

Putting Ricardo to Work

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Presented with the opportunity to trade, countries benefit by specializing in the activities they do relatively better. This finding, the principle of comparative advantage, is one of the first analytic results in economics. While Adam Smith (1776) made a much earlier case for free trade, he based it on increasing returns to scale, and provided no formal demonstration. In contrast, David Ricardo (1818) provided a mathematical example showing that countries could gain from trade by exploiting innate differences in their ability to make different goods.

The basic Ricardian example, in which two countries do better by specializing in one good and exchanging it for another, even when one of them is better at making both, typically gets presented in the first or second chapter of a text on international trade, and sometimes appears even in a principles text. Its purpose is to demonstrate the gains from specialization and trade in a way that at least a bright student can absorb quickly.

But having served its pedagogical purpose, the model was rarely heard from again. As one example, Feenstra (2004), the leading Ph.D. text in international trade, devotes only three pages to the Ricardian model. During the Twentieth Century, the theoretical and quantitative analysis of international trade turned first to differences in factor endowments and then to increasing returns to scale as explanations for trade and its benefits. The Ricardian model became something like a family heirloom, brought down from the attic to show a new generation of students, and then put back to allow them to pursue more fruitful lines of study and research.

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Nearly two centuries later, however, the framework has experienced a revival. Much work in international trade during the last decade has returned to the assumption that countries gain from trade because they have access to different technologies. These technologies may be generally available to producers in a country, as in the Ricardian model of trade, our topic here, or exclusive to individual firms, as Marc Melitz discusses in the companion paper in this issue. This line of thought has brought Ricardo’s theory of comparative advantage back to center stage. Our goal is to make this new-old trade theory accessible and to put it to work on some current issues in the international economy.

Revisiting Ricardo’s Example

Ricardo (1818) posited a world of two countries, England and Portugal, which can make each of two goods, cloth and wine. What he assumed about how many workers it takes to make a unit of each good in each country appears in Table 1. Since the workers required to make one unit of a good are the same no matter how many units are produced, Ricardo was assuming constant returns to scale.

Table 1

	Cloth	Wine
England	100	120
Portugal	90	80

Ricardo argued that trade could allow England to obtain a unit of wine with the effort of only 100 workers (instead of 120) and Portugal to obtain a unit of cloth with the effort of only 80 workers (instead of 90), the outcome if international trade established an international price of 1 unit of cloth exchanging for 1 unit of wine.

Of course, to our Twenty-First Century eyes, Ricardo’s example is very incomplete. For example, he does not explain what assumptions about tastes, endowments, or competition are needed for this world price ratio of 1 to arise. However, in using this example Ricardo was advocating policy in a very modern way. He compared an “actual” world with one policy, trade prohibited, with a “counterfactual” world of free trade. In making the comparison he described each world in terms of a common set of parameters,

the labor requirements in Table 1, that are plausibly exogenous to the policy in question, thus immunizing himself to the Lucas critique (1976) of the following century.¹

Why, when it delivers such a slick demonstration of the gains from trade, did the Ricardian model hit such a dead end in terms of providing a framework for more sophisticated and quantitatively meaningful analysis? A major reason is that even this basic formulation gives rise to different types of equilibria that need to be analyzed separately. Even in Ricardo's minimalist setting, three types of outcomes are possible: (i) England makes only cloth and Portugal only wine, (ii) England makes both cloth and wine and Portugal only wine, or (iii) England makes only cloth and Portugal both cloth and wine. In case (i), the one assumed in Ricardo's example, outputs can be immediately solved for from labor endowments, with prices then determined by demand. In the second two, relative prices are given by the relative labor requirements in the incompletely specialized country, with demand then determining outputs. At the intro level, the lesson from his sort of example is that gains from trade are possible, although we can only put bounds on what the gains are. At a more advanced level, students are told to solve for the equilibrium outcome by assuming one case and then checking that it satisfies the requirement that prices don't exceed costs or that labor is fully employed. Already the model has to confront a clumsy taxonomy.

International trade is a field rich in data. United Nations COMTRADE, currently the major source of statistics on merchandise trade, reports the annual value of bilateral trade between over 242 countries (making for $242 \times 241 = 58,322$ bilateral pairs) in 776 product categories going back to 1990. Given that even the two-country, two-good example is awkward to work out, what hope does the Ricardian model have of sorting out data of this complexity?

In fact, a handful of developments have recently culminated in a formulation of the Ricardian model that is highly amenable to exploiting exactly such data. This formulation has spawned a surge of studies to address various policy questions quantitatively. We chart this evolution and show where it has led.

¹Chipman (1965), in his magnificent three-part survey of the theory of international trade, attributes the first complete statement of a Ricardian equilibrium to Mill (1844), who implicitly assumed what we now call Cobb-Douglas preferences, with equal shares for each good. Using the labor requirements in Table 1 the reader can verify that Ricardo's posited price of 1 will then emerge if Portugal has 80 percent as many workers as England.

Ricardian Trade Theory: From Textbook Example to Practical Tool

To begin, let's reformulate Ricardo's example in terms of England's wage ω relative to Portugal's, setting the Portuguese wage to 1. Making a unit of cloth in England will then cost 100ω while making it in Portugal will cost 90. Making a unit of wine in England will cost 120ω while making it in Portugal will cost 80. With free trade and perfect competition the prices of cloth and of wine are the same in each location and constitute the lowest cost way of producing each good. Say that ω is bigger than $90/100$, the ratio of Portuguese to English workers required to make cloth. Then, since

$$\frac{90}{100} > \frac{80}{120}$$

cloth wine

both cloth and wine will be produced more cheaply in Portugal, leaving English labor out of work. Hence an English wage that is more than 90 percent of the Portuguese wage is not compatible with employment in England. At the other extreme, if ω is smaller than $80/120$ then both cloth and wine will be cheaper if made in England, putting Portuguese workers out of work. Hence we need ω to be somewhere in between $2/3$ and $9/10$. (Since Ricardo granted Portugal an absolute advantage in both goods, he doomed English workers to a lower wage in order to be employed.) The idea that a Ricardian equilibrium involves identifying the source that can supply a good at minimum cost is at the heart of taking the model to more goods and countries.

Any hope of applying this example to actual world trade requires adding more goods and countries. How can we do that? Let's proceed step by step.

More Goods

Let's add another good, linen, while sticking with just our two countries. Say England needs 100 workers to make a unit of linen and Portugal needs 100 as well. These numbers grant England an even stronger comparative advantage in linen than in cloth. We can extend the previous inequality to:

$$\frac{100}{100} > \frac{90}{100} > \frac{80}{120}$$

linen cloth wine

This ordering of goods in terms of England's relative productivity is called a "chain" of comparative advantage. Under free trade the English relative wage

ω breaks this chain between goods for which England's relative productivity is above or below its relative wage. The goods to the left of the break are produced more cheaply in England and those to the right of the break are produced more cheaply in Portugal. For example, an ω of .95 breaks the chain between linen (produced more cheaply in England) and cloth and wine (cheaper from Portugal). An ω of .9 breaks it at cloth (costing the same from either country, with linen cheaper from England and wine cheaper from Portugal).

What determines the relative wage ω that breaks the chain? In general, finding it can be quite complicated but, if the two countries spend their income the same way (specifically, if tastes are identical and homothetic), the problem simplifies. We can then use the chain of comparative advantage to construct the demand curve for English labor relative to world labor (on the x axis) as it varies with the English wage ω (on the y axis).

If $\omega > 1$ then English labor has priced itself out of all goods. Hence the demand curve is just a vertical line at zero for ω above England's relative productivity for good 1. At a wage $\omega = 1$ England is competitive in linen, and buyers are indifferent between England and Portugal as a source. The demand curve for English labor is then flat (perfectly elastic) between zero and the point at which the demand for linen is saturated at the price of 100. A decline in ω from this point renders England the sole producer of linen. Since the price of linen is 100ω , a drop in ω lowers the price of linen, increasing demand for it and hence for English labor. At the point $\omega = .9$, England becomes competitive in cloth as well as linen. The demand curve for English labor thus hits another flat as world buyers are indifferent between England and Portugal as sources of cloth (continuing to buy all their linen from England and wine from Portugal). Proceeding along the chain the demand curve for English labor is a downward stairway with treads along which England and Portugal share production of a good connected by risers along which England and Portugal specialize in producing distinct sets of goods. The treads are horizontal, as with a standard staircase, but the risers are vertical only in an extreme case. Otherwise they slope downward to the next tread. The equilibrium can be found by imposing the vertical supply curve for English labor as a share of the world's, which could cut the demand curve along a tread (corresponding to a good for which England and Portugal share production) or through a riser (with no shared goods).

