The Heckscher-Ohlin Framework and the Craft of Economics

Edward E. Leamer
UCLA

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Edward E. Leamer
UCLA

The Ohlin lectures are a time for admiration of the Heckscher-Ohlin framework of global competition.   I claim a lifetime relationship with Heckscher-Ohlin and I am prepared to praise her lavishly.   Others who came before me in this lecture series, including Robert Baldwin, Alan Deardorff, Ronald Findlay, and Ronald Jones, have also spent intellectual lifetimes exploring the possibilities of the HO model, and know her as well as I. But I think I have something special to say about her.   My infatuation with her beauty has long since passed, but I have grown to appreciate her wisdom. I think I know how to tease insights from her, and how not to.   I know from personal experience how well she conforms with real data.   This affords me the opportunity to comment on the craft of economics – what we think we know, how we learned it, how we teach it to others, how much is valid, how much is sound, how much is useful, and most importantly, what we are doing right and what we can hope to do better.

This will be a spirited defense of Bertil Ohlin against the onslaught of translations of his ideas into formal mathematical theorems.   Below you will find the suggestion that Ohlin offered us something useful though vague and not necessarily valid, while the mathematizers who came after him offered us something precise and valid but not necessarily useful.

Of course there are great benefits from both formal and informal thinking, and both suffer serious limitations as well.[1] The best economists since Paul Samuelson and others introduced math into economics do both formal and informal thinking, and do both well. We as a profession go astray when we put too much emphasis on one approach or the other.   The history of the conversation among economists regarding the Heckscher-Ohlin framework that I summarize below is a case study. When Ohlin wrote, the profession used informal modeling to guide government policy.   When Samuelson first entered the conversation, he introduced formal modeling to help clarify the informal thinking. But Samuelson's paper with Wolfgang Stolper was rejected by Homan(1941), editor of the flagship journal of the US, *The American Economic Reviewl*, because "it is a very narrow study in formal theory, which adds practically nothing to the literature of the subject with which it is nominally concerned."   Subsequently the conversation flipped 180 degrees into exercises in formal modeling only, and the goals of the informal modeling were much forgotten. In 1968, the very same *American Economic Review* published Melvin's completely correct but utterly irrelevant description of the production possibilities frontier for the 3-good 2-factor HO model.

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[1] Mayer(1998) "The Dark Side of Economic Modeling" provides a list of the problems created by formal modeling.

With the ashes of the mathematical models used to rate mortgage-backed securities still smoldering on Wall Street, now is an ideal time to revisit these issues.[2] Some have suggested that the fundamental error made by the statisticians and mathematicians who built models for the pricing and rating of complex securities is their use of models without social contagion "behavioral economics" effects, which is a shortcoming that is completely remediable by business as usual with an extra variable or two. The problem, I suggest, is more fundamental. The problem is the use of two-valued logic: true or false, yes or no, a security is either AAA-rated or it has another rating. Two-valued logic works well for modeling mechanical systems with behaviors that are sufficiently repetitive that we can usefully assume stable statistical properties and wisely plan the future from historical data based on the fiction of a "data-generating-process."   But the evolving, self-organizing, self-healing human system we call the economy is not well described this way. For human systems, we need three-valued logic: "Yes" or "No" or "We don't know."   I have been making this point in the econometrics sphere since before I wrote *Specification Searches: Ad Hoc Inference With Nonexperimental Data* in 1978. That book was stimulated by my observation of economists at work who routinely pass their data through the filters of many models, and choose a few results for reporting purposes. The range of models economists are willing to explore creates ambiguity in the inferences that can properly be drawn from the data, and I have been recommending mathematical methods of sensitivity analysis that are intended to determine the limits of that ambiguity.[3] "Extreme bounds analysis" is a simple example that is the best known. When the bounds are wide, we must opt for the third logical value: we don't know; we remain confused. Thus my contribution to econometrics has been confusion!   One reason these methods are rarely used is that they tend to be destructive – a fanatical commitment to fanciful formal models is often needed to create the appearance of progress.

