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The Empirics of General Equilibrium Trade Theory: What Have We Learned?

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Abstract
This paper provides a selective survey of over half a century of research linking the neoclassical trade model to the data. Tensions between restrictive formulations of the model and real world complexities have launched a research agenda aimed at refining and reformulating theory to provide more convincing links between theoretical specification and empirical research design. Three lessons stand out. First, competitive and new trade theory models are complementary rather than competing ways to look at many existing empirical regularities. Second, the Ricardian formulation has proved to be a useful framework for structural estimation exercises regarding the pattern of international specialization. Third, empirical confirmations of the core predictions of the model provide scientific support for employing the competitive trade model in structural estimation.

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Outline:

Non-technical summary

This paper reviews the empirical applications of the general equilibrium model. I highlight the changing positions that have occurred on both the empirical and theoretical sides in the quest to link the theoretical frameworks to the empirics. The apparent tensions between the Heckscher-Ohlin model and the Leontief paradox as well as the phenomenon of 'intra-industry' trade have been resolved. Competitive and the new trade theory models should be viewed as complementary rather than competing explanations for international specialization. Modelling approaches aimed at relaxing the symmetry assumptions of the Heckscher-Ohlin-Vanek framework have shown that this framework is quite compatible with the pattern of the factor content of international trade. Theoretical advancement of the Ricardian model has expanded its application beyond an 'undergraduate classroom tool' to a general equilibrium framework capable of structural estimation. The Ricardian framework is capable of providing predictions about the parameters of gravity equations as well as firm heterogeneity regarding export activities. The competitive trade model distinguishes itself from the monopolistic competition trade model by linking production specialization to economic fundamentals rather than postulating such specialisation as arbitrary. The exploitation of a natural experiment confirms the various predictions of the competitive trade model at the individual product level.

1. Introduction

General equilibrium trade theory is one of the oldest sub-fields of economics, accumulating an impressive body of theoretical insights. This paper surveys the empirical approaches that have been utilized linking the theory to the data. My emphasis will be on the development of the theoretical specifications that have been fruitfully applied to the empirical domain rather than on the empirical findings per se.

The empirical literature on the neoclassical trade model has grown quite extensively during the past decades. Consequently, there have already been a number of excellent surveys published on the subject, such as Deardorff (1984), Leamer and Levinsohn (1995), Harrigan (2003), Davis and Weinstein (2003) and Feenstra (2004). The strategy of this survey is to briefly discuss topics previously surveyed and examine in more depth subsequent empirical research.

A landmark goal of empirical work is either to refute or verify a theory.[1] Leontief's (1954) famous study which concluded that the US post World War II trading pattern was incompatible with the Heckscher-Ohlin prediction –the famous *Leontief paradox* -was for many years viewed as evidence against the competitive trade model. In fact, the Leontief paradox and Balassa's (1966) empirical documentation of substantial *intra-industry trade* among economies with similar factor endowments provided the key stimuli for the development of trade theories under imperfectly competitive markets.

During the 1980s tension between the simple formulations of the theories and the real world complexities launched an empirical research agenda aimed at refining and reformulating competitive trade theory to provide more convincing links between theoretical specification and the data. This empirical reorientation has both led to a deeper understanding of competitive trade theory and also of its position relative to the theories under imperfect competition. One of the key lessons we have learned is that the competitive and the new trade theory models are complementary rather than competing ways to look at many existing empirical regularities. The Leontief paradox has been long resolved (Leamer, 1980), and the existence of intra-industry trade (Davis, 1995), gravity (Eaton and Kortum, 2002) and firm heterogeneity (Bernard, Eaton, Jenson and Kortum, 2003) have all been shown to be compatible with different specifications of the competitive framework.

A distinguishing feature of the competitive model is that in a frictionless world, market prices convey important information about underlying fundamentals like technologies, endowments and preferences.[2] As a result, competitive goods and factor prices are able to yield predictions on the pattern, gains and distributional implications of international specialization without having to impose strong restrictions on the preferences of the underlying agents. Since prices are most informative about the economy's underlying fundamentals if they are observed in the absence of international trade, the most robust and general predictions are based on autarky goods or factor price data. Since prices don't play this role under imperfect competition, these predictions are a special feature of the competitive model.[3] Hence,

[1] Some philosophers of science argue that we are never in the position to verify a theory, but we can either refute or not refute.

[2] The insight that in a market economy prices convey information about underlying fundamentals goes back to the seminal work by Hayek (1945).

[3] As Krugman (2009, p. 566) has pointed out in his Nobel Prize lecture, specialization based on economies of scale is arbitrary at the product level. The standard model of monopolistic competition invokes "...some notion of randomness, but without any explicit random mechanism in mind". In

empirical confirmations of these predictions, which will be reported later in the survey, provide strong scientific support for employing the competitive trade model in structural estimation exercises.

The competitive trade model is intrinsically linked to the concept of comparative advantage. Since there are different sources of comparative advantage, the competitive trade model comes in different formulations, each isolating specific determinants of comparative advantage. Topics are presented in the traditional way, beginning with the most general formulation of comparative advantage and then proceeding to the Ricardian and Heckscher-Ohlin sub-models and the more recent hybrid specifications, which combine elements of both. Our focus will be on predictions regarding the pattern of international specialization.

The natural starting point in section 2 is the general price formulation of comparative advantage. Here I highlight that the higher dimensional formulation of comparative advantage has the same underlying structure as the two-good textbook formulation. The set-up of a natural experiment that allows for testing the comparative advantage prediction is discussed as well as the estimation of the aggregate gains that arise from comparative advantage. This line of research has defied the conventional wisdom that comparative advantage is an untestable proposition.

Section 3 covers the Ricardian trade model which until recently, was in the empirical shadow of the Heckscher-Ohlin framework. The recent seminal work by Eaton and Kortum (2002) has defied previous judgment of the Ricardian model to be empirically irrelevant. The key insight is that the randomization of technology provides a Ricardian explanation for the empirically highly relevant gravity equation. The multi-country dimension of the model has provided a new building block for structural estimation exercises pertaining to the pattern of world trade and also refined Balassa's (1965) old insight that observed export shares reveal technological comparative advantage.

Section 4 discusses the Heckscher-Ohlin framework in its different formulations. Since a bulk of the empirical Heckscher-Ohlin-Vanek literature has been already surveyed in depth, only the seminal papers in the development of that literature have been included. The focus of this section will be on the recent tests of the multi-cone and price formulations of Heckscher-Ohlin.

Section 5 discusses some hybrid specifications which try to disentangle the different roles that technologies, endowments, or institutions play in determining the pattern of international specialization. Section 6 concludes the survey.

contrast, the competitive trade model is based on the notion of the 'invisible hand' which works through the price mechanism.

2. Comparative advantage and the gains from trade

"*Proofs of the static gains from trade fall into the unrefutable category yet these are some of the most important results in all of economics*".

(Leamer and Levinsohn, 1995, p.1342)

We start out with the most general formulation of comparative advantage, but restrict ourselves initially to the case of only two commodities. Consider a small open economy that considers trading with the rest of the world, called foreign. This implies that foreign prices p_1^f and p_2^f determine the country's terms of trade. The country's net import quantities are denoted by T_1 and T_2, with the balance of trade (BOT) being defined as:[4]

$$p_1^f T_1 + p_2^f T_2 = 0$$

The BOT condition implies that there are only two feasible patterns of trade predictions: (i) export good 1 and import good 2 (i.e. $T_1<0$ and $T_2>0$) or (ii) import good 1 and export good 2 (i.e. $T_1>0$ and $T_2<0$). The law of comparative advantage predicts the pattern of trade by a comparison of relative prices under free trade with those prevailing if the economy had been operating in a state of no trade or autarky. Denoting the autarky prices with p_1^a and p_2^a, the predictions are: (i) if $p_1^a/p_2^a < p_1^f/p_2^f$, then $T_1<0$ and $T_2>0$ and (ii) if $p_1^a/p_2^a > p_1^f/p_2^f$, then $T_1>0$ and $T_2<0$. Using the balance of trade condition, it is easily verified that these conditional predictions can be expressed compactly in a single inequality:

$$p_1^a T_1 + p_2^a T_2 > 0. \tag{1}$$

[insert Figure 1 here]