We count five possible types of outcomes, going from linen, cloth, and wine made in England and wine elsewhere to linen, cloth, and wine made

in Portugal and linen elsewhere. Of course, more goods can be added by inserting them into the chain, raising the number of types of outcomes.

Figure 1 illustrates the case for four goods, adding one to the example above, say anchovies, for which England requires twice as many workers as Portugal to produce a unit. Changing the English labor supply involves sliding the English relative labor supply curve $L/(L + L^*)$ along the x axis.

Trade economists now speak frequently of the extensive and intensive margins of trade. A country's exports can increase on the intensive margin, exporting more of a given set of goods, or on the extensive margin, exporting a wider range of goods. The stairway shows how the two operate in a Ricardian framework. Along a riser a drop in ω raises demand for English exports only at the intensive margin, by lowering the price of the given set of goods that England produces. When ω hits a tread, however, expansion is also at the extensive margin as England expands the set of goods it produces and exports.

An implication of the framework is that, given technologies around the world, having a larger share of the world labor force may require a country to have a lower wage. In order to employ more labor with its given set of technologies a country needs to sell more of the goods it currently produces (going down a riser) or to take over goods from other countries (reaching a lower step). The result holds even though technologies are constant returns to scale. The reason is that larger size reduces the gains from trade. This basic implication of the Ricardian model will survive its modern reincarnation.

While the construct is intuitive, stairways are trouble not only for wheeled vehicles but for comparative statics. Solving the equilibrium is tedious.

More Goods Than You Can Count

A classic paper by Dornbusch, Fischer, and Samuelson (1977) made life much simpler by replacing the stairway with a ramp. These authors had the insight that inserting more and more goods into the chain of comparative advantage would render the gaps between the ratios of the labor requirements miniscule, in which case the three types of equilibria around any good in the original model collapse to the same outcome. They assumed that the set of goods correspond to all the points on an interval between 0 and 1, and sorted the goods to form a chain of comparative advantage, with England having the strongest comparative advantage in goods closest to zero and Portugal in goods closest to one. They defined a function $A(j)$ as the ratio of Portugal's labor requirements to England's labor requirements for good j ,

hence England's relative productivity, for each j between 0 and 1. They went on to assume that $A(j)$ was smooth and strictly decreasing. The downward sloping curve in Figure 2 illustrates such a function.

For any English wage ω between $A(0)$ and $A(1)$ there is some good, let's call it \bar{j} , satisfying $A(\bar{j}) = \omega$. This good \bar{j} costs the same whether it is produced in England or Portugal. England produces goods $j \leq \bar{j}$, Portugal goods $j \geq \bar{j}$. Who produces good \bar{j} is irrelevant to anything else as this good is only an infinitesimal fraction of the total. Since j goes from 0 to 1, \bar{j} is also the share of goods produced in England, for consumption in either England or Portugal. Since $A(j)$ is decreasing, a change that increases England's relative wage ω , given the function $A(j)$, must reduce the share of goods produced in England.

To figure out what ω will break the chain we need to look at the demand side. A higher \bar{j} means that England is producing a larger share of goods, increasing demand for its labor and hence its wage ω . Figure 2 depicts this positive relationship between ω and \bar{j} . Where it intersects the downward sloping $A(j)$ curve determines the equilibrium.²

Figure 2 illustrates how a shift up in the productivity curve $A(j)$, meaning that England gets relatively more productive at making every good, raises England's relative wage ω and expands the share of goods it produces.

In all of the examples so far, if England and Portugal spend their incomes the same way (again, meaning identical, homothetic preferences) there is no reason for English and Portuguese to consume goods in different proportions. But a robust feature of data on trade and production is that countries tend to buy most goods from themselves. We could explain this fact in terms of

²To get an exact expression for this upward sloping relationship requires us to say something about demand. The simplest assumption is that individuals in either country spread their spending evenly across the goods (as with symmetric Cobb-Douglas preferences). In this case the share of goods produced in England becomes the share of spending devoted to goods produced in England. Labor market equilibrium requires full employment of workers in England and in Portugal at a relative wage ω , with English workers paid a fraction \bar{j} of world income, which is just the wage income in each country added together:

$$\omega L = \bar{j}(\omega L + L^*).$$

A lower English wage ω increases demand for English labor in two ways. At the intensive margin, a lower ω lowers the price of all goods England makes, so increases demand for them and thus for English workers (with an elasticity of -1 since people spend the same amount on each good regardless of its price). At the extensive margin, lower ω increases the range of goods that England exports.

the basic Ricardian model by assuming that Portuguese like wine more than the English. But it would be coincidental if tastes always happened to align with comparative advantage, and there is little evidence that they do.

A more plausible explanation is that moving goods between countries is costly. Another useful contribution of Dornbusch, Fischer, and Samuelson (1977) is to introduce trade costs into their Ricardian model. Specifically they make Samuelson's classic "iceberg" assumption that delivering one unit of any good from one country to the other requires shipping d units, where $d \geq 1$. The specification is consistent with a fraction of some of the goods getting lost, rotten, or broken in shipment, but admits many other interpretations as well.

Because the iceberg assumption entails a trade barrier, goods no longer cost the same in each location. Consider the case of cloth in Ricardo's example. If the wage in England is .8 then cloth costs 80 if made in England and 90 if made in Portugal. But say that a third of the cloth that gets shipped from England to Portugal gets ruined by salt water in transport. Then 1.5 units of cloth need to be shipped to deliver 1 usable unit to Portugal, raising the cost of English cloth in Portugal to 120. It no longer pays for Portugal to import cloth from England rather than make it at home.

What happens to the Dornbusch, Fischer, and Samuelson (1977) model if we introduce a trade cost d to all goods (meaning that delivering 1 unit to a foreign destination requires shipping out $d \geq 1$ units)? The trade cost creates a range of goods that are not traded as each country makes them more cheaply for itself. As long as d is not too big there is still a range of goods (with j near zero) that England makes for everyone and another range (with j near one) that Portugal makes for everyone.

An important implication of the trade cost, which we exploit in our applications below, is that it introduces a relationship between any trade deficit that England runs with Portugal and its relative wage. A transfer from England to Portugal diverts spending away from the nontraded goods that England was producing for itself toward the production of those same goods in Portugal. As a consequence the English wage falls, leading to an expansion of the range of goods that England exports and a contraction of the range that Portugal exports.

The work of Dornbusch, Fischer, and Samuelson (1977) moved the Ricardian model framework far forward from being a toy example to a tool that can address a variety of questions. For example, Matsuyama (2008) uses variants of the model to examine the consequences of country size, technology

change, and technology transfer on the gains from trade and the distribution of income. But a limitation remains. There are still only two countries.

More Countries

It's just as easy to add more countries to Ricardo's example as more goods. Let's add a third country, France, with labor requirements 120 in cloth and 60 in wine. Begin by rewriting Ricardo's earlier inequality as:

$$\frac{120}{100} > \frac{80}{90}$$

England Portugal

and then insert France into the chain to get:

$$\frac{120}{100} > \frac{80}{90} > \frac{60}{120}$$

England Portugal France

England, at one end of the chain, will produce cloth and France, at the other end, will produce wine. As before, tastes and the sizes of the labor forces in each country will determine where the chain is broken. As above, we count five types of possible outcomes. We are back to a stairway. More countries can be added straightforwardly but the number of cases expands. As with two countries and many goods, finding the solution is relatively straightforward but tedious.

The Challenge: Many Goods with Many Countries

But what about more goods **and** more countries! In this setting, chains no longer work. Jones (1961) provides an example with the following labor requirements for three countries in three goods:

	America	Britain	Europe
Corn	10	10	10
Linen	5	7	3
Cloth	4	3	2

Two assignments, America-Linen/Britain-Corn/Europe-Cloth and America-Corn/Britain-Cloth/Europe-Linen, each satisfy Ricardo's inequality for any two countries and any two goods looked at in isolation from the third.³

³Graham (1948) solved for competitive equilibria in numerical examples of the Ricardian model with many countries and many goods. His generalizations from these exam-

But only the second is a possible competitive equilibrium. The reason comes from writing Ricardo's inequality a third way as

$$\begin{array}{ccc}
 120 \times 90 & > & 100 \times 80 \\
 \text{incorrect} & & \text{correct} \\
 \text{assignment} & & \text{assignment}
 \end{array}$$

which shows that England producing cloth and Portugal wine minimizes the product of the labor requirements for the technologies used. Jones can rule out the first assignment in his example since it involves a higher value for the product of the labor requirements used ($5 \times 10 \times 2 = 100$ versus $10 \times 3 \times 3 = 90$).⁴

ples were not always correct. McKenzie (1954) formalized Graham's model and used it in his demonstration of the existence and uniqueness of a competitive equilibrium. (Weintraub, 2011, provides a detailed account of McKenzie's unheralded contribution.) McKenzie (1953-54) established the equivalence between an efficient solution and a competitive equilibrium in Graham's model, and pointed to the inadequacy of bilateral comparisons in determining efficient specialization. The contribution of Jones (1961) is to obtain a simple characterization of efficient specialization in this model.