For the rating agencies, three-valued logic requires another rating: AAA-H, where H stands for hypothetical. The AAA-H rating is given when sensible models of mortgage defaults suggest these mortgage-backed securities deserve AAA ratings, but until these innovative securities are tested in stressful conditions like a major recession, they must retain the H suffix. We do this for mechanical systems with statistical properties much better understood than economics/financial systems. Engineers may design aircraft that according to their computer models can fly, but until real airplanes are actually tested in normal and stressful conditions, the aircraft are not certified by the FAA to carry passengers. Indeed, Boeing's composite plastic 787 Dreamliner has been suffering production delays when wing damage has shown up "when the stress on the wings was well below the load the wings must bear to be federally certified to carry passengers."[4] Too bad we couldn't have stress-tested those mortgage-backed securities before we started travelling around the world with them.

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[2] See also Colander et.al.(2009) who argue the fault lies not in the models, but in ourselves, who use the models inappropriately.

[3] Parenthetically, if you are alert, you might have been unsettled by the use of the word "with" in my title: *Ad Hoc Inference With Nonexperimental Data*, since inferences are made *with tools* but *from data*. That is my very subtle way of suggesting that knowledge is created by an interactive exploratory process, quite unlike the preprogrammed estimation dictated by traditional econometric theory.

[4] Seattle Times, July 30 2009, Boeing 787 wing flaw extends inside plane

H for hypothetical is not the solution for Economics, since most of what we believe comes from the manipulation of models. But in economic theory just as in econometrics, there is an important sensitivity issue. Some conclusions are conceptually sturdy in the sense that major changes in the assumptions do not alter substantively the conclusions. Others are fragile, meaning that small perturbations of the assumptions fundamentally alter the conclusions. Formal modeling tends to provide valid but fragile results. Informal modeling tends to provide invalid but sturdy results. Samuelson's formal factor price equalization is very fragile. Ohlin's informal tendency toward factor price equalization is reasonably sturdy.

So let's have some H, for humility, and let's have the ratings SSS for very sturdy and FFF for very fragile.

Formal two-dimensional Heckscher-Ohlin-Samuelson models have had a large and rather inappropriate impact on the way that economists think about international competition because much of the economics they embody is fragile, even if the math isn't. What about data and the HO model? Ohlin did not have access to large organized data bases on trade, production, employment, land, labor and capital that have been studied over the last several decades. One might imagine that these data would help keep us focused. It hasn't worked out that way. Data analysis confronts exactly the same tensions between the formal and the informal. Like economic theory, data analysis has moved increasingly toward the formal, imposing the straightjackets of complex but simplistic mathematical models on the data. Our theoretical insights would be more frequent and more reliable if they come from a combination of informal and formal thinking. Our discoveries from data would be more surprising and more persuasive if we used both formal and informal ways of processing the data and reporting our findings.

As it has turned out, the informal data analyses have been supportive of the HO ideas, while the formal analyses have mostly raised serious doubts. I am sorry to report that the formal results seem to have taken control of the conversation, leading many to question the usefulness of the HO framework. This a completely wrong conclusion. The strongest currents in global trade continue to come from the uneven geographic distribution of the globe's productive assets, just as Ohlin hypothesized.

Please forgive me if I seem critical. You should be used to that. There are not enough sheets of paper in all the Universe to describe what you are doing right. Please forgive me also if I sometimes overstate the argument. You should be used to that too. The essence of the economic theory that you do is to simplify and exaggerate.

Fiction and Journalism

In response to Medema and Samuels(1996) title question "How Do Economists Do Economics?" some of the essayists sought the answer in similes: Economics is like engineering, or Economics is like medicine or Economics is like mapmaking.[5] As for

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[5] E.g. Varian(1996,p.239)

myself, I have been using the map-making analogy for a long time. In writing this piece, a new thought occurred to me.   To make sure you do not miss it, I begin this essay on the craft of economics with the conclusion:

Economic theory is fiction, and data analysis is journalism.

The difference between fiction and journalism is the way the facts are treated. Fiction is mostly about the story and is loosely connected to the facts; journalism is mostly about the facts and is loosely connected to the stories. Historical fiction lies between.