Figure 1 depicts the economy's feasible trading patterns and how they are related to commodity prices. The balance of trade condition restricts the economy to trade along the BOT line. Relative prices are chosen such that $p_1^a/p_2^a < p_1^f/p_2^f$ which implies that the economy has a comparative advantage in good 1. Hence it will export good 1 and import good 2. An advantage of writing the two-good prediction as a single inequality is that it reveals that autarky goods prices impose a single refutable prediction on the commodity pattern of trade. For a given vector of data, denoted by T^*, to be compatible with the law of comparative advantage requires that $p_1^a T^*_1 + p_2^a T^*_2 > 0$. In addition, it highlights that the basic structure of the two-good prediction carries over to the n-good formulation of comparative advantage, as formulated by Deardorff (1980) and Dixit and Norman (1980). Denoting p^a and T the economy's *n*-vectors of autarky prices and net import quantities, the general comparative advantage prediction is given by:

$$p^a T > 0. \tag{2}$$

If n>2, the prediction does not identify which particular good is exported or imported. The inequality is generally interpreted as a correlation version of

[4] If $T_i>0$ (<0) good i is imported (exported).

comparative advantage which says that the economy will, on average, export goods with low autarky prices and import goods with high autarky prices. Figure 1 illustrates that the n-good formulation preserves the nature of the two-good prediction. In particular, the hyperplane $p^aT=0$ can be thought of cutting the set of feasible pattern of trading configurations (i.e. those that fulfil the balance of trade condition p^fT) into half. The property that the economy's autarky price vector p^a yields a *single* refutable prediction on its net import vector T, with the rejection region given by $p^aT<0$, is invariant to dimensionality. Finally, the prediction holds, as demonstrated by Deardorff (1980), under a minimum of critical assumptions on technologies, consumer preferences and government intervention. In particular, the only thing that needs to be assumed is that exports are, on average, not subsidized.

Bernhofen and Brown (2004) have identified Japan's opening up to international trade in the 19th century after 200 years of self-imposed isolation as a natural experiment to test the general comparative advantage prediction (2). The unique feature of the case of Japan, and why it deserves to be called a natural experiment, is that it fulfils all the key assumptions of the neoclassical trade model. In particular, since Japan was a market-based economy producing fairly homogeneous products under autarky, Japan's autarky prices are good measures of the economy's opportunity costs. Furthermore, since Japan's move from autarky to free trade was rapid, Bernhofen and Brown were able to identify a "free trade window" 1868-1875 in which the traded goods were compatible with the goods the economy was able to produce during its "late autarky window" of 1851-53. Matching detailed commodity market price data during the late autarky period with the observed trade data during 1868-75, they find that the comparative advantage prediction holds in each single year.

The pattern of trade prediction is also tightly linked to the economy's aggregate gains from trade. In fact, the *sign* of the inner product p^aT provides information about whether an observed net import vector T yields gains (or losses) to the economy and the *magnitude* of p^aT provides information about the size of these gains. This can be illustrated in Figure 1. The net import vector T^{**} yields a loss (that is $p^aT^{**}<0$) since the international exchange of good 2 for good 1 occurs at the rate p^f_2/p^f_1 which is less favourable than the domestic rate of exchange p^a_2/p^a_1 under autarky. By the same reasoning, the net import vector T^* yields a welfare gain since $p^f_1/p^f_2> p^a_1/p^a_2$. This illustrates that the existence of gains from trade can, in principle, be refuted by the data.

The magnitude of p^aT^* captures the size of the gains from trade. This can be seen as follows: fixing p^a_1/p^a_2, an increase in p^f_1/p^f_2 leads to a more favourable terms of trade, which results in larger gains from trade. This will cause T^* to move further away from the hyperplane $p^aT=0$; hence, a more favourable terms of trade is associated with an increase in p^aT^*.

A more rigorous treatment of the gains from trade relates the inner product to the Slutsky compensation measure of welfare, which is defined as the increase in income which would allow the economy to move from autarky to free trade consumption when both are valued at autarky prices. However, as stressed in Bernhofen and Brown (2005), since autarky and free trade are observed at different points in time, the comparison involves a counterfactual. In the case of Japan it involves a comparison between Japan's actual consumption point C^a_{1850} under autarky with the counterfactual consumption bundle C^f_{1850} that the economy could have obtained if trade had taken place during the 1850s. Denoting the counterfactual trading vector during the 1850s as T_{1850s}, the inner product p^aT_{1850s} can be shown to provide an upper bound to the Slutsky welfare measure[5]:

$$\Delta W_{Slutsky}=p^aC^f_{1850s} - p^aC^a_{1850s} \leq p^aT_{1850s} \quad (3)$$

The welfare question suggested by $\Delta W_{Slutsky}$ is then the following: 'By how much would real income have had to increase in Japan during its final autarky years 1851-1853 to afford the consumption bundle the economy could have obtained if it had been engaged in international trade during the period?' Using different historical estimates on Japan's GDP levels at the time around its opening, Bernhofen and Brown obtain upper bounds on the gains from trade of about 8 to 9 percent of Japan's GDP.[6]

3. The Ricardian framework

In the Ricardian framework comparative advantage arises from technological differences. The multi-good formulation of the Ricardian model, which goes back to Haberler (1930), assumes a single factor (labour), two countries (home and foreign) and *n* goods. The technology of producing good *i* in home and foreign is given by the per unit labour requirements a_i and a_i^* which can be arranged into a productivity ordering or *a chain of comparative advantage*:

$$a_1^*/a_1 > a_2^*/a_2 > \ldots > a_n^*/a_n \quad (4)$$

The productivity ordering (4) postulates that home has the highest productivity advantage in good 1 and the least productivity advantage in good n. Haberler postulated that demand factors will determine some breakpoint in the chain predicting that the home economy completely specializes in and exports the low indexed goods (that is to the left of the break) and the foreign economy will specialize and export the high indexed goods. Comparative advantage and trade is determined by relative productivity advantages in a bilateral comparison.

The first empirical studies which used the formulation (4) as the basis of an empirical analysis of the Ricardian model were conducted by MacDougall (1951, 1952) who calculated relative labour productivity differences for US and British manufacturing industries and linked them to the countries' relative export volumes. MacDougall found that in those industries in which the US had a higher productivity advantage it had also a higher share on the export market relative to the UK. Subsequently, Stern (1962) and Balassa (1963) built upon MacDougall by using different data and methodology and also found a consistently positive and significant

[5] In the case of constant opportunity costs, as in the Ricardian 1-factor case, p^aT_{1850s} gives an exact measure of the gains from trade.

[6] Irwin (2005) identifies the US 1807-09 trade embargo as another opportunity to estimate the welfare costs of autarky. However, since the trade embargo lasted only for about 14 months Irwin is not able to cast his analysis in terms of a counterfactual, and the welfare comparison needs to be treated with some caution. Using fairly aggregated trade and price indices, Irwin provides welfare costs of about 5 percent of GDP. This seems quite high given that the economy had little time to reallocate its resources along the new prices under the embargo. One might expect that US producers anticipated that the embargo might not be lasting.

correlation between US and UK relative export shares and the corresponding productivity ratios.

These robust empirical regularities have been difficult to interpret on theoretical grounds since they consider export shares to third countries, whereas the chain logic (4) is tied to a two-country framework. Furthermore, there is nothing in the theoretical specification (4) suggesting a positive relationship between export shares and productivity ratios. An unsettling feature of this formulation is that it implies a sharp edge prediction of complete international specialization which are not expected to be found in aggregate data. For that reason, the Ricardian framework has for many years been judged to be of 'little empirical relevance' (Leamer and Levinsohn, 1995) compared to its Heckscher-Ohlin sibling.

This view has been challenged by Eaton and Kortum (2002) who opened a line of inquiry which has demonstrated that the Ricardian framework *is* empirically relevant. Since Eaton and Kortum is a multi-country extension of Dornbusch, Fischer, and Samuelson (DFS) (1977), we sketch the main features of DFS.[7]

DFS generalizes Haberler's chain formulation (4.5) to a continuum of goods, which are indexed by $z \in [0,1]$. The comparative advantage ranking is then given by a relative productivity curve $A(z)=a^*(z)/a(z)$ which is assumed to be decreasing in z. Home has its highest productivity advantage in good 0 and it diminishes as one moves towards good 1. A key innovation of DFS is that they derive the breakpoint in an analytical model from underlying demand and cost fundamentals. In particular, free trade relative labour costs of home w/w^*, which can be thought of as the *factoral terms of trade*, yield the breakpoint by defining a marginal good *m* such that home will specialize and export [0,m] and foreign will export [m,1].[8]

A second key innovation of DFS is the incorporation of trade frictions, modelled as iceberg trade costs τ (τ>1), into the Ricardian framework.[9] In the presence of trade costs, the equilibrium is characterized by two marginal goods m_1 and m_2 which partition the unit interval into three segments. Home and foreign will then specialize in and export those sectors where they have the highest relative productivity advantages, that is home in $[0,m_1]$ and foreign in $[m_2,1]$ whereas $[m_1,m_2]$ is the endogenously determined non-traded sector. In many ways, DFS is the foundation article of modelling trade costs in a fully articulated general equilibrium model which allows for comparative statics.[10] For a given trade cost level τ, countries will export only in sectors (or activities) in which they have a high relative productivity advantage. A reduction in trade costs, i.e. a fall in τ, will affect the volume of bilateral trade through both the intensive and extensive margin. Resource savings from less waste in international shipping will increase the volume of goods which have been traded before - the so-called *intensive margin*- via an income effect. Increased foreign competition will result in a shrinking of the non-traded sector and new trade in goods which were previously sheltered by trade costs, the so-called *extensive margin*.

