider the case with $L_{i,k} = 0$. In this case we know that in equilibrium we must have $G_{i,k} \geq 0$, and using again $w_l = 1$ this can
be rewritten as
\[
P_{i,k} \leq \mu_{i,k} \left( \frac{1 - \Delta_{i,k}}{S_{i,k} \beta_{i,k} \bar{L}_i} \right)^{1/\varepsilon_k},
\]
where \(\Delta_{i,k} \equiv \sum_{n \neq i} S_{i,k} \tau_n^{-\varepsilon_k} \mu_n^{-\varepsilon_k} \beta_{n,k} \bar{L}_n\). But in autarky we have \(P_{i,k}^A = \mu_{i,k} (S_{i,k} \beta_{i,k} \bar{L}_i)^{-1/\varepsilon_k}\), and hence
\[
P_{i,k} / P_{i,k}^A \leq (1 - \Delta_{i,k})^{1/\varepsilon_k}.
\]
With trade we have \(0 < \Delta_{i,k} < 1\), and hence \(P_{i,k} < P_{i,k}^A\). \(\square\)

### C.2. Data on Tariffs and Estimates of Elasticities of Scale

#### C.2.1. Data on Tariffs

We use data on *ad-valorem* tariffs for the year 2008 from the United Nations Statistical Division, Trade Analysis and Information System (UNCTAD-TRAINS). For some countries 2008 tariff data are missing. In these cases we use tariff data for the nearest available year. Following Caliendo and Parro (2015), we focus on effectively applied tariffs and use simple tariff line average as the measure of tariff for each importer-exporter-sector combination.

The original UNCTAD-TRAINS data for 2008 do not cover individual European Union (EU) member countries, but they include the EU as a reporter. We infer tariffs for the EU member countries by using the fact that the EU members enjoy free circulation of goods within the EU and exert a common external tariff on all goods entering the EU market.

The UNCTAD-TRAINS data cover 31 two-digit (in ISIC rev.3) sectors, 181 reporters, and 245 partners. We aggregate these data into 16 sectors and 34 countries that we use in the current paper: we first aggregate tariffs across reporters by using reporters’ total imports as weights; then we aggregate tariffs across partners by using partners’ total exports as weights; and, finally, we aggregate tariffs across sectors by using sectors’ total imports as weights. When calculating the weights, we use imports and exports only in the sectors for which UNCTAD-TRAINS has data on tariffs.

Tables 5 and 6 present average tariffs for importers and sectors. Averaging is done...
<table>
<thead>
<tr>
<th>Country</th>
<th>Average Tariff, %</th>
<th>Country</th>
<th>Average Tariff, %</th>
<th>Country</th>
<th>Average Tariff, %</th>
<th>Country</th>
<th>Average Tariff, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUS</td>
<td>2.71</td>
<td>ESP</td>
<td>3.12</td>
<td>ITA</td>
<td>3.16</td>
<td>SVK</td>
<td>3.05</td>
</tr>
<tr>
<td>AUT</td>
<td>3.06</td>
<td>FIN</td>
<td>3.06</td>
<td>JPN</td>
<td>6.68</td>
<td>SVN</td>
<td>3.05</td>
</tr>
<tr>
<td>BEL</td>
<td>3.07</td>
<td>FRA</td>
<td>3.15</td>
<td>KOR</td>
<td>12.64</td>
<td>SWE</td>
<td>3.06</td>
</tr>
<tr>
<td>BRA</td>
<td>9.66</td>
<td>GBR</td>
<td>3.12</td>
<td>MEX</td>
<td>5.35</td>
<td>TUR</td>
<td>6.18</td>
</tr>
<tr>
<td>CAN</td>
<td>3.42</td>
<td>GRC</td>
<td>3.06</td>
<td>NLD</td>
<td>3.08</td>
<td>TWN</td>
<td>5.97</td>
</tr>
<tr>
<td>CHN</td>
<td>8.92</td>
<td>HUN</td>
<td>3.06</td>
<td>POL</td>
<td>3.08</td>
<td>USA</td>
<td>2.81</td>
</tr>
<tr>
<td>CZE</td>
<td>3.06</td>
<td>IDN</td>
<td>7.16</td>
<td>PRT</td>
<td>3.06</td>
<td>ROW</td>
<td>6.50</td>
</tr>
<tr>
<td>DEU</td>
<td>3.21</td>
<td>IND</td>
<td>13.83</td>
<td>ROM</td>
<td>3.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DNK</td>
<td>3.06</td>
<td>IRL</td>
<td>3.06</td>
<td>RUS</td>
<td>8.20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: Original data on tariffs are from UNCTAD-TRAINS for year 2008. Average tariffs are calculated across exporters and sectors with exporters weighted by their total exports and sectors weighted by total sector imports.

Table 5: Average Tariffs by Importers

only for the sectors that have data on tariffs in UNCTAD-TRAINS. In the exercises with tariffs in Section 6.2, we assume zero tariff for all sectors that have empty values in the “Average Tariff, %” column of Table 6.