By this intentionally provocative statement, I am suggesting that we economists would do better if we dialed back our daily warm showers of scientific rhetoric. We would do better theory if we judged economic theories by the same standards that we judge novels, and we would do better econometrics if we judged empirical work with the same standards that we judge journalism.   Fiction can be revealing, innovative, insightful, even inspirational, or it can be derivative, boring and tedious. Journalism can be balanced and informative, or it can be prejudiced and irrelevant.

Our goal should be the greatest insight, wisdom and understanding at the least possible cost for the writer and the reader.   "What did we learn from that?" is the question we need to ask, followed by "Was that worth the effort?" Though entertainment *per se* is not an appropriate goal for the discipline of Economics, entertainment and accessibility are highly desirable because they lower the cost of learning and internalizing the messages.
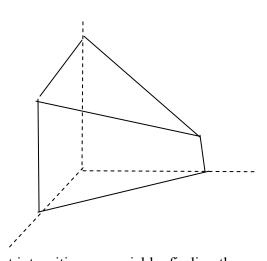
Math is Only a Language

We economists pursue truth, knowledge and understanding mostly with deductive logic, noodling away with formulae or sentences in our offices. While Ohlin relied much on sentences and intuition for his deductive work, today most of us use mathematical symbols and equations to support our claims.   The great benefit of the precise language of mathematics is that the enterprise of sorting valid from invalid deductions is algorithmic, meaning you can write computer code to check the steps, within the limits of Gödel's Theorem. Though the benefits are great, there is a cost as well.   There is something about the hard work needed to express ourselves mathematically that fundamentally changes the psychological properties of the object we are describing. The language is so difficult, by the time we find the words, we cannot help but fall in love with the message, turning a vague idea into what we fantasize is a literal description of reality.
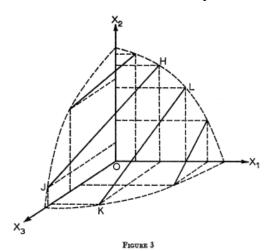
But a model is only a metaphor. Belief in a model is a symptom of someone who is still learning a new language (mathematics). After having first mastered the grammar and the syntax and the vocabulary, most novice speakers do not have the experience that allows them to decode the metaphors, and instead they interpret the words as the literal truth and thus totally miss the message. To illustrate the point, I ask students in my classes what I might mean when I say "Joe's elevator doesn't stop on all floors."   Foreign students, who are new to English, take this statement literally, and think about elevators and floors

of a building. Students with decades of experience with English and with understanding of the context, know that I am saying "Joe isn't playing with a full deck."

Beginning students in Economics make the same mistake – they take the models literally. With more experience, economists learn that a model has both **mathematical properties and messages**, that are not necessarily the same. If you don't understand the difference, you are a mathematician not an economist. A culture that doesn't emphasize or even make reference to the difference inevitably produces mathematicians not economists.

Jumping ahead a bit, the production possibilities surface of a Heckscher-Ohlin model with three goods and two factors of production has a straight line embedded in it, illustrated in the figure at the right. If you are skilled at visualization, you can see that this production possibilities frontier has been created by placing two planes over the positive orthant, one plane representing the labor constraint and the other representing the capital constraint. The straight line floating in the positive orthant is the intersection of these two planes.

If the input intensities are variable, finding the right shape of the production possibilities is hard enough that it won a spot for Melvin(1968) in the *American Economic Review*, his figure 3 (p1254) depicted on the left. You can be sure that in 1968 when this article was accepted Homan(1941) was no longer editor of the AER.

FIGURE 3

Here is the noteworthy property of this 3-good 2-factor model. If the price plane is placed up against a straight line in the positive orthant, all three products may be produced but there is a one-dimensional indeterminacy in the GDP maximization problem, meaning that, given the product prices, one cannot find a unique output mix. Moreover, the slightest change in relative prices can induce this hypothetical economy to jump from one two-product specialization to another. This same oddly discontinuous supply function is a familiar property of the Ricardian model with two goods and one factor. More generally, the dimensionality of this indeterminacy is the number of goods minus the number of factors, 2-1=1 in the Ricardian 2-good model.