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[7] See the preceding chapter by Woodland (2010) for a thorough discussion of DFS.
[8] On the demand side, DFS assume identical and homothetic preferences. But the framework also accommodates non-homothetic preferences.
[9] Samuelson's iceberg assumption implies that delivering one unit of a good to a foreign destination requires the shipment of τ units, where τ>1.
[10] Matsuyama (2007) exploits the DFS set-up for a creative general equilibrium approach of modeling trade costs not using the iceberg framework. I am not aware of any empirical work which is guided by Matsuyama's approach.

Since the size of the non-traded sector is increasing in the trade costs, trade costs reduce the volume of trade. Furthermore, assuming identical and homothetic preferences it can be shown that the volume of two-way trade is increasing in the size of the economies' labour forces. As a result, DFS already yields a gravity prediction, where the volume of bilateral trade is increasing in the countries' relative country size and decreasing in trade costs, but only in the two-country case.

The key innovation of Eaton and Kortum (2002) is to extend DFS to a multi-country framework by modelling technological heterogeneity as a random process rather than assuming it to be deterministic. Country i's labour productivity $a^i(z)$ in producing good z is assumed to be a random variable with a Fréchet distribution, with the distribution function given by $\Pr[a^i(z) \leq A] = F^i(A) = e^{-T^i A^{-\theta}}$. Furthermore, it is assumed that the productivity drawings are independent across goods and countries.

Since all goods fall in [0,1], $F^i(A)$ is also the fraction of goods for which country i's labour productivity is lower than or equal to A. This fraction is affected by the technology parameters T^i and θ. The country-specific parameter T^i captures the country's state of technology, reflecting its absolute advantage across the continuum and corresponds to the absolute size of the input coefficients in (4). The parameter θ corresponds to the steepness of A(z) in the DFS formulation. A higher θ is equivalent to a flatter A(z) schedule. In the limiting case where A(z) is horizontal, the absence of relative productivity advantages would reduce the incentive for trade.

On the demand side, buyers –who could be final consumers or firms buying intermediate goods - purchase goods to maximize a CES objective. Buyers in country *j* compare prices from all source countries and are only willing to pay the minimum price for a good z. As in DFS, country-pair specific iceberg trade costs, τ^{ij}, impose frictions to trade as they affect prices at the point of delivery. A country *i* with a lower state of technology T^i which is more remote from its trading partners (that is τ^{ij} is high), will sell a narrower range of goods to the destination country *j.* A key feature of this model set-up is that the probability that country *i* provides the good at the lowest price to country *j* is equal to the fraction of the goods that *j* purchases from *i*. As a result, the share of country j's expenditure on the goods from country *i*, x^{ij}, in its total expenditure e^j can be written in its gravity type form:

$$x^{ij}/e^j = Q^i / \Phi(.), \tag{5}$$

where Q^i denotes the exporter's total sales. The function $\Phi(.)$ in the denominator captures how the interaction of technological heterogeneity and geographical distance affects the volume of bilateral trade.

The gravity equation can also be derived from models that are based on product differentiation, as in the Armington model or the model of monopolistic competition (see chapters 10 and 17).[11] Consequently, the uniform empirical success of gravity regressions cannot be interpreted as empirical evidence for the Ricardian framework. Instead it suggests that the forces of gravity might work through the Ricardian mechanism where a decrease in trade costs increases the volume of trade as it induces countries to specialize in and export goods in which they have a

[11] In the Armington model, goods are imperfect substitutes because they come from different locations. Under monopolistic competition consumers have a taste for product variety and scale economies induce countries to specialize in distinct varieties.

productivity advantage. This is in contrast to models of product differentiation where a decrease in trade costs does not affect the set of traded goods, but rather induces consumers to spend more on each imported variety.[12]

An attractive feature of Eaton and Kortum (2002) is that it provides a structural multi-sector, multi-country model whose parameters can be estimated to explore comparative statics effects in general equilibrium. In their original paper, they apply their framework to 19 OECD countries and conduct a variety of counterfactual exercises regarding the gains from trade, the role of geographic barriers on international specialization, the welfare effects of tariff reductions and the benefits of new technology. Donaldson (2010) applies the Eaton and Kortum's framework creatively to colonial India and estimates the general equilibrium effects of the colonial railroad expansion from 1853 to 1930. An attractive aspect of this application is that the empirical domain is compatible with the key features of the model where the production of homogenous products is dispersed geographically among Indian regions subject to productivity (or weather) shocks. He finds that this massive transportation infrastructure project improved overall welfare by regions exploiting their comparative advantage.[13]

An essential feature of the multi-sector Ricardian model is its emphasis on technological heterogeneity. Introducing Bertrand competition into the Eaton Kortum set-up, Bernard, Eaton, Jenson and Kortum (2003) are able to generate empirical predictions that have been found in many plant level data sets around the world.[14] Regarding predictability, the Eaton Kortum framework is isomorphic to Melitz (2003). Both models imply new gains from trade in the form of overall productivity gains that stem from trade inducing the exit of low productivity and the expansion of high productivity activities.[15] Bernard, Eaton, Jenson and Kortum (2003) calibrate their model to bilateral trade between the US and their trading partners and examine counterfactual exercises on the impacts of globalization on aggregate and plant level variables.

Building on Eaton and Kortum, Costinot, Donaldson and Komunjer (2010) develop a Ricardian structural model where technological differences across countries yield predictions on the pattern of trade. They accomplish this by introducing exogenous productivity differences in the Eaton Kortum set-up. Consider a slight modification of the above set-up by assuming that each good k comes in N^k varieties and N^k is assumed to be large. Technology is modelled such that labour productivity of variety v of good k in country i is given by:

$$\ln a_k^i(v) = \ln a_k^i + u_k^i(v),$$

[12] Deardorff (1998) derived a gravity equation in a Heckscher-Ohlin model with complete specialization. However, by assuming that each country produces a different good, the underlying mechanism generating gravity is complete specialization and product differentiation rather than comparative advantage. By contrast, in Eaton and Kortum (2002) the same homogeneous good is produced by multiple producers.

[13] Donaldson (2010) argues that by employing a general equilibrium approach he does not assume that policy treatments by one unit of observation do not affect outcomes of any other unit, as it is usually done in the policy evaluation literature. He suggests that ignoring general equilibrium effects would bias his estimates by almost 20 percent.

[14] For example: exporters are larger and appear to be more productive than non-exporters. However, in most empirical studies measured productivity is only correlated with export status and might be driven by other factors, like firm investment etc.

[15] The key difference is that Bernard, Eaton, Jenson and Kortum (2003) consider competition within a variety while Melitz (2003) focuses on competition between varieties. I am not aware of any empirical work that exploits this distinction between the two models.

where a_k^i is a deterministic labour unit requirement that is common to all varieties, and u_k^i (v) is stochastic and variety-specific. The deterministic component a_k^i, can be thought of capturing the fundamental productivity of country *i* in industry *k*. The stochastic component u_k^i (v), which is assumed to be drawn independently from the same distribution, captures random productivity shocks which give rise to intra-industry heterogeneity. The degree of intra-industry heterogeneity is captured by the productivity parameter θ, which is similar to the specification discussed above.

A key feature of this specification is that cross-country and cross-industry variations in the distribution of productivity levels stem from variations in the fundamental productivity parameters a_k^i. The existence of exogenous productivity differences across industries shifts the indeterminacy in trade in individual industries to indeterminacy in trade in varieties.