⁴This idea generalizes to the I -good I -country case. To see why this rule works it helps to go back to prices and to think about finding the minimum cost source. Let's index countries by $i = 1, \dots, I$ and goods by $j = 1, \dots, I$, and denote the amount of labor needed to make good j in country i as $a_i(j)$. Let w_i be the wage in country i and $p(j)$ the world price of good j (as there are no transport costs). Let's also number countries and goods so good j is produced by country $i = j$ in an efficient outcome (so that we can label by j the country producing good j under the correct assignment). Perfect competition then means that $p(j) = a_j(j)w_j$ (zero profits where good j is produced) and $p(j) \leq a_i(j)w_i$ for all other countries i (no profit opportunities anywhere else). Multiplying the equalities together for the correct assignment gives:

$$\prod_{j=1}^I p(j) = \prod_{j=1}^I a_j(j) \prod_{j=1}^I w_j.$$

Multiplying together the inequalities for any other one-to-one assignment $i(j)$ of country i to good j gives:

$$\prod_{j=1}^I p(j) \leq \prod_{j=1}^I [a_{i(j)}(j)w_{i(j)}] = \prod_{j=1}^I a_{i(j)}(j) \prod_{j=1}^I w_{i(j)}$$

Since the terms $\prod_{j=1}^I p(j)$ and $\prod_{j=1}^I w_{i(j)} = \prod_{j=1}^I w_j$ are the same in each, the only way both

Fun as this example is, it doesn't provide much guidance into how to solve for the equilibrium in high dimensional cases. For one thing, we're still left with the problem of figuring out if the solution is on a tread or a riser. But now we have stairways running in multiple directions in ways that only M.C. Escher could diagram.

A Solution: Distributions of Worker Requirements

Again we need a ramp. To construct one let's return to the Dornbusch, Fischer, and Samuelson (1977) formulation with a continuum of goods, but now allow for an arbitrary (integer) number I of countries. We must deal with unit labor requirements for each good (one for each point on the unit interval) in each country (of which there are I), vastly more numbers than Ricardo's four.

To tackle the problem let's first give up on actual numbers and, following Dornbusch, Samuelson, and Fisher (1977), label the labor requirement for good j in country i by $a_i(j)$. With $I > 2$ countries and lots of goods it doesn't help to think about ratios of the a 's, so chains are out of the question. Instead, we will think about the a 's as the realizations of random variables drawn from a particular family of probability distributions. This way of thinking about technology (the labor requirements to produce different goods in different locations) has two advantages: First, the distributions themselves can be smooth, giving us our ramp. Second, we don't have to keep track of all the individual $a_i(j)$'s, of which there are many, but only the parameters of the distributions from which they are drawn, which can be small in number.

Before getting into the details, it's useful to step back and articulate some principles that guide the choice of a family of distributions. First, we want to stay within the family when we move from the distribution of labor requirements to the distribution of the costs of producing goods. Second, we want to stay within the family when we consider the distribution of the price of a good in a country, which is the minimum of the cost of acquiring it across all potential source countries. Finally, we want a simple expression for the probability that a particular country is the low-cost source.

These considerations led us, in Eaton and Kortum (2002), to a family of what are called "extreme-value" distributions. The well-known central

expressions can be true is if

$$\prod_{j=1}^I a_j(j) \leq \prod_{j=1}^I a_{i(j)}(j).$$

limit theorem states that, if a large sample is taken from a well-behaved distribution, then the mean of the sample has an approximate normal distribution. Less well-known is that the highest or lowest observations in such a sample also can approach a particular distribution, called an extreme-value distribution.

For example, consider the winning (fastest) times in a series of races. If each runner's time is drawn from a particular distribution, such as the lognormal, then the fastest time across a large number of races has an extreme value distribution, which, if the times are lognormal, turns out to be the type III extreme value, or Weibull distribution.

What's the connection between winning a race and the number of workers needed to make a product? As derived in Kortum (1997) and Eaton and Kortum (1999), if technologies for making a good are the results of inventions that occur over time, and if the output per worker delivered by an invention is drawn from the Pareto distribution, then output per worker using the most efficient (that is, winning) technology discovered to date have a type II or Fréchet distribution.

The Ricardian language describes a technology by its worker requirement rather than by its reciprocal, output per worker. Translating our results on the Fréchet distribution above into Ricardian, the probability that the labor requirement for producing any particular good j in country i is less than any positive number x is distributed Weibull, specifically:

$$\Pr [a_i(j) \leq x] = 1 - e^{-(A_i x)^\theta}.$$

Its two parameters relate to absolute and comparative advantage. The parameter A_i captures country i 's absolute advantage: A higher value means that the labor requirement is likely to be lower for any good. Having absolute advantage vary across countries allows us to capture the fact that some countries are much more productive than others across a wide range of activities: for example, in the way Portugal is more productive than England across both goods in Ricardo's example. A country that has accumulated more technology will have a higher A_i .

The parameter θ captures (inversely) how variable the labor requirement is, with a higher value meaning that a country's labor requirement is typically close to its mean, weakening the force of comparative advantage. In Ricardo's example above, suppose Portugal could make cloth with 67 workers rather than with 90. While Portugal would still be better at both goods

than England, it's no longer differentially much better at wine. As Ricardo's inequality gets closer to equality, the scope for gains from trade decreases. Similarly, a high value of θ in our model reduces the gains from trade. Imposing a common θ across countries makes it easy for us to see how technologies around the world interact through trade.

The extreme value distribution is very convenient, but how well does it reflect reality? As described above, a way of generating this distribution is to draw worker efficiencies repeatedly from a Pareto distribution, taking the largest. The upper tail of the distribution, representing the most efficient firms, itself resembles a Pareto distribution. Wilfredo Pareto invented what we now call the Pareto distribution to describe how income was distributed. It turns out that the Pareto distribution, sometimes called a power law, describes the upper tail of a large number of magnitudes, such as city population and firm sales and employment. Hence the extreme value distribution fits the data quite well.

Since we now have I countries, iceberg trade costs can now vary with the pair of countries in question, so that delivering a unit of a good to country n requires shipping $d_{ni} \geq 1$ units from country i (with $d_{ii} = 1$). These trade costs can capture a well-known regularity in data on trade, which is that the amount of trade between two countries tends to fall as the distance between them rises. This feature is known as "gravity," and gravity models of trade build on this insight. The multi-country framework developed here will deliver gravity if iceberg costs between any two countries rise systematically with the distance between them. Here, although we incorporate iceberg costs, we steer away from giving them too specific an interpretation. The issue of how well iceberg costs capture reality remains subject to debate. See Anderson and van Wincoop (2004) for further discussion.

Putting all these ingredients together, the cost of producing a good j in country i and delivering it to country n is $c_{ni}(j) = a_i(j)w_id_{ni}$, the product of the labor requirement in i , the wage in i , and the iceberg cost of moving goods from i to n . As in Dornbusch, Fischer, and Samuelson (1977), wages and trade costs are the same for all goods produced in a country, and so $c_{ni}(j)$ has the same distribution as $a_i(j)$, only with the absolute advantage parameter A_i replaced by $A_{ni} = A_i/(w_id_{ni})$. The positive effect of raw efficiency in country i (through a higher A_i) on the cost distribution in n is offset by a higher wage and a higher cost of shipping to country n .