Now I ask you, is there a message here, or are these only mathematical properties?   If you don't understand that there is no message here, and that these are only mathematical properties, then you are a mathematician and not an economist. If you want to test this,

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try explaining these properties to your Mom and Dad, and tell them why the properties are important to understanding how real economies function. If you cannot find the words to accomplish this task, then there are no messages. (I know you can tell Mom and Dad what a Heckscher-Ohlin model is all about.) I fully recognize that in a classroom, there is considerable value in exploring these possibilities because *the exercise helps us understand the model better.* But the properties do not help us understand real economies better, and we do a great disservice to our students when we don't make clear what is the difference. Mathematical properties or messages? Mathematical properties or messages? Say it over and over. We need to work hard to understand the difference.

We need to understand that for economists, **math is only a language**. The language we adopt to discuss economics can either help or hinder progress. Oliver Sacks (1989) in *Seeing Voices* explains the highly relevant history of the deaf and dumb. Though "dumb" in everyday language has come to mean "intellectually slow", the original definition was "incapable of oral expression," which of course goes hand in hand with deafness. There was a time when intellectual slowness also went hand-in-hand with deafness, and the deaf were herded into institutions together with the mentally retarded. The language of "Sign" was developed in France and Britain in the 18th Century, and when adopted by the Deaf, it released their intellectual capabilities that had been bottled up for so long. The Deaf community used Sign as a bridge toward written language and in the 19th Century enjoyed a flourishing intellectual life. But the Victorians were upset by people wiggling their hands and fingers, and thought it better if the Deaf were assimilated into "normal" society. At the Second International Congress on Education of the Deaf held in Milan in 1880 the participants (who could hear) passed a sequence of resolutions including these two:

- The Convention, considering the incontestable superiority of speech over signs, for restoring deaf-mutes to social life [and] giving them greater facility of language, declare that the method of articulation should have preference over that of signs in the instruction and education of the deaf and dumb;
- Considering that the simultaneous use of signs and speech has the disadvantage of injuring speech and lip-reading and precision of ideas, the convention declares that the pure oral method ought to be preferred.

Guess what happened. With the language of Sign discouraged, Deaf educators lost their jobs, the Deaf had oral language forced on them, and the intellectual attainments of the community plummeted.

Do you get my point? The problem with Math is that few Economists can hope to speak it fluently. I am afraid that we, like the Victorians, are forcing onto our students a language that few can ever master and as a result we are impairing their intellectual development. We are actively replacing "Deaf" but not-dumb economists on our faculties with those who can speak Math. We risk graduating economists who are experts in the grammar and syntax of Math, who can hardly say anything intelligible in Economics. Employers may be thinking of them as retarded, when they are only deaf.

Worst of all is when our value system gets distorted and we start to admire the grammar and the syntax, not the message. On this point Schotter(1996,p212) recalls the story of the reaction of a prominent macroeconomist to a paper on rational expectations: "The paper was like the movie 2001. While the plot is totally mundane, the special effects are amazing."

Validity or Usefulness: Maps or Mathematical Novelettes?

> "You're Not Making Sense, You are Only Being Logical" Neil Bohr
> Quoted in Schotter(1996)

In formal logic, a deduction is said to be sound if the argument is valid and also the premises are true. The pursuit of soundness could be a devastating blow to the deductive method in economics, since the premises of our models are at best approximations, and in a strictly logical sense none of our deductions is sound because the premises are false. Fortunately, our goal as economists is not soundness but usefulness. Though we know our premises are not exactly true, we hope and often imagine that our premises are approximately true, and there is consequently a domain of usefulness for our deductions that extends well beyond the exact premises we use to make the argument.