Given a pair of countries i_1 and i_2, we can order the industries according to their relative fundamental productivities:

$$\frac{a_1^{i_1}}{a_1^{i_2}} > \frac{a_2^{i_1}}{a_2^{i_2}} > \ldots > \frac{a_n^{i_1}}{a_n^{i_2}}$$

which coincides with (4) for the two-country case with no random productivity shocks. However, in the presence of productivity shocks, the ranking of fundamental productivities implies a stochastic ranking of total labour requirements:

$$\frac{a_1^{i_1}(v)}{a_1^{i_2}(v)} \succ \frac{a_2^{i_1}(v)}{a_2^{i_2}(v)} \succ \ldots \succ \frac{a_n^{i_1}(v)}{a_n^{i_2}(v)} \tag{6}$$

where $\succ$ denotes the first-order stochastic dominance operator. Since (6) is a stochastic ordering, there is some indeterminacy in the trading pattern of individual varieties. As a result, there is no sharp edge prediction of country i_1 producing and exporting all varieties in the high indexed industries. Rather that it is more likely to export relatively more of these varieties. However, the ranking of fundamental productivities determines the ranking of relative export shares to any third trading partner:

$$\left\{\frac{a_1^{i_1}}{a_1^{i_2}} \succ \frac{a_2^{i_1}}{a_2^{i_2}} \succ \ldots \succ \frac{a_n^{i_1}}{a_n^{i_2}}\right\} \Leftrightarrow \left\{\frac{x_1^{i_1 j}}{x_1^{i_2 j}} \prec \frac{x_2^{i_1 j}}{x_2^{i_2 j}} \prec \ldots \prec \frac{x_n^{i_1 j}}{x_n^{i_2 j}}\right\} \tag{7}$$

where x_k^{ij} denotes the exports of country *i* to *j* in good *k*.[16] The one-to-one relationship in (7) is quite a remarkable result since it predicts an ordering of export shares to *any* trading partner from an ordering of relative labour productivities. Alternatively, (7) implies that the ranking of relative export shares reveals the ranking of relative fundamental productivity differences.

The idea that observed export shares reveal productivity differences resembles Balassa's (1965) concept of revealed comparative advantage, which has been widely used in the empirical trade literature. However, the literature on revealed comparative

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[16] It should be noted that (7) is derived from (6) under the assumption that the productivity of the varieties are drawn independently from a Fréchet distribution.

advantage has been criticized as having no trade-theoretical foundations. Balassa's approach used data on relative exports to infer the revealed pattern of comparative advantage across countries and industries. He aggregated exports across countries and industries to obtain a measure of revealed comparative advantage of country *i* in industry *k* against an ad-hoc benchmark, which is not rooted in economic theory. In contrast, (7) *is* derived from economic theory. It suggests that a pair-wise comparison of countries' productivities are linked to the corresponding export shares to a specific third country rather than a benchmark of countries.

Costinot, Donaldson and Komunjer (2010) use the ordering (7) to derive a structural equation that predicts how variations in observed productivity levels across countries and industries affect the variation in bilateral exports. Their empirical findings are consistent with the theoretical predictions and their estimated parameter of intra-industry heterogeneity θ is compatible with values found in previous studies.

The Eaton-Kortum model provides a useful general equilibrium framework conducive for deriving predictions on how trade costs affect the pattern of international specialization. Harrigan (2010) considers a variation of Eaton and Kortum by considering differences in trade costs across goods. He indexes goods $z \in [0,1]$ by increasing weight where good 0 is the lightest (computer chips) and good 1 is the heaviest (oil). Goods can be shipped by two modes of transportation: surface (i.e. ship, train or truck) or airfreight. Surface shipping costs are the same for all goods, but airfreight costs depend on weight and are therefore increasing in z. Since air transport is more costly, consumers must value speed. So Harrigan assumes that a good yields a higher utility if it is shipped by air.

Harrigan derives a prediction about the relationship between unit values of imported goods and distance for a specific country: imports from nearby trading partners have lower unit values than imports from more distant partners. The intuition for this finding is that nearby countries will specialize in low value/weight products which will be sent by surface; whereas, more distant countries specialize in high value/weight products shipped by air. Applying the model to US imports data from 1990-2003, Harrigan finds empirical support for these predictions.

4. The Heckscher-Ohlin framework

In the Heckscher-Ohlin model comparative advantage arises from endowment differences. This requires a second factor of production, capital. The second factor of production can be mobile or specific to an industry; the latter gives rise to the specific factor model. Because the free trade equilibrium is in the normal case characterized by incomplete specialization, the Heckscher-Ohlin model has long been viewed as empirically more relevant than the Ricardian model and inspired a considerable amount of empirical work.

The seminal study by Leontief (1953) was the first attempt to confront the Heckscher-Ohlin theory with data. Leontief developed input-output accounts for the US economy in 1947 and used them to calculate the capital and labour content of aggregate US export and import flows with the rest of the world. Leontief's analytical framework was the textbook two-good, two-factor version of the Heckscher-Ohlin Model which predicts that a capital abundant country should export the capital-intensive good and import the labour-intensive good. Applying this prediction to the US data, Leontief compared the capital labour ratios of US exports with that of its imports. Surprisingly, Leontief found that the capital labour ratio of

US imports was larger than the capital labour ratio of US exports. Since the US was clearly the most capital abundant country in the world at that time, his findings seemed at odds with the Heckscher-Ohlin prediction and the outcome of his test was famously labelled the *Leontief Paradox*.

Leontief's finding stimulated a large empirical literature aimed at providing explanations for this paradox and also provided a stimulus for extending the Heckscher-Ohlin model to higher dimensions.[17] Among the many explanations, Leamer (1980) provided the most convincing resolution of the paradox. Building on the theoretical work by Vanek (1968), Leamer argued that the Leontief paradox is based on a conceptual misunderstanding of the Heckscher-Ohlin Theorem. Leamer showed that Vanek's theoretically correct Heckscher-Ohlin prediction involves a comparison between the capital-labour ratios of a country's production and consumption rather than the capital-labour ratios of the country's exports and imports. When applying the correct comparison to Leontief's 1947 US data, the paradox disappeared. Leamer's paper triggered a large research agenda aimed at investigating the empirical validity of the Heckscher-Ohlin Theorem in its Heckscher-Ohlin-Vanek (HOV) formulation.[18]

Since in the HOV model relative factor abundance is captured by differences in the countries' factor endowment, this is called the quantity formulation of Heckscher-Ohlin. Alternatively, relative factor abundance can be captured by differences in countries' factor prices giving rise to the price formulation of Heckscher-Ohlin. We start out by introducing the HOV model and discuss the key developments in this literature.[19] Then we review recent empirical work which is based on the price formulation of Heckscher-Ohlin.

4.1 Quantity formulation of Heckscher-Ohlin: HOV

Consider an integrated world economy with *m* countries, *l* factors and *n* goods and no impediments to international trade.[20] The Heckscher-Ohlin-Vanek model is based on three critical assumptions that characterize the integrated equilibrium. First, it assumes that countries have the same technology matrix, $A(.)=<a_{vg}(.)>$, where a_{vg} denotes the units of factor *v* necessary to produce 1 unit of good g. Second, it assumes that endowment differences are such that all countries produce the goods with the same production techniques. An implication of these two assumptions is that the free trade equilibrium is characterized by factor price equalization (FPE).[21] A common factor price vector w implies that the input coefficients $a_{vg}(w)$ are the same everywhere. The third critical assumption is that all consumers in the world have the

[17] The prominent early empirical papers are Baldwin (1971), Harkness (1978), Stern and Maskus (1981), Brecher and Choudhri (1982) and Maskus (1985), which are reviewed in Deardorff (1984). See Ethier (1984) for a review of the theoretical Heckscher-Ohlin formulations in higher dimensions.

[18] This research agenda was launched by Leamer's (1984) influential monograph.

[19] See Davis and Weinstein (2003) and chapters 2 and 3 in Feenstra (2004) for a more in depth coverage of the HOV literature.

[20] For expositional reasons we assume a discrete number of goods. In some instances it is more convenient to use the Heckscher-Ohlin continuous goods formulation, introduced by Dornbusch, Fischer and Samuelson (1980), as in Romalis (2004) which I discuss later.

[21] It is common to talk about the factor price equalization assumption. From a theory perspective, factor price equalization is a prediction of the model rather than an assumption (see Woodland, 2010). It is the implication of assuming that countries have identical technologies and that factor endowments are "not too dissimilar". "Not too dissimilar" is made rigorous by requiring that factor endowments lie in the FPE set given in Figure 2. See Helpman and Krugman (1985) for a formal definition of the FPE set in higher dimensions.

same homothetic preferences, which means that they consume all goods in the same proportions.