Just as in the basic Ricardian model, perfect competition guarantees that the price $p_n(j)$ of good j in country n is the lowest cost $c_{ni}(j)$ looking across

all potential sources i . Unlike the simple Ricardian model with no trade costs, in the more general set-up here, which country i provides the good at lowest cost may differ across destinations n . We already saw such an outcome in the two-country Dornbusch, Fischer, and Samuelson (1977) model with trade costs: Each country produced a range of goods for itself while other goods, for which differences in productivity were more extreme, were produced in only one country. While the multi-country formulation here is more complicated, the distribution of the price of a good j in country n is straightforward. It inherits the extreme value distribution from the costs $c_{ni}(j)$ of which $p_n(j)$ is the minimum across all potential sources i , with its distribution remaining in the Weibull family.⁵

Aside from telling us about prices, the model can also tell us about trade between any two countries via the probability π_{ni} that a particular country i is the lowest cost source of a good in country n . This probability is lower the higher d_{ni} , the trade barrier in shipping from i to n , and the higher the wage in the source country, adjusted for absolute advantage. Since there are a continuum of goods, the probability π_{ni} is also the share of goods in country n supplied by country i . Furthermore, with the same symmetric Cobb-Douglas preferences used by Dornbusch, Fischer, and Samuelson (1977), the π_{ni} 's also correspond to the fraction of country n 's spending devoted to goods bought from country i . These purchases are imports if i and n are different but are domestic sales when i and n are the same.⁶ Since data on the value of trade and production are readily available to calculate trade shares, the π_{ni} 's

⁵In particular, the distribution of prices $p_n(j)$ emerges just by replacing A_i in the distribution of labor requirements with a term \bar{A}_n , that aggregates the A_{ni} 's from each source i :

$$(\bar{A}_n)^\theta = \sum_{i=1}^I (A_{ni})^\theta .$$

The expression for \bar{A}_n shows how higher efficiency, lower wages, and greater proximity of country n 's trading partners translates into lower prices.

⁶The trade share turns out to be country i 's contribution to the term \bar{A}_n given in the previous footnote: $\pi_{ni} = (A_{ni}/\bar{A}_n)^\theta$. With Cobb-Douglas preferences, the ideal price index p_n in country n is the geometric mean of the price distribution, which is simply γ/\bar{A}_n . The constant γ is given as equation (5) in the on-line appendix at <http://e-jep.org>. We could be much more general in our specification of preferences, but for our analysis here nothing would be gained. For example, with Dixit-Stiglitz preferences, the only change is in the formula for γ , which then depends on the elasticity of substitution.

provide a crucial link between the model and data.

Anything that lowers a country's cost of serving a market (such as a lower tariff) means more purchases are shifted there. How much depends on θ . Remember that a larger θ means that technologies are more similar across goods from any given country. Hence a given change in costs implies a bigger shift in trade shares when θ is high, since costs don't vary that much across goods.

Trade economists have long sought to measure the elasticity of trade with respect to relative costs, which are affected by such things as changes in tariffs or exchanges rates. In our analysis θ determines that elasticity. It plays an important role in all that follows. In our numerical analysis below we use a value of $\theta = 4$ suggested in a recent paper by Simonovska and Waugh (2011). Their recommended value is based on a careful analysis of the prices of 62 manufactured goods across 123 countries, and the estimate is in line with several earlier studies based on other evidence.

How does trade translate into welfare in this framework? The model delivers a handy expression for the real wage in country i , which is proportional to $A_i \pi_{ii}^{-1/\theta}$. The absolute advantage parameter A_i captures labor productivity in the country. In a closed economy, with $\pi_{ii} = 1$, productivity by itself determines the real wage. The second term $\pi_{ii}^{-1/\theta}$ captures the gains from trade.⁷ A country i with a small home share π_{ii} makes use (via imports) of technologies from elsewhere for a large range of goods. Without trade, of course, it would be using its own technologies to make these goods. How much a given drop in the home share, in moving from autarky to trade, raises welfare depends on how different the technologies embodied in imports are from the domestic technologies they replace. The smaller θ the bigger the difference, on average, and hence the larger the gains. Hence a country without many advanced technologies itself may nevertheless have a high living standard because it specializes in the technologies in which it is most advanced and purchases the rest from abroad. Using our value of $\theta = 4$ we can infer that a country importing 25 percent of what it consumes from abroad, hence purchasing 75 percent locally, gains about 7.5 percent in real income.

While it's very useful to infer the gains from trade by knowing just the home share in expenditure and the parameter θ , the home share itself depends on wages around the world, which are determined by the labor market

⁷ Arkolakis, Costinot, and Rodríguez-Clare (2012) show how, with θ suitably reinterpreted, this result on the gains from trade generalizes to a wide class of models.

equilibrium in each country. In order to solve for wages we need to know not only the trade costs but the labor endowment L_i in each country and the trade deficit D_i each country runs with the rest of the world.

In general, we can't solve the system of labor market equilibrium conditions for wages analytically, although a computer can spit out the answers rapidly, even with several hundred countries. But with costless trade (that is, no iceberg costs), we can obtain an analytic solution. In this special case the relative wage between two countries is increasing in the ratio of their productivities (their A_i 's), with an elasticity of $\theta/(1+\theta)$. That this elasticity is below one reflects the fact that in an open economy a country passes on some of the benefits of its own higher productivity to others through lower export prices. In this way, even without international technology diffusion, international trade allows countries to benefit from having trading partners with a high level of technology. The relative wage is decreasing in the ratio of labor endowments (the L_i 's), with an elasticity of $-1/(1+\theta)$. That this elasticity is negative is just as in the basic Ricardian model. A country with more workers, in order to employ them, produces more of an existing set of goods (the intensive margin), lowering their relative price. Here, in addition, the country diversifies into additional goods (expanding at the extensive margin) in which its relative productivity is lower. Without trade barriers, the relative wage is independent of trade deficits, just as deficits don't matter for wages in Dornbusch, Fischer, and Samuelson (1977) when there are no trade costs.

In a world of costless trade we can see exactly how countries' endowments of labor and technology interact to determine their relative welfare. Recognizing that distance matters introduces location as a third major determinant of a country's relative income and welfare. Proximity to large markets and to inexpensive sources of goods then becomes another important feature of a country in determining its welfare.

To get some sense of the magnitude of geography's role in a country's wellbeing let's perform a numerical exercise with just two countries. Say that one country is large, with 99 percent of the world's labor, and the other small, with one percent of the world's labor. Let's start by assuming free trade and labor efficiencies such that with no trade barriers the two countries have the same wage (and hence the same real wage since prices are the same). In a frictionless world with no trade barriers, the small country would spend only one percent of its income on goods from itself.

Now imagine introducing a trade barrier between the two countries, so

that the iceberg costs are $d = 2$ for sending goods in either direction. In the resulting equilibrium the small country spends just under half of its income on goods from itself (a typical amount for an actual small country). While the large country is virtually unaffected by the change, the real wage in the small country falls to 38 percent of that in the large country. This decline is the result of two effects. First, to be competitive in the large country, the small country's wage has to fall to 65 percent of the large country's. Second, because goods from the large country are expensive to import, the price index is 70 percent higher.

With these trade barriers in place how much of a productivity boost would we have to give the small country to bring its real wage back up to the level in the rich one? The answer is so much that under costless trade its wage would be more than double the large country's. An implication of this example is that, by influencing trade costs, geography can play as important a role in determining income differences as technology.

Applying the Tool

Having shown how the Ricardian model can accommodate a complex world of many goods and many countries separated by trade barriers, we now connect it to data. We can then use it to ask many questions both about the world as it is and what it would look like under different circumstances. In this section we investigate four particular ones: 1) How much do countries gain from trade, and how have these gains evolved over the last two decades? 2) How much will these gains grow if falling trade costs lead to further increases in world trade? 3) To what extent do countries benefit from the technological improvements of their trading partners? 4) What are the costs to deficit countries of moving to balanced trade?

We fit the model to data on 32 "countries," 31 actual ones and a "rest of the world" which combines all the others. The limit on the number of countries arises from the availability of data; adding countries adds little to computational complexity. See Table 2 for a list.

While any model is a simplification, we can bring the model we have been discussing here much closer to reality with three embellishments:

First, the model applies quite naturally to manufactures, the dominant component of trade for most rich countries. Indeed, manufactures make up 64 percent of trade in goods and services among our 31 actual countries. It is less clear how well this model applies to services or to products in which

natural resources play a major role. To focus on trade in manufactures we follow Alvarez and Lucas (2008) and divide the economy into two sectors, which we call manufacturing and services, with labor mobile between them. Among our set of countries manufactures represent only a share α of about 0.2 of final spending.

Second, while manufactures are not a large share of final spending, a great deal of manufacturing output goes into the production of manufactures. Among our countries the share β of labor in manufacturing production is only about 0.3 with most of the rest manufactured intermediates. As pointed out, for example, by Krugman and Venables (1995), recognizing the importance of manufactures as inputs makes location as well as geography an important determinant of manufacturing costs. (Dekle, Eaton, and Kortum, 2007, describe how we set α and β .)