The troubling distinction between validity and usefulness is not confined to economics. It afflicts all practical endeavors, even numerical calculation. For example, applied economists are sometimes disturbed to find two different statistical packages using the same data producing different regression results, or the same statistical package operated on two different computers producing different results. Though two algorithms for computing the inverse of a matrix may both be valid, neither is sound because a premise of the algorithms isn't true. It is assumed, but it is not the case, that a computer can carry out a computation to an infinite degree of accuracy. Just like you, an electronic computer actually does "interval" arithmetic, with numbers rounded depending on the computer hardware, as in 7/3=2. With interval arithmetic, the inverse of a matrix depends on the way the algorithm is sequenced, on the number of significant digits carried by the computer and on the way the computer does the rounding. Though not sound, an inversion algorithm may nonetheless be useful if it approximates adequately the inverse of a matrix for a wide enough class of matrices. Identifying the domain of usefulness is no trivial task, but, fortunately, computing power has progressed vastly beyond the Monroe mechanical calculator whose domain of usefulness did not extend even to three-dimensional near-singular moment matrices. Modern computers have made numerical inaccuracy the least of our worries by a very large margin. But that's not my point. The point is that validity and soundness are rarely the goal in the real world. The goal is usefulness.

We would make progress if we could agree that our models are neither true nor false, they are sometimes useful and sometimes misleading. The craft of Economics depends on the subtle skill of judging when a model is useful and when it is not. We don't teach this in graduate schools, but we should. What we do is very much the opposite. We often teach and speak as if our models were true.

A useful analogy might be map-making.[6] A map of the globe is not very useful for travelling around Los Angeles.   A map of the freeway system in Los Angeles isn't very useful for navigating from Los Angeles to Stockholm.

Krugman(1995) likes the map-making analogy. "Of course doing economics, or for that matter just about any kind of intellectual inquiry, is a kind of mapmaking" (p.2) "This means that to do development theory, one must have the courage to be silly, writing down models that are implausible in the details in order to arrive at convincing higher-level insights."

However, the maps that Krugman has created do not come with users' manuals that alert us to their limited domains of applicability. Guessing the circumstances under which the maps might work adequately is left to the users to decide. If we had an intellectual culture that understood we are only making maps, this would be fine, but our emphasis on formal theory and formal econometrics has provided precious few opportunities to build critical skills at applying models in real settings. What we need now is for the Consumer Product Safety Commission to require a warning on all the theory and econometrics we do:

> ***"Contraindicated during the formative years. Side effects include quickening of speech and hearing impairment. Head gear highly recommended to limit the chance of losing one's mind."***

This warning would not be required if there were some explicit consideration of the domain of usefulness of the results. What might be the domain of usefulness of an HO model.   The maps produced by the Heckscher-Ohlin framework seem appropriate for designing trade interventions, migration policy and educational subsidies in response to the economic integration of the United States and Mexico but are probably inappropriate if the countries are the United States and Canada, or Sweden and Western Europe.

In truth, we don't treat our models as maps.   We bestow on the models we create the same love we bestow on our human children. To increase the appeal of our mathematical progeny, we often mislead. We usually make the domain of usefulness seem large with a sleight of words – using affectless language for expressing our assumptions. In the Heckscher-Ohlin framework we assume that "factors of production are mobile across sectors" when what we mean is that we assume that workers operating sewing machines in Los Angeles could equally well solder welds in automobile assembly plants in Detroit, and that sewing machines could equally well serve as factories to make automobiles. When expressed in terms of real world examples, the affectless assumption of factor mobility suddenly becomes fantastical.

Doubt about our deductions that comes from our fantastical assumptions can only be alleviated with a sensitivity analysis that ideally shows that small perturbations in the assumptions do not cause major changes in the deductions. Our goal in economics

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[6] I used it this analogy in Leamer(2004) to comment on the inappropriateness of formal hypothesis testing.

should be "sturdy" deductions, not sound ones.   We should be asking how much factor mobility is needed to make the HO model applicable. We should be restricting HO applications to settings that allow enough factor mobility.

Models should talk back

My colleague here at UCLA, Bruce Carlin, wisely in a seminar complained that a student's model was carefully designed and solved, but it didn't "talk back."   There are many models in economics and many in international economics that are only complex ways of saying the obvious.   They don't talk back. When used to carry out a data analysis these complex models tightly bind the evidence collected from the real world, and create a suffocating straightjacket that prevents the data from talking back too.

Krugman's (1994, p.80) methodological Ohlin lecture recognizes this "…a formal model, which may seem like a ridiculously stylized sketch of reality, will often suggests things that you would never think of otherwise."

Unique among frameworks in Economics, the Heckscher-Ohlin framework talks back. To give an example early in its history, in 1941 Wolfgang