Figure 2 illustrates an integrated equilibrium with three countries, six goods and two factors (labour and capital). Countries are characterized by their endowment vectors V^1, V^2, V^3 which add up to the world endowment vector V^w and are capable of producing the six goods $g_1,\dots g_6$ with the capital-labour ratios given in the diagram.[22] In a world with more than two goods, it is not possible to identify which particular good a country is either exporting or importing. However, the assumption of identical and homothetic preferences allows one to identify which particular factors are traded. Specifically, the homotheticity assumption implies that a country's equilibrium consumption vector is given by $C^i=s^iV^w$, where s^i denotes country i's share of world GDP. Figure 2 illustrates Leamer's (1980) point that the Heckscher-Ohlin prediction involves a comparison of an economy's capital-labour ratio of production and consumption. For example, since country 1's endowment vector V^1 lies to the left of the diagonal, it is capital abundant relative to the world. But since the preference symmetry assumption implies that the country's equilibrium consumption vector C^1 also lies on the diagonal, it follows immediately that the capital-labour ratio of its production, which is its endowment, exceeds the capital-labour ratio of its consumption. In a free trade equilibrium, country 1 will implicitly export X units of capital and import M units of labour.[23]

[insert Figure 2 here]

As a commodity trading vector is the difference between domestic production and domestic consumption, the factor content of trade is the difference between the factor content of consumption and the factor content of production. Country i's factor content of net imports F^i is constructed by multiplying the common technology matrix A with the country's net import vector T^i, i.e. $F^i=AT^i$. Since the country's production vector is V^i and its consumption vector is s^iV^w, the Heckscher-Ohlin-Vanek (HOV) relationship for country *i* in factor *k* is given by:

$$F_k^i = AT_k^i = V_k^i - s^i V_k^w = V_k^i - s^i \sum_j V_k^j \qquad (8)$$

The HOV equation implies a sign prediction on the individual factors of production:

$$(V_k^i - s^i V_k^w)\, F_k^i > 0 \qquad (9)$$

The restrictions (9) are derived from the factor-balance-of-trade equilibrium conditions given in (8). A pair-wise comparison of factor specific endowment differences between country *i* and the world in factor *k* predicts the sign of the factor content of trade in that factor. The number of restrictions increases with the number of factors and countries in the trading equilibrium. This is quite different to the comparative advantage formulation (1) which yields a single restriction that is

[22] Each country is capable of producing the six goods with the given techniques since each country's capital-labour ratio is below the capital labour ratio of the most capital-intensive good g_1 and above the capital-labour ratio of the least capital-intensive good g_6.

[23] Geometrically, the consumption point C^1 is linked to the endowment point V^1 by a line with slope w/r, where w and r are the free trade factor prices. This line can be interpreted as the factoral terms of trade line.

invariant to the number of countries or factors in the trading equilibrium. The reason for this is that (1) is based on the gains from trade argument which does not depend on dimensionality and where the predictor stems from the autarky equilibrium.

In (9) the direction of trade of an individual factor is predicted by the country's endowment of this factor minus the world endowment scaled by the country size. Alternatively, we can rank the factors according to their factor scarcities relative to the world.

$$\frac{V_1}{V_1^w} < \frac{V_2}{V_2^w} < .. \frac{V_k}{V_k^w} < s < \frac{V_{k+1}}{V_{k+1}^w} < ... \frac{V_l}{V_l^w} \qquad (10)$$

The Heckscher-Ohlin-Vanek relationship implies then a chain prediction where the economy is a net importer of its scarce factors (1,...,k) and a net exporter of its abundant factors (k+1,…,l).

Bowen, Leamer and Sveikauskas (BLS) (1987) were the first to test the full implications of (8) on a broad data set comprising of 27 countries and 12 factors.[24] A key feature of BWL is their use of a single US technology matrix to measure each country's factor content of trade. They tested both the sign predictions (9) and a rank comparison, i.e. whether $F_k^i > F_l^i \Leftrightarrow (V_k^i - s^i V_k^w) > (V_l^i - s^i V_l^w)$, and found that both performed quite poorly. Their findings that the predictions of the model were no more successful than the toss of a coin dampened further inquiry of HOV.

Motivated by the observation that a common US technology matrix is clearly an implausible assumption, Trefler (1993) reinvigorated interest in HOV by relaxing the assumption of identical technologies. Inspired by Leontief's (1953) claim that the United States is abundant in labour when labour is measured in "productivity equivalents", Trefler asks whether one can find plausible factor productivity parameters π_k^i such that the data fit a productivity-adjusted HOV equation:

$$F_k^i = \pi_k^i V_k^i - s^i \sum_j \pi_k^j V_k^j \qquad (11)$$

The specification (11) allows factors in all countries to differ in their productivities. Taking the US as a benchmark, π_k^i measures the productivity of factor k in country i relative to its productivity in the United States, assuming $\pi_k^{US}=1$. From a measurement point of view, the factor content of trade in country i is still evaluated with a common US technology matrix, i.e. $F^i = A^{US} T^i$. However, a country's factor content of trade is now explained by productivity-adjusted endowment vectors $\pi^i V^i$ and factor price equalization is assumed to hold in a world of *effective endowments*. Trefler views (11) as a system of equations which can be solved for the unknown productivity parameters. From a methodological viewpoint this is quite a different approach from BLS as it shifts the emphasis from testing to 'reasonability of fit'. Trefler solves for the productivity parameters in (11) and argues that they are reasonable since the labour productivity parameters are highly correlated with wages and the capital productivity parameters correlate with the price of capital.[25] Trefler's

[24] Maskus (1985) provided an earlier test of (8), but only for a single country across factors. In contrast, BLS were able to test HOV across factors and countries.

[25] Gabaix (1999) points out that, if the labour content of trade is small, the correlation just reflects correlation between wages and per capita GDP which has nothing to do with the Heckscher-Ohlin model.

finding can be interpreted as support of HOV as long as productivity differences are taken into account.

In a follow-up piece, Trefler (1995) goes back to (9), revisits BLS using an extended dataset, confirms their negative finding for an unadjusted HOV equation and identifies an empirical regularity in the relative magnitudes of the left and right hand side of (8). Trefler finds that the measured factor content of trade F_k^i is much smaller relative to its factor endowment prediction, i.e. $V_k^i - s^i V_k^w$, which he calls the *mystery of the missing trade*".[26] Trefler suggests then an alternative way of modeling productivity differences which does not lead to a perfect fit in the HOV equation. Assuming uniform productivity differences, a country's technology matrix A^i is given by $A^i = A^{US}/\delta^i$, where the single parameter δ^i captures the productivity difference of country *i* relative to the US. If $\delta^i < 1$, country *i* is less productive than the US in all factors. The modified HOV equation then becomes:

$$F_k^i = \delta^i V_k^i - s^i \sum_j \delta^j V_k^j \qquad (12)$$

where a country's factor content of trade is still evaluated using the US technology matrix, i.e. $F^i = A^{US} T^i$. The productivity parameters δ^i are then chosen to minimize the sum of squared residuals in (12). A comparison of the variance of the left-hand side with the estimated right-hand side of (8) or (12) can then be used as a measure of the R^2 of the model under the different specifications. Trefler finds that the incorporation of uniform productivity differences explains about one half of the missing trade and improves the success of the sign tests (9) from 50% to 62%.[27]

Davis and Weinstein (2001) depart from Trefler (1993, 1995) in empirical methodology and data approach. Rather than focusing on the technology matrix of a single country (that is the U.S.), they rely on OECD input-output data that allows them to construct technology matrices for 10 OECD countries and for a composite rest of the world. Davis and Weinstein's approach is to spell out different hypotheses of why prior tests of HOV fail. In particular, they ask how relaxing one of the critical assumptions improves the fit of the model. They specify and estimate 7 different specifications and judge sub-model performance by the highest R^2. Their preferred model does not only allow for technical differences and non-homothetic preferences, but also for non-traded goods and costly trade.

Fisher and Marshall (2008) provide an alternative approach to incorporate technological differences into the HOV model. Rather than estimating productivity parameters relative to the US, as done by Trefler (1993,1995), or constructing technology matrices, as done by Davis and Weinstein (2001), they tackle the issue from the endowment side. Instead of using data on actual endowments as predictors

[26] The mystery of the missing trade has been also identified in other data sets and inspired quite a lot of follow-up work aimed at providing explanations for it. Estevadeorale and Taylor (2002) identify the missing trade when applying the HOV model to a 1913 data set. Conway (2002) explains the missing trade by noticing an anti-trade bias which is rooted in factor-specific differences in domestic factor mobility. Feenstra and Hanson (2000) stress the role of aggregation bias. Reimer (2006) investigates how accounting for traded intermediate inputs in the measured factor content of trade affects the missing trade.

[27] Trefler also considers modifications of HOV that account for home bias in consumption but finds that this accounts only for a small fraction of the missing trade.

for the factor content of trade, they suggest using *virtual endowments*.[28] A country's virtual endowment vector V^{vi} is defined as the factor services needed to produce a country's production output y^i using a reference country's technology matrix A^o, i.e. $V^{vi} = A^o y^i$. Since this approach imposes full employment at the reference country's factor prices and technology, it assumes that every country has the same technology and factor prices as the reference country. Accordingly, the virtual world endowment vector is then the sum of the individual countries' virtual endowments. A country's factor content of trade is defined using the country's domestic technology matrix, i.e. $F_k^i = A^i T^i$, which leads then to the following modified Heckscher-Ohlin prediction:

$$\left(V_k^{vi} - s^i \sum_j V_k^{vj} \right) F_k^i > 0 \qquad (13)$$

Fisher and Marshall implement (13) on a sample of 33 countries and conduct the test using every country as a possible reference. Their results are quite striking. The success rate of the predictions ranges between 73 percent (Poland as a reference) and 93 percent (Taiwan as a reference). The hypothesis that the model does not predict the direction of trade better than the flip of a coin can be rejected with 99 percent for each reference country. In addition, since the magnitudes of the virtual endowment predictors come close to the magnitudes of the factor content of trade there is hardly any missing trade.