Third, the textbook Ricardian model typically assumes that trade is balanced. However, we design our model to accommodate deficits both in manufacturing and in everything else. In fact, one of our exercises is to examine the consequence of shifting these deficits in order to balance each country's current account.

To finish putting numbers on the model we go to the Organization of Economic Cooperation and Development STAN database for data on bilateral trade and production of manufactures and to the Economics Intelligence Unit for data on unilateral trade in goods and services, GDP, and the current account. Along with our values for the three parameters $\theta = 4$, $\alpha = 0.2$, and $\beta = 0.3$, these data tell us all that we need to know about the rest of parameters in order to answer our four questions.

We can answer our first question, about the magnitude of gains from trade, directly from data by using a relationship discussed in the previous section. The other three questions force us to consider all of the shifts in wages and prices around the world that would result from a change in trade costs, technology, or trade deficits.

We calculate counterfactuals as follows: We shock the model by changing the relevant parameters. We denote the new level of a variable or parameter x as x' and the proportional change in it as $\hat{x} = x'/x$. In particular, we consider changes \hat{d}_{ni} in trade costs (keeping them at one when $i = n$), changes \hat{A}_i in technology, or counterfactual deficits D'_n (and $D_i^{M'}$ for manufactures). We then calculate the changes in wages \hat{w}_i and prices \hat{p}_i needed to reequilibrate the world economy. Our baseline is the world as it was in 2009, the last year

for which data are available for all of our countries.

Gains from Trade

As discussed above, we can measure the gains from trade using data on only the home share, π_{ii} . For this exercise we employ a direct measure of the home share: gross manufacturing production less *gross* exports divided by gross manufacturing production less *net* exports.⁸ This statistic deserves some consideration on its own.

Table 2 reports the home share in 2006 for the 25 countries with data on gross manufacturing production. The mean value of the home share is just under 50 percent. In a world of frictionless trade (all $d_{ni} = 1$) there is no reason for a country to spend a larger share of its income on its own goods than any other country. A country's home share, in that case, would correspond to its share in world GDP. As Table 2 makes clear, for each of these countries the home share is many times larger than the country's share in world GDP: three times higher for the United States, ten times for Germany, 50 times for Denmark, and 100 times for Greece. Such multiples illustrate the extent to which trade barriers continue to chop up world markets. Even though countries buy much more of their manufactures from home than a world of costless trade would predict, in line with theory large countries tend to buy much more from themselves than small countries: The overall correlation between home share and share in GDP is close to 0.5 in 2006.

The third column of Table 2 shows that the home share declined substantially between 1996 and 2006, reflecting globalization of manufactures production over the period. (Only Ireland bucked this trend.) The last two columns calculate the implications of the level of the home share and its changes over time for countries' gains from trade and how those gains have evolved. In making these calculations our first two embellishments to the model require two modifications. Since we look at the gains from trade only in manufactures, the fact that manufactures are only 20 percent of final spending limits the benefit. But since manufactures are a major input into the production of manufactures, there are large indirect benefits of trade in lowering input costs. Putting the two together, the elasticity that translates a smaller home share into larger gains from trade is no longer $1/\theta$ but rather $\alpha/(\theta\beta) = 1/6$. Thus, we calculate the gains from trade for country i at date

⁸In our counterfactual simulations we use a different measure, as in Dekle, Eaton, and Kortum (2007).

t as

$$G_i^t = 100 \left[(\pi_{ii}^t)^{-1/6} - 1 \right],$$

where π_{ii}^t is country i 's home share at date t .

Clearly, gains from trade are substantial, particularly for small countries: for example over 25 percent of income for Denmark, Estonia, and Hungary. For the largest countries, Japan and the United States, gains from trade amounted to only two or three percent of GDP twenty years ago. But, those gains are now over 50 percent higher.

Benefits of Further Globalization

Our measure of the gains from trade compare where we are now with no trade. We can also consider the gains that would accrue in the future if globalization, driven by lower trade costs, continues. Our counterfactual experiment considers a uniform proportional 25 percent drop in the costs of trade, ($\hat{d}_{ni} = 0.75$ for all foreign-country pairs), a magnitude chosen so that world trade in manufactures approximately doubles relative to world GDP. As a point of reference, world trade in goods and services did double relative to world GDP over the past 30 years.

Figure 3 plots the results against each countries' share of world GDP. The gains, measured by the increase in the real wage, are substantial, with a median gain of about ten percent. The gains are also very heterogeneous, with small countries typically gaining proportionately much more than large countries. Given their size, isolated countries, such as Iceland, New Zealand, and Greece gain much less than countries proximate to many others, such as Belgium-Luxembourg, the Netherlands, and Germany.

Benefits of Technological Improvements

As the basic Ricardian model illustrates, trade provides a conduit through which foreign countries benefit from an improvement in a country's ability to produce a good. We can measure the strength of this mechanism by considering the effects on welfare around the world from a shift in the distribution of technologies in a particular country i (as reflected in the parameter A_i). Our particular experiment makes the United States ten percent more productive, $\hat{A}_{US} = 1.1$.

The world economy responds in two important ways. First, the U.S. wage rises by about 30 percent relative to other countries' wages. Second, manufacturing prices everywhere fall slightly relative to foreign wages and

considerably relative to the U.S. wage. As a result, the U.S. real wage (in terms of goods and services) rises by about six percent, while real wages in other countries rise much less, if at all.

The change in the relative wage is much greater than would be predicted in the frictionless-trade case discussed above. A major reason is that, with trade costs, relative price levels typically move in the same direction as relative wages. The change in the relative *real* wage is much closer to the analytical result of the previous section, in which the relative wage and the relative real wage are the same.

The effects of geography are apparent in where wages change, as the greatest foreign beneficiaries are Canada and Mexico, which experience a real wage gain one-tenth that in the United States. A few countries, if they are initially running a trade surplus in manufactures, experience a small real wage decline. (If we first eliminate all trade imbalances and then increase U.S. technology, all foreign countries experience a real wage gain.)

Overall, the increase in U.S. technology raises the GDP-weighted real wage around the world by 1.6 percent, with 8 percent of this gain experienced outside the United States. Foreign countries gain both due to the lower prices of final goods and of intermediate inputs relative to wages. Performing the same experiment, but with China in place of the United States, yields similar results. Better technology in China raises the world's average real wage by 0.6 percent, with 10 percent of this gain experienced outside China. These results reflect the fact that the improvement in technology in China adds to a smaller base, yet China's greater export orientation means the overall benefits are spread somewhat more to foreign destinations.⁹

Consequences of Eliminating Current Account Imbalances

Our model, like Dornbusch, Fischer, and Samuelson (1977) with trade costs, implies that transfers between countries have implications for relative wages. Our third counterfactual, following Dekle, Eaton, and Kortum (2007), considers exogenous shifts in manufacturing trade deficits that would

⁹Our results on the benefits of foreign technology are much smaller than some of the results in Eaton and Kortum (2002). The main reason is in that paper the mobile-labor case held wages fixed so that foreign countries did not suffer a decline in their terms of trade. Our results here, in that respect, are more in line with the immobile-labor case of Eaton and Kortum (2002). See Fieler (2011) and Hsieh and Ossa (2011) for a related analysis of the benefits to foreign countries of China's technology gains. Hsieh and Ossa's analysis is retrospective rather than counterfactual.

simultaneously balance every country's current account, holding fixed any deficits outside of manufacturing. We also hold trade costs and technologies fixed. Table 3 shows the results. To undo the huge 2009 U.S. deficit, the wage in most countries rises relative to the United States, by over 13 percent in China and 14 percent in Germany since the large surpluses of these two must decline. The small European deficit countries of Greece and Portugal are the dramatic exceptions, declining 21 and 12 percent relative to the United States.

Figure 4 shows that initial current account balances (as a share of GDP), determining the required adjustment of trade imbalances, go a long way toward explaining the direction (positive) and magnitude of wage adjustment. A question is why Iceland, Portugal, and Greece experience very different wage responses even though their current account deficit to GDP ratio was similar in 2009. It turns out that another important factor in explaining the magnitude of the change in wages is the initial size of the manufacturing sector in a country's GDP. This share is lowest in Greece, worsening the wage decline necessary to bring about current account balance via an increase in net exports of manufactures.

The consequences for the real wage are much more muted than the those for the relative wage. Even Greece, the most negatively affected, suffers less than a 4 percent decline. The United States, with its large current account deficit, would see its real wage decline by only half a percent. The reason is a combination of large home shares in manufacturing spending and small shares of manufactures in overall final demand. For goods and services produced at home, prices move in line with wages. The change in the relative wage acts only through import prices.