C.2.2. Estimates of Trade and Scale Elasticities

We use industry-level estimates of trade and scale elasticities obtained by Bartelme et al. (2018, BCDR). These values are provided in Table 6. Several comments are in order. First, in their paper, the list of industries is more disaggregated than the one in the current paper. In particular, three industries from our list: “Basic metals and fabricated metal”, “Electrical and optical equipment”, and “Transport equipment” are broken into subindustries in BCDR, each with its own estimated elasticities. To assign values of elasticities to industries from our list, we compute simple averages over corresponding industries in BCDR. Second, we only use BCDR’s estimates for the manufacturing industries. Finally, BCDR do not have an estimate for one industry that we classify as manufacturing: “Manufacturing, N.E.C.; recycling”. In our counterfactual exercises we assign the same trade and scale elasticities to this industry as for the non-manufacturing industries.

46For example, BCDR have estimates for “Coke, refined petroleum and nuclear fuel”, which we classify as non-manufacturing, and as a result we exclude BCDR’s estimates for this case.
<table>
<thead>
<tr>
<th>Sector</th>
<th>$\varepsilon_k$</th>
<th>$\psi_k$</th>
<th>Average Tariff, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture, hunting, forestry and fishing</td>
<td></td>
<td></td>
<td>12.05</td>
</tr>
<tr>
<td>Mining and quarrying</td>
<td></td>
<td></td>
<td>0.94</td>
</tr>
<tr>
<td>(M) Food, beverages and tobacco</td>
<td>4.40</td>
<td>0.16</td>
<td>16.47</td>
</tr>
<tr>
<td>(M) Textiles and textile products, Leather, leather products and footwear</td>
<td>7.70</td>
<td>0.12</td>
<td>10.27</td>
</tr>
<tr>
<td>(M) Wood and products of wood and cork</td>
<td>8.70</td>
<td>0.11</td>
<td>4.15</td>
</tr>
<tr>
<td>(M) Pulp, paper, printing and publishing</td>
<td>7.80</td>
<td>0.11</td>
<td>3.10</td>
</tr>
<tr>
<td>Coke, refined petroleum and nuclear fuel</td>
<td></td>
<td></td>
<td>2.87</td>
</tr>
<tr>
<td>(M) Chemicals and chemical products</td>
<td>3.40</td>
<td>0.21</td>
<td>3.76</td>
</tr>
<tr>
<td>(M) Rubber and plastics</td>
<td>2.90</td>
<td>0.26</td>
<td>5.59</td>
</tr>
<tr>
<td>(M) Other non-metallic mineral</td>
<td>6.80</td>
<td>0.14</td>
<td>6.02</td>
</tr>
<tr>
<td>(M) Basic metals and fabricated metal</td>
<td>7.15</td>
<td>0.13</td>
<td>3.55</td>
</tr>
<tr>
<td>(M) Machinery, not elsewhere classified</td>
<td>6.20</td>
<td>0.13</td>
<td>3.38</td>
</tr>
<tr>
<td>(M) Electrical and optical equipment</td>
<td>9.75</td>
<td>0.09</td>
<td>5.82</td>
</tr>
<tr>
<td>(M) Transport equipment</td>
<td>5.55</td>
<td>0.16</td>
<td>6.31</td>
</tr>
<tr>
<td>(M) Manufacturing, not elsewhere classified; recycling</td>
<td></td>
<td></td>
<td>5.82</td>
</tr>
<tr>
<td>Electricity, gas and water supply</td>
<td></td>
<td></td>
<td>0.60</td>
</tr>
<tr>
<td>Construction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sale and repair of motor vehicles and motorcycles; retail sale of fuel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wholesale trade, except of motor vehicles and motorcycles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retail trade and repair, except of motor vehicles and motorcycles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hotels and restaurants</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Inland transport</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Water transport</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Air transport</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other supporting transport activities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post and telecommunications</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Financial intermediation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real estate activities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Renting of machinery and equipment and other business activities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Health and social work</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other community, social and personal services. Private households with employed persons. Public administration and defence; compulsory social security</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:** Manufacturing sectors are marked by “(M)”. Values for $\varepsilon_k$ and $\psi_k$ for manufacturing sectors are based on estimates from BCDR (see description in the text of how these estimates are used to get the values for $\varepsilon_k$ and $\psi_k$). Original data on tariffs are from UNCTAD-TRAINS for year 2008. Average tariffs are calculated across importers and exporters with importers weighted by their total imports and exporters weighted by their total exports. Empty entries in the columns for $\varepsilon_k$ and $\psi_k$ mean that either BCDR do not have estimates for the corresponding sectors or their estimates are not used in the current paper. Empty values in the column for average tariffs mean that UNCTAD-TRAINS does not have data for the corresponding sectors.

**Table 6:** List of Sectors with Trade and Scale Elasticities. Average Tariffs by Sectors