So what accounts for this apparent improvement over the previous literature? Fisher and Marshall argue that the answer lies in the quality of the data. Previous studies gathered data on endowments and factor uses from sources other than input-output accounts and that are known to be plagued by measurement errors. Fisher and Marshall's approach picks up countries' endowment differences from differences in local output levels which are "accurately" matched with local technology matrices.[29] A virtue of this approach is that they do not have to estimate anything and let the data speak for itself.

Since the Heckscher-Ohlin framework emphasizes country differences as a determinant of trade, we would expect that the theory would fare better explaining North-South trade than trade between similar economies. Motivated by Wood (1994) who has stressed that North-South trade has not been directly studied within the HOV framework, Debaere (2003) derives factor content expressions that relate bilateral differences in factor endowments to bilateral differences in factor contents. Since his relationships compare multi-lateral factor contents for two countries only, he is able to compare the predictions on the entire sample relative to North-South trade. Using Trefler's (1995) data set, Debaere finds that the bilateral factor content predictions show a success rate of 70 percent if one considers the entire sample which improves up to 90 percent if one explicitly includes the factor content of North-South trade. In the case of North-South trade, the incorporation of Hicks-neutral differences do not significantly improve the results. Debaere's finding is important since it suggests a

[28] Their methodology echoes Davis, Weinstein, Bradford and Shimpo (1997) who construct imputed world endowments to investigate the HOV relationship using Japanese regional trade data. There is also some similarity to Hakura (2001) who uses actual technology matrices to investigate the role of technological differences on bilateral trade in the HOV framework.

[29] However, as a trade-off, Fisher and Marshall's analysis is restricted to three factors of production: capital. labour and social capital.

significant improvement if HOV is tested in a data domain where countries' endowments differ significantly.

In concluding our discussion of the HOV framework, it is worthwhile to point out that in the quest for improving the empirical fit of the HOV model, it has become apparent that the empirical literature has been suffering from I previously called 'the tyranny of non-refutability'.[30] This stems from the fact that the factor content prediction is based on an identity. More precise measurement of this identify is expected to lead a better fit. Now we turn to a factor content formulation which can overcome this identify problem.

4.2 Autarky price formulation

The Heckscher-Ohlin theory explains comparative advantage by relative factor scarcity. But factor scarcity can be measured in two different ways. The Heckscher-Ohlin-Vanek formulation follows the Leontief tradition which measures factor scarcity by differences in factor endowments. Alternatively, in Ohlin's (1933) original formulation factor scarcity is measured by differences in relative factor prices under autarky. Deardorff (1982) has provided a general formulation of the Heckscher-Ohlin Theorem which uses Ohlin's autarky price measure as a predictor for the factor content of trade. Denoting w^a and F the *l*-vectors of autarky factor prices and net factor content of imports respectively, the country's autarky factor prices impose a single restriction on a country's factor content of trade with the rest of the world:

$$w^a F > 0 \tag{14}$$

The prediction (14) is similar to the comparative advantage prediction in (2).
A country is predicted, on average, to import its scarce factors and export its abundant factors. Deardorff (1982) derives (14) using three different methods of measuring the factor content of trade but under the assumption of identical technologies.[31] Building on Deardorff (1982), Neary and Schweinberger (1986) have shown that as long as the factor content of trade is measured using the domestic technology matrix, the gains from trade is the only sufficient condition for deriving (14).

The link between the gains from trade and the prediction on the factor content of trade can be illustrated in a factor content diagram given in Figure 3. The autarky price vector w^a defines a hyperplane w^aF which identifies the rejection region. A factor content vector F^{**} which falls in that region (i.e. $w^aF^{**}<0$) yields a loss (measured in units of factor 1) since the international exchange of factor 1 for factor 2 occurs at a less favourable rate than the domestic factor exchange rate given by the autarky factor prices. On the other hand, the factor content vector F^* yields positive gains from trade (measured in units of factor 2) and $w^aF^*>0$.

An attractive feature of (14) is that it can be tested using data for a single economy without having to assume anything about the technologies of the trading partners. However, it requires compatible data of an economy observed under autarky and free trade. Bernhofen and Brown (2010) revisit the natural experiment of Japan to test (14). Since Bernhofen and Brown (2005) have already provided evidence that

[30] See Bernhofen (2005).

[31] The factor content of trade can be measured using either the domestic technologies, technologies at the location of production or based on the actual content of consumption.

Japan experienced gains from trade, as discussed in section 2, we already know that the data environment fulfils the critical assumption of the theory. As a result, there is something at stake in testing (14) since a rejection could not be explained by unmet assumptions. Bernhofen and Brown (2010) employ a self-constructed input-output matrix from around 1870 to obtain Japan's factor content of trade during its early trading period $F^i = A^{1870}T^i$ (i=1865,..., 1876). When evaluating F^i at the factor prices w^{1850s} in the late autarky period, they are unable to reject (14) for each single trading year. Hence, the case of Japan provides further empirical support for the general Heckscher-Ohlin prediction in its autarky price formulation.

4.3 Multiple cones

In its core formulation, the Heckscher-Ohlin-Vanek model assumes that countries' endowments are not too dissimilar so that the free trade equilibrium is characterized by factor price equalization and countries are said to be in a single cone of diversification. If endowments are sufficiently different, countries will specialize in different sets of goods and factor prices can differ in a free trade equilibrium.

The empirical multi-cone literature focuses on two different, but related issues. The first approach attempts to derive hypotheses aimed at testing Heckscher-Ohlin specialization in the absence of factor price equalization. Lack of factor price equalization stems from multiple cones, rather than trade costs. The second approach asks whether countries occupy different cones. We first look at the testing literature and then survey the papers that aim to match countries to cones.

The theoretical framework for the multi-cone approach goes back to Deardorff (1979) who identified a Heckscher-Ohlin chain of comparative advantage ranking in the case of two factors. Ordering countries in terms of relative factor prices implies a ranking of relative factor abundance:

$$w^1/r^1 > w^2/r^2 > \ldots > w^m/r^m \qquad (15)$$

In (15) country 1 is most capital abundant and has therefore the highest wage rental ratio, whereas country m is least capital abundant and has the lowest wage rental ratio. The implication for the pattern of specialization can be illustrated with the Lerner-Pearce diagram in Figure 4 which depicts a free trade equilibrium with three countries, six goods and three cones C^1, C^2 and C^3. Goods are ranked by their relative factor intensities and the equilibrium production level is characterized by the tangency between the country-specific factor price line and the corresponding unit value isoquant.[32] The model predicts that the most capital abundant country 1 specializes in the most capital-intensive goods 1 and 2; country 2 specializes in goods 3 and 4 and country 3, which is most labour abundant, specializes in the most labour-intensive goods 5 and 6.

Deardorff's (1979) chain of comparative advantage goods prediction cannot be easily adapted to the data. Building on the cost efficiency logic of the free trade equilibrium, Helpman (1984) derives restrictions on the factor content of bilateral trade which generalizes Deardorff (1979) to the case of an arbitrary number of factors. Consider a free trade equilibrium characterized by *m* *l*-vectors of factor prices $w^1,\ldots,w^m$, where w^i denotes the factor price vector of country i and a common technology matrix, A(.). If T^{ij} denotes the vector of gross exports from country i to

[32] This specification assumes that countries have identical technologies.

country j, the corresponding factor content of exports F^{ij} is defined as $F^{ij} = A(w^i)T^{ij}$. Helpman (1984) shows then that the factor price difference (w^i-w^j) imposes a restriction on F^{ij}:

$$(w^j - w^i)'F^{ij} > 0, \qquad (16)$$

The restriction (16) has some similarity to (14) in the sense that factor prices impose a restriction on the factor content of trade. But whereas (14) constitutes a single refutable Heckscher-Ohlin prediction, (16) yields as many restrictions as there are country pairs. The intuition behind (16) is that since F^{ij} originates in country i, it is more expensive to evaluate F^{ij} at the foreign factor price vector w^j than at w^i. By symmetry, we obtain $(w^i - w^j)'F^{ji} > 0$ and adding the two restrictions implies a joint restriction on the net factor content of exports:

$$(w^j - w^i)' (F^{ij} - F^{ji}) > 0. \qquad (17)$$

An attractive feature of (16) and (17) compared to the Heckscher-Ohlin-Vanek specification (9) is that they can be tested on a subset of countries. Choi and Krishna (2004) investigate (17) with a data set of eight OECD countries for which the identical technology assumption appears to be justified. An innovative feature of their study is their construction of economy-wide factor price data from cost components of GDP where GDP is decomposed into compensation of employees, operating surplus and an aggregate of other components such as indirect taxes and subsidies. They consider various factor classifications, where wage rates are disaggregated either into two or four subcategories. Their approach treats capital as a residual when employee compensation is taken out of GDP. They then propose two different rates of capital, depending on the treatment of taxes. Applying the different factor price measures to (17), Choi and Krishna find strong empirical support since the restrictions hold for over 80 percent of the bilateral factor flows between the 28 country-pairs. In a follow-up piece, Lai and Zhu (2007) test the restrictions on a broader data set of 41 countries. Since the assumption of identical technologies is now no longer justified, Lai and Zhu consider a modification of (17) which incorporates various forms of technological differences.