More dramatic are the changes in the share of manufacturing in GDP required to rebalance current accounts. This share rises by over ten percentage points in Iceland and by nearly as much in Greece and Portugal. It falls by over four percentage points in the large surplus countries (China and Germany) and by five percentage points in the smaller ones (Norway, Sweden, and Switzerland). These extreme predictions about the impact on the size of the manufacturing sector follow from our Ricardian assumption that labor can flow seamlessly between manufacturing and other activities. Dekle, Eaton, and Kortum (2008) introduce rigidities and examine their effect.

Extending and Improving the Tool

Much recent work has extended this new-old Ricardian trade theory in various ways, sometimes combining elements of it with other theories to address new questions. Here we briefly discuss a few of these contributions.

The field of international trade has traditionally used industry as its unit of analysis, a natural choice given the heterogeneity of industries and the fact that most trade policy is implemented at the industry level. In moving from a small number of goods, with labor requirements specified in a table, to a continuum of goods, with labor requirements only described probabilistically, we lose track of this industry dimension. A number of papers have brought industries back into the analysis, including Chor (2010) and Shikher (2011). The idea is that each industry k consists of a continuum of differentiated goods and each country i has an absolute advantage parameter A_{ik} in each industry. Costinot, Donaldson, and Komunjer (2010) use this approach to revisit the connection between trade and industry-level productivity implied by Ricardian theory, avoiding ambiguities that plagued the early analysis of MacDougall (1951, 1952). Incorporating input-output linkages between industries, Caliendo and Parro (2011) use the model to explore the welfare gains from tariff reductions under NAFTA.

While the basic Ricardian trade model treats labor as the only primary factor, many applications require incorporating other factors of production. In his monumental study measuring the gains from rail transport in 19th century India, Donaldson (2010) applies this Ricardian model, replacing labor with land as the primary factor, with land rents appearing in place of wages. Incorporating several factors, and multiple industries, leads to a hybrid Ricardian-Heckscher-Ohlin model, as in Shikher (2011), used by Parro (2011) to account for the rise of the skill premium in developing and developed countries. Burstein and Vogel (2010) interweave these two theories at a deeper level, introducing a correlation between labor requirements and skill intensity at the level of the individual goods on the continuum.

Our applications above were limited to trade in manufactures among OECD countries. Extending the analysis more broadly, the theory has to confront the fact that poor countries trade less than rich ones, even taking into account their economic size and location. Waugh (2010) proposes a model in which barriers to exporting are the culprit, consistent with evidence on prices. Fieler (2011) pursues another explanation, introducing different classes of goods with different income elasticities of demand and with different degrees of technological heterogeneity (in the notation in the model we have presented here, different θ 's). She finds that poor countries have a com-

parative advantage in goods that are both more income inelastic and more technologically homogeneous (that is, with a higher θ). Tombe (2011) finds that barriers to food trade are higher than for manufactures, particularly in poor countries. He also departs from the standard Ricardian tradition by introducing barriers to domestic labor mobility between rural areas (where food is produced) and cities (which produce manufactures and services).

In keeping with Ricardo's original analysis, the models discussed so far mostly assume perfect competition. Breaking with that tradition, Bernard, Eaton, Jensen, and Kortum (2003) incorporate Bertrand competition, allowing the theory to make contact with data on individual producers. This extension also opens up the possibility to address pricing puzzles in international economics, as explored in Atkeson and Burstein (2008). While the basic model with Bertrand competition yields a distribution of price markups that is invariant to trade, de Blass and Russ (2011) develop a variant of the model that breaks that result. Homes, Hsu, and Lee (2012) investigate a related model that yields new results on the gains from trade.

Having introduced imperfect competition, Eaton and Kortum (2001) show that innovation and growth fit seamlessly into the theory. Incorporating technology diffusion and multinational production has turned out to be more challenging. The problem is that the theory can easily deliver myriad treads and risers again when groups of countries have access to the same technologies for producing some goods. Recent work by Ramondo and Rodríguez-Clare (2010) has begun to map a way through these difficulties. Another promising approach, representing a greater departure from the basic theory, is pursued by Alvarez, Buera, and Lucas (2011).

In short, the framework we present in this paper is tractable, versatile, and amenable to empirical analysis. It is keeping Ricardo busy.

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Table 2: The Home Share and Gains from Trade

Country	World GDP Share (%) in 2006	Home Share of Spending		Implied Gains from Trade	
		level in 2006 (%)	change since 1996 (percentage points)	level in 2006 (%)	change since 1996 (percentage points)
Austria	0.66	31.4	-16.2	21.3	8.1
Canada	2.60	49.1	-1.5	12.6	0.6
Czech Republic	0.29	42.6	-14.7	15.3	5.5
Denmark	0.56	25.6	-18.1	25.5	10.7
Estonia	0.03	2.5	-19.6	85.4	56.7
Finland	0.42	58.2	-7.3	9.4	2.1
France	4.60	56.9	-10.3	9.9	3.0
Germany	5.94	53.7	-16.4	10.9	4.8
Greece	0.54	52.7	-11.6	11.3	3.6
Hungary	0.23	26.0	-34.5	25.1	16.4
Iceland	0.03	27.9	-10.0	23.7	6.2
Ireland	0.46	39.6	9.9	16.7	-5.7
Italy	3.80	68.9	-7.1	6.4	1.7
Japan	8.88	84.9	-5.6	2.8	1.1
Korea	1.94	77.2	-0.7	4.4	0.1
Mexico	1.94	58.3	-7.9	9.4	2.3
New Zealand	0.22	53.6	-8.2	11.0	2.6
Norway	0.68	51.9	-2.5	11.6	0.9
Poland	0.69	53.4	-15.8	11.0	4.7
Portugal	0.41	50.8	-10.2	12.0	3.4
Slovenia	0.08	27.2	-15.5	24.3	9.0
Spain	2.51	62.8	-10.2	8.1	2.7
Sweden	0.81	49.2	-10.0	12.5	3.4
Switzerland	0.80	35.3	-20.0	18.9	8.6
United States	27.26	73.5	-8.3	5.3	1.9
All Others	33.62				

Table 3: Eliminating Current Account Imbalances

ID	Country	Data			Counterfactuals		
		GDP (US\$ billions)	Current Account Balance (% GDP)	Manufactures Trade Balance (% GDP)	Change in		Change in mfg share (percentage points)
				Relative wage (%)	Real wage (%)		
1	Australia	973.7	-5.0	-8.1	-4.6	-1.4	3.5
2	Austria	382.0	2.4	1.2	11.4	0.3	-1.9
3	Belgium-Luxembourg	525.2	0.6	7.4	8.3	0.0	-0.5
4	Canada	1337.6	-3.4	-4.7	-1.0	-0.7	2.6
5	China	5050.5	4.7	10.6	13.4	0.3	-4.1
6	Czech Republic	190.2	-3.7	6.4	3.1	-0.9	3.3
7	Denmark	308.9	3.1	1.3	13.3	0.4	-2.4
8	Estonia	19.3	4.2	-3.9	17.5	1.5	-2.6
9	Finland	241.3	2.0	5.6	11.0	0.1	-1.7
10	France	2632.7	-2.0	-1.2	4.3	-0.4	1.6
11	Germany	3308.3	5.2	8.6	14.4	0.7	-4.4
12	Greece	326.4	-11.5	-12.3	-20.7	-3.7	8.7
13	Hungary	128.8	-0.1	7.7	7.4	-0.3	0.0
14	Iceland	12.1	-12.2	3.2	-6.1	-2.1	11.4
15	Ireland	223.8	-3.4	27.9	4.8	-0.2	3.2
16	Italy	2116.7	-2.5	2.9	4.1	-0.4	2.1
17	Japan	5031.6	2.4	3.4	12.7	0.2	-2.0
18	Korea	834.1	3.5	16.1	11.3	0.2	-3.3
19	Mexico	879.2	-1.2	-2.9	2.7	-0.4	0.9
20	Netherlands	796.2	4.4	7.5	13.6	0.7	-3.7
21	New Zealand	116.2	-3.6	-2.2	1.1	-0.6	2.9
22	Norway	370.7	11.6	-6.0	41.9	3.9	-4.8
23	Poland	430.5	-4.4	0.1	1.7	-1.0	3.8
24	Portugal	234.9	-11.4	-7.6	-11.9	-2.6	9.7
25	Slovak Republic	87.8	-3.7	6.5	3.3	-0.9	3.3
26	Slovenia	49.2	-1.7	-1.4	5.0	-0.5	1.4
27	Spain	1468.4	-5.6	-2.4	-2.0	-1.0	4.7
28	Sweden	403.5	6.7	4.8	18.6	1.0	-5.2
29	Switzerland	492.3	7.5	4.6	18.9	1.3	-5.7
30	Turkey	613.8	-2.7	-2.7	2.9	-0.6	2.2
31	United States	13939.0	-3.2	-2.6	0.0	-0.5	2.6
32	ROW	13961.0	0.9	-5.4	9.4	0.2	-0.6

Data are for 2009

Figure 1: Wage Determination in the Many Good Model

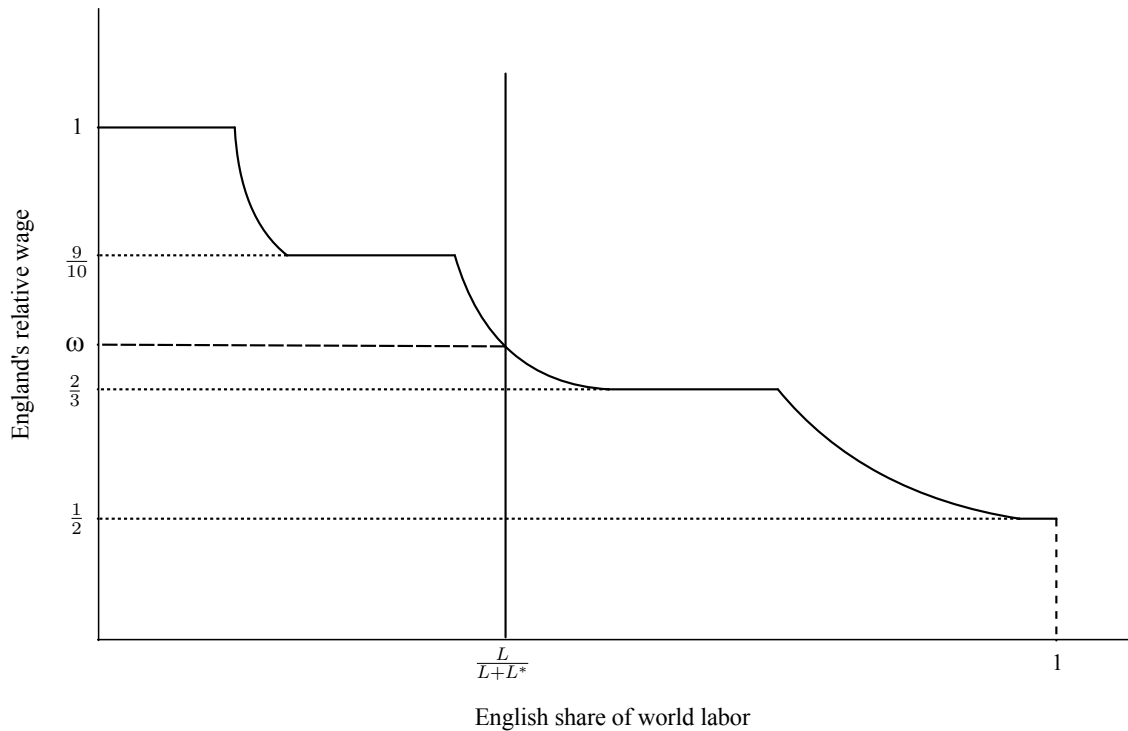


Figure 2: Wage Determination with a Continuum of Goods

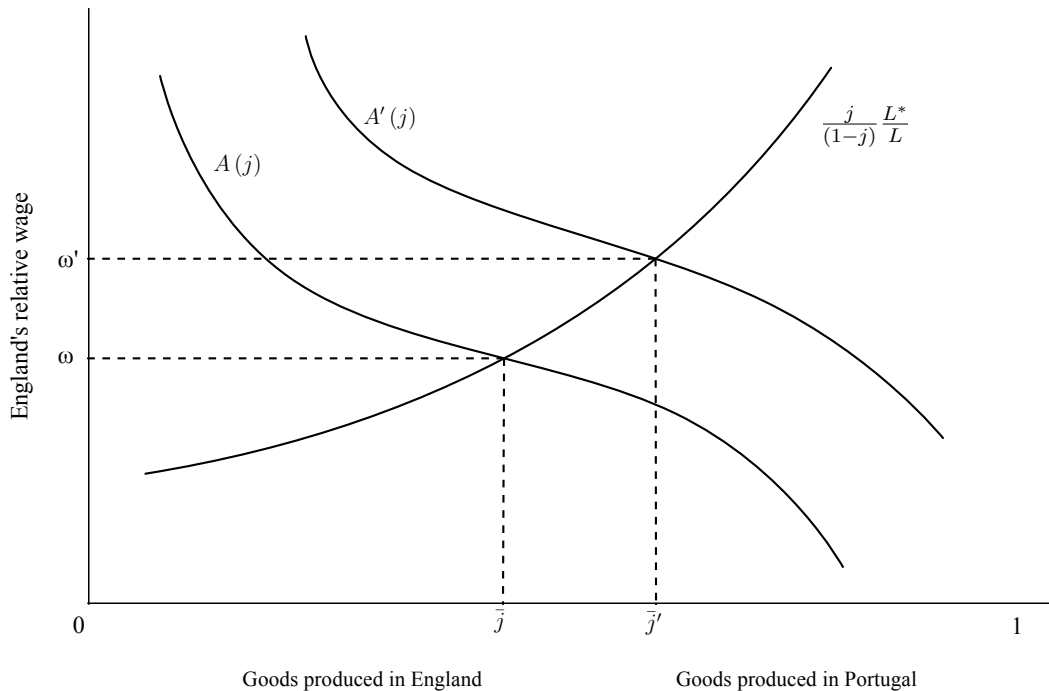


Figure 3: Real Wage Response to a Decrease in Trade Barriers

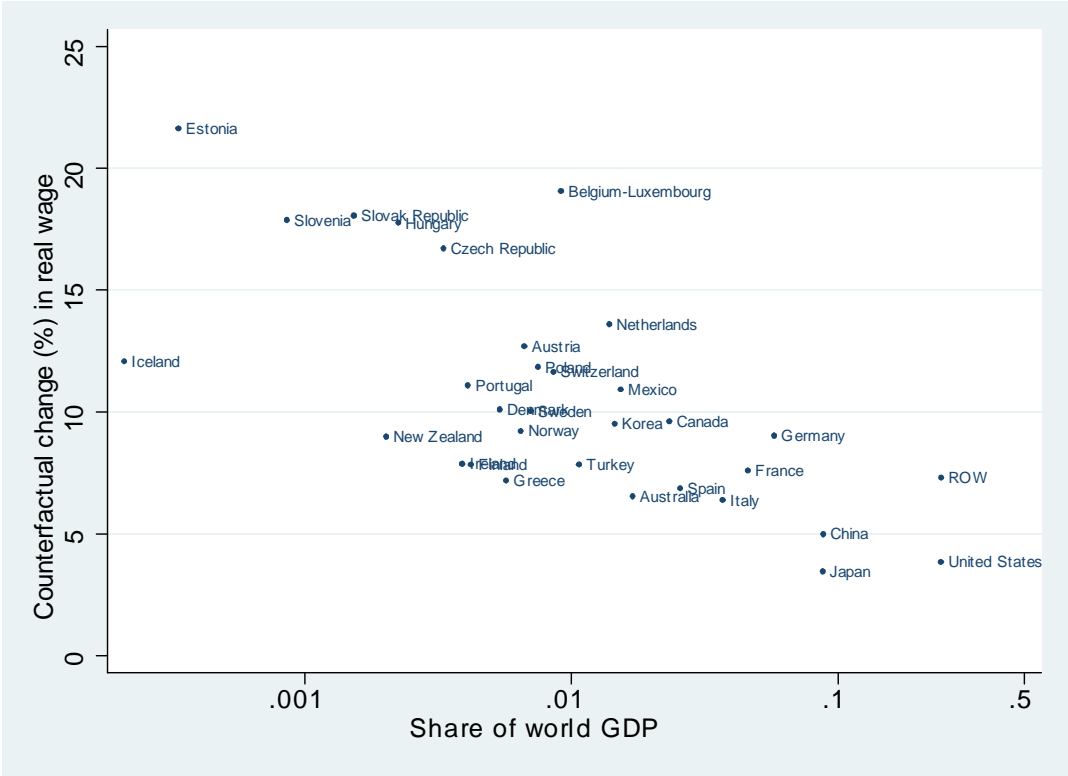
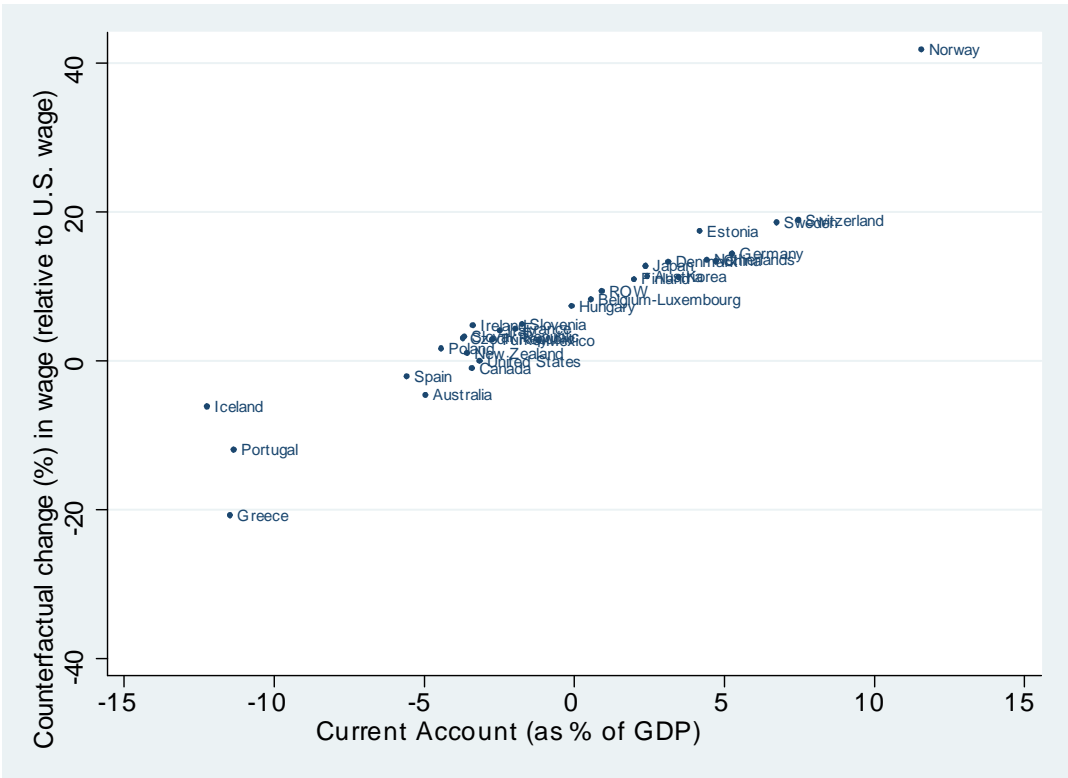