Bernhofen (2009b) extends Helpman (1984) by pointing out that Helpman obtains these restrictions by applying the cost efficiency logic to a bilateral factor cost comparison between two trading partners. However, since a free trade equilibrium is globally cost efficient, one obtains an extended set of restrictions:

$$(w^k - w^i)'F^{ij} > 0. \qquad (18)$$

The inequality (18) can be thought of capturing global cost efficiency since it requires that F^{ij} is not only restricted by the factor price difference between countries i and j as in (16), but also by the factor price difference between country i and *any* other third country *k*. An important implication of this is that the multi-cone specification implies restrictions involving third country factor price comparisons. In addition, we are back to a Heckscher-Ohlin-Vanek world where a complete test requires data on *all* countries in the world economy. Bernhofen (2009b) applies (18) to Choi and Krishna's data set and finds limited empirical support for the extended set of restrictions and considerable variation in the success rate across the country sample.

This is not too surprising given that a prior inspection of the country sample would have suggested endowment differences that are not too dissimilar.

Helpman's bilateral restrictions and their extensions rely on equilibrium factor price differences to generate restrictions on factor service flows. Alternatively, since the multi-cone framework depicted in Figure 4 focuses just on production, it lends itself to a cross-country investigation of international production, without looking at trade. Building on Leamer (1987), Schott (2003) provides a dynamic interpretation of the multi-cone model, where capital accumulation moves a country into a more capital abundant cone (for example C^3 to C^1) and a higher wage-rental ratio. He develops an estimation technique that allows him to distinguish between the single and multi-cone specification. Employing his method to 3-digit ISIC manufacturing industries, he rejects the single cone-specification. However, since he finds significant variation in input intensities within the 3-digit classes, he clusters the industries into three Heckscher-Ohlin (HO) aggregates (labour-intensive, middle and capital-intensive). When applying his empirical model to HO aggregates he finds support for Deardorff's (1979) multi-cone notion that more capital-abundant countries specialize in more capital-intensive industry clusters, whereas more labour-abundant countries specialize in more labour-abundant clusters.

Identification of cones

If countries are within a cone of diversification, the Heckscher-Ohlin-Vanek framework yields sharp predictions of how endowment differences affect a country's factor content of trade with the rest of the world. If countries are in different cones, equilibrium factor prices will be different and factor price differences will yield predictions on the bilateral factor content of trade as in (16)-(18). Besides yielding different types of predictions on the pattern of trade, the identification of countries to cones is important for predictions on how shocks in the form of factor inflows (that is immigration, capital inflows) affect domestic factor prices. For example, Hanson and Slaughter (2002) investigate how US states absorb differential changes in relative labour supplies. Their finding that states absorb changes in employment through changes in their production techniques and changes in the output of traded goods rather than changes in factor prices provides evidence that US states are within a cone.

Debaere and Demiroglu (2003) focus on a cross-section of developed and developing countries and investigate whether they are in a single cone. Their analytical framework is based on Figure 2 which provides a condition for factor price equalisation. The factor price equalization set FPE, which is spanned by the endowment vectors V^1, V^2 and V^3, can be viewed as an endowment lens. The sectoral employment vectors $g_1,\ldots g_6$ define a goods lens. Following Deardorff (1994), countries will produce the same set of goods if the endowment lens lies within the goods lens. Applying this logic to their data set, Debaere and Demiroglu find that only the rich OECD countries are sufficiently similar to constitute a cone.

A distinctive feature of the aforementioned empirical studies of diversification cones is that they assume identical technologies and employ cross-country panels of industry data where the industry codes might represent different goods for different industries. Xiang (2007) suggests overcoming these difficulties by looking at distribution functions of factor usage intensities. Since Xiang's approach is based on a two-factor formulation it can be illustrated by Figure 4. If countries are in different cones, there should be distinct differences in the capital-labour ratios and the between-cone differences should be statistically larger than the within-cone differences. Applying this logic to a set of ten OECD countries, Xiang identifies a country clustering around three different groups which, under the assumption of zero trade costs, is compatible with Figure 4 where each group is associated with a cone. This finding is an important departure from Debaere and Demiroglu (2003) as it suggests multiple cones even within the OECD. However, the model compatibility is not unique. Alternatively, the results are also consistent with Romalis' (2004) hybrid Heckcher-Ohlin-monopolistic competition model with non-zero trade costs which we discuss in the next section.

5. Hybrids

In this section I briefly survey empirical approaches that combine elements from Ricardian, Heckscher-Ohlin, monopolistic competition and more recently, contract theory models. Since the literature has not yet produced a coherent framework for organizing the individual determinants of international specialization, empirical researchers have taken different approaches to estimating the individual sources of comparative advantage.[33]

Harrigan (1997) focuses only on the production side of the Heckscher-Ohlin model and estimates the joint effects of technology and factor supply differences on industry output. He considers a specification where the output share of an industry in a country's GDP depends on productivities and factor endowments and finds that his estimated Rybczynski effects are in line with theoretical conjecture and previous empirical work.[34] A key lesson of Harrigan's paper is that technological differences are an important determinant of international specialization even within the OECD.

Romalis (2004) considers a hybrid specification that incorporates Krugman's (1980) monopolistic competition model with trade costs into Dornbusch, Fischer and Samuelson's (1980) continuum of goods Heckscher-Ohlin model. Transportation costs make the commodity structure of trade determinate and monopolistic competition generates predictions about the volume of trade. Combined, Romalis' hybrid model predicts that countries will have larger shares of world production and trade in goods that use their abundant factors intensively. Since the theory is based on a two-factor framework, there is a bit of a leap of faith between the theory and his empirical specification which allows for multiple factors. Applying his predictions to the data, Romalis finds strong empirical support for his predictions.

Morrow (2009) builds a structural model that augments Romalis (2004) by incorporating productivity differences. With his model he derives expressions that allow him to test for the contributions of Ricardian and Heckscher-Ohlin forces in production data. He emphasizes that Rybczynski regressions à la Harrigan (1995, 1997) provide valid comparative statics exercises as long as total factor productivity is uncorrelated with factor intensity. He confirms previous findings of a joint role of factor productivity and factor abundance in affecting the pattern of international specialization. But since he is working with a two-factor model, his specification suffers from potential omitted factor biases.

[33] Applying the concept of log-super modularity, Costinot (2009) has taken an important step towards a unifying theory of comparative advantage. His approach is a bit more restrictive than Deardorff's (1980) autarky price formulation but has the advantage of focusing just on the trading equilibrium.

[34] Harrigan's approach builds on Kohli (1991) and Harrigan (1995). See Harrigan (2003) for an in depth discussion of empirical approaches to the neoclassical trade model that build on the Rybczynski relationships.

Finally, recent theoretical work on trade and contracts have suggested a role of contract enforcement on international specialization and comparative advantage. Nunn (2007) considers an empirical specification that aims to focus on one specific channel through which contract enforcement affects the pattern of trade: underinvestment in relation-specific investments.[35] His hypothesis is that, ceteris paribus, countries with better contract enforcement should specialize in industries where relation-specific investments are more important. Nunn's major innovation is to construct an industry-level measure of contract intensity and interact it with a country-level measure of the quality of a country's contract enforcement institutions. He examines his hypothesis empirically by using this interaction variable as an explanatory variable in a cross-industry, cross-country export regression equation. Nunn claims that his contract intensity variable explains more of the export variation than 'the traditional' capital and labour measures (which are his controls) combined. Although a creative exercise, it suffers -like some of the other hybrid approaches- from a lack of a general theoretical framework from which the predictions are derived.

6. Concluding remarks

Over half a century of research on refining the theoretical formulations of the general equilibrium trade model and confronting it with data have revealed the resilience and useful of this model. Apparent paradoxes and empirical regularities which at the time appeared threatening -the *Leontief Paradox*, the occurrence of *intra-industry trade*, the *mystery of the missing trade*- have left the framework unharmed. In fact, theses empirical challenges have resulted in a deeper understanding of the model and an appreciation for what it is able to explain empirically.

In this paper I focused only on empirical approaches which examined patterns of international specialization. The general price formulations of the model have yielded refutable predictions about the pattern and gains from trade that couldn't be refuted by the data. Pattern of international specialization are driven both by endowment differences (Heckscher-Ohlin forces) and technological differences (Ricardian forces). Heckscher-Ohlin specifications that either do not rely on the identical technology assumption and depart from it in creative ways find broad empirical support. The recent multi-country extension of the Ricardian model has provided a framework for structural estimation involving many useful policy experiments.

Regarding future research, more work is needed on empirical examination of the influence that sector-specific trade costs have on international specialization. This will call for general equilibrium modelling that goes beyond the uniform iceberg assumption, as in Matsuyama (2007). Second, although the empirical general equilibrium literature has taught us quite a bit about the pattern of international trade, we still have very scarce theory-based evidence on the aggregate gains from international trade. The key theoretical challenge here will be the inference of the magnitude and sources of these gains from data in a trading equilibrium in the absence of strong parametric assumptions about the underlying fundamentals.

[35] See also Levchenko (2007) and Levchenko and Do (2007) for alternative approaches that examine the role of institutions on trade patterns.

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Figures

Figure 1: Comparative advantage prediction

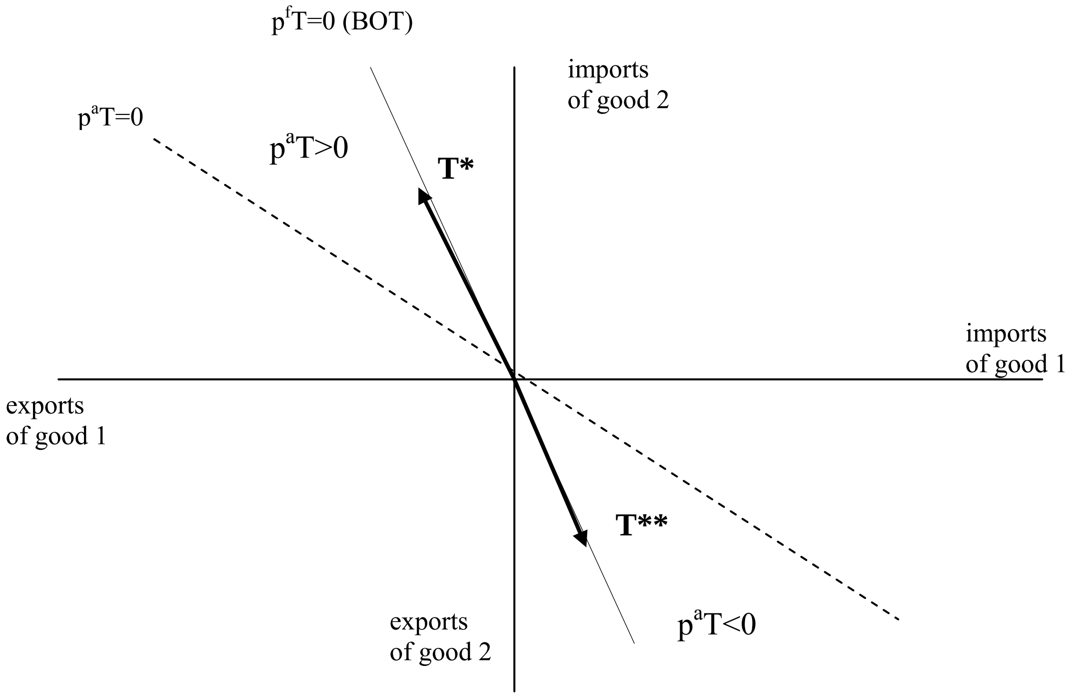

Figure 2: Heckscher-Ohlin-Vanek model

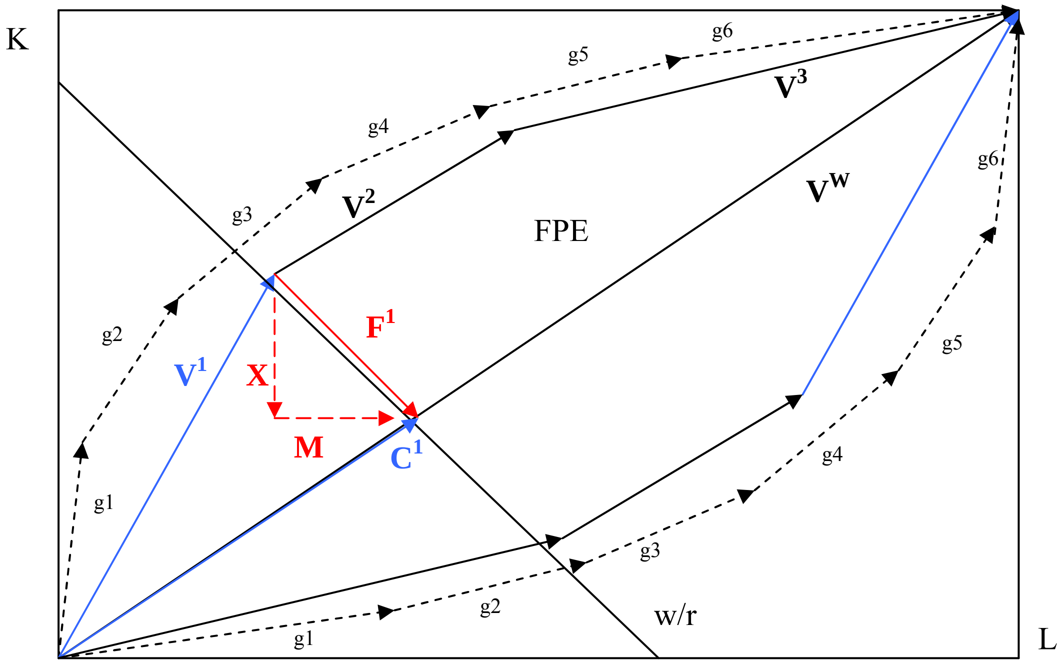

Figure 3: Heckscher-Ohlin price prediction

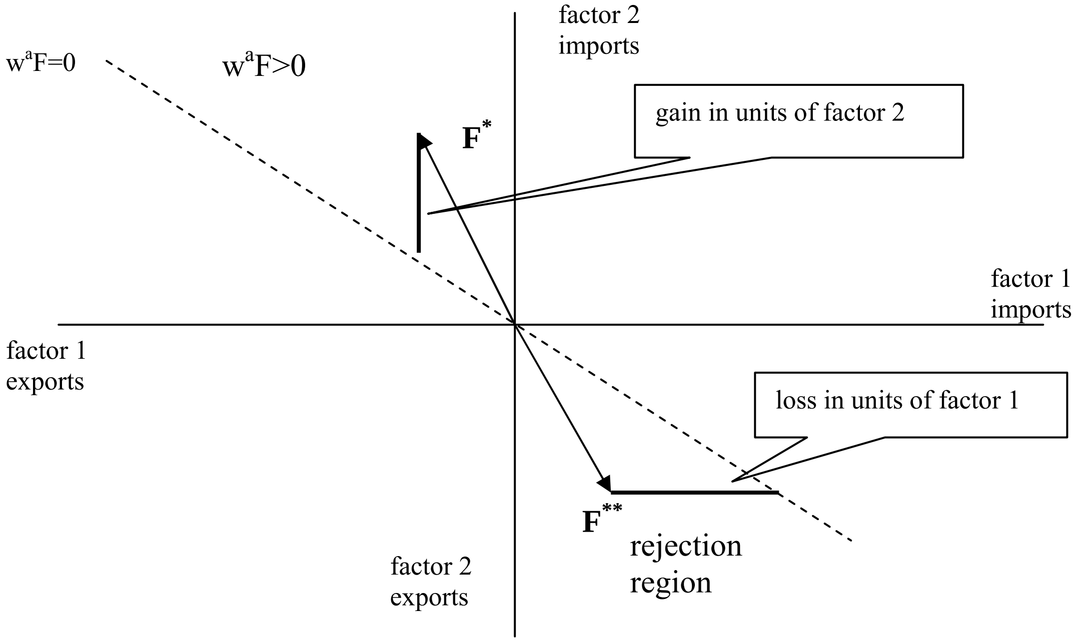

Figure 4: Multi-cone specification