Figure 4: Wage Response to Eliminating Current Account Imbalances



Putting Ricardo to Work

Jonathan Eaton and Samuel Kortum

1 Mathematical Appendix

1.1 Probabilistic Approach

The distribution of labor requirements takes the form:¹

$$\Pr[a_i(j) \leq a] = 1 - e^{-(A_i a)^\theta} \quad (1)$$

We can use (1) to derive the distribution of the cost $c_{ni}(j)$ of good j if supplied by i to n :

$$\Pr[c_{ni}(j) \leq c] = 1 - e^{-(A_{ni}c)^\theta},$$

where $A_{ni} = A_i/(w_i d_{ni})$. Taking the minimum cost of delivery to n , the distribution of prices $F(p)$ is given by

$$\Pr[p_n(j) \leq p] = 1 - \prod_i \Pr[c_{ni}(j) > p] = 1 - e^{-(\bar{A}_n p)^\theta}, \quad (2)$$

where:

$$\bar{A}_n = \left[\sum_{i=1}^I (A_{ni})^\theta \right]^{1/\theta}. \quad (3a)$$

¹An equivalent statement to (1), which clarifies the role of the two parameters, is:

$$\ln a_i(j) = \frac{1}{\theta} \ln x_i(j) - \ln A_i,$$

where

$$\Pr[x_i(j) > x] = e^{-x}.$$

Thus for the log of the labor requirement, $\ln A_i$ is a mean shifter and $1/\theta$ a variance shifter. Note the close analogy to the Normal distribution in which a family of distribution emerges by applying an additive shifter μ and multiplicative shifter σ to a standard Normal random variable.

Integrating over the distribution of prices (2) gives the price index:

$$p_n = \exp \left(\int_0^\infty \ln(p) dF(p) \right) = \frac{\gamma}{\bar{A}_n}, \quad (4)$$

where $\gamma = \exp(-\varepsilon/\theta)$ and $\varepsilon = 0.5772\dots$ is Euler's constant. The probability π_{ni} that a particular country i is the lowest cost source of a good in country n is its contribution to the price index in n :

$$\pi_{ni} = \left(\frac{A_{ni}}{\bar{A}_n} \right)^\theta. \quad (5)$$

Evaluating (5) at $n = i$, applying (4), and rearranging, we get the simple relationship between the real wage, productivity, and the home share π_{ii} , described in the text:

$$\frac{w_i}{p_i} = \gamma^{-1} A_i \pi_{ii}^{-1/\theta}. \quad (6)$$

The model is closed with conditions for labor market equilibrium. Denoting the labor endowment in country i by L_i and the trade deficit in country n by D_n , these conditions are

$$w_i L_i = \sum_{n=1}^I \pi_{ni} (w_n L_n + D_n). \quad (7)$$

1.2 Case of Frictionless Trade

In a world with no trade barriers, trade shares are source-specific but are not destination-specific. We can use this property to solve the labor market equilibrium conditions for the relative wage between any two countries:

$$\frac{w_i}{w_n} = \left(\frac{A_i^\theta / L_i}{A_n^\theta / L_n} \right)^{1/(1+\theta)}.$$

Multiplying by the relative labor force and summing shows that country i 's income Y_i relative to world income (which is also its home share) is:

$$\pi_{ii} = \frac{Y_i}{Y} = \frac{(A_i L_i)^{\theta/(1+\theta)}}{\sum_{n=1}^I (A_n L_n)^{\theta/(1+\theta)}}. \quad (8)$$

Substituting this expression for the home share into (6), the real wage is thus:

$$\frac{w_i}{p} = \gamma^{-1} A_i^{\theta/(1+\theta)} \left[\sum_{k=1}^I \left(\frac{A_k L_k}{L_i} \right)^{\theta/(1+\theta)} \right]^{1/\theta}. \quad (9)$$

1.3 Extension for Quantitative Analysis

The model used in the quantitative application is augmented with an intermediate share $1 - \beta$ so that

$$A_{ni} = \frac{A_i}{w_i^\beta p_i^{1-\beta} d_{ni}}$$

and with a share α of final spending on manufactures so that (7) becomes

$$\alpha (w_i L_i + D_i) - D_i^M = \sum_{n=1}^I \pi_{ni} [\alpha (w_n L_n + D_n) - (1 - \beta) D_n^M],$$

where D_i^M is country i 's trade deficit in manufactures.

We can express the equations of the model in terms of changes in the endogenous variables. Substituting (3a) into (4), exponentiating, and then substituting in (5) we get:

$$\hat{p}_n^{-\theta} = \sum_{k=1}^N \pi_{nk} \left(\frac{\hat{A}_k}{\hat{w}_k^\beta \hat{p}_k^{1-\beta} \hat{d}_{nk}} \right)^\theta. \quad (10)$$

By a similar set of steps, and also using $Y_i = w_i L_i$ we can write the labor market equilibrium conditions as

$$\begin{aligned} & \alpha (\hat{w}_i Y_i + D_i') - D_i^{M'} \\ &= \sum_{n=1}^N \pi_{ni} \left(\frac{\hat{A}_i \hat{p}_n}{\hat{w}_i^\beta \hat{p}_i^{1-\beta} \hat{d}_{ni}} \right)^\theta [\alpha (\hat{w}_n Y_n + D_n') - (1 - \beta) D_n^{M'}]. \end{aligned} \quad (11)$$

These two sets of equations, (10) and (11), are what we solve for our counterfactual analysis.

We calculate the change in a country's price level (including the prices of services) as

$$\hat{P}_i = \hat{p}_i^\alpha \hat{w}_i^{1-\alpha}.$$

The real wage in our counterfactual results is defined as

$$\frac{\hat{w}_i}{\hat{P}_i} = \left(\frac{\hat{w}_i}{\hat{p}_i} \right)^\alpha.$$

In the tables and figures we express the change in any variable x in percentage terms: $100 \times (\hat{x} - 1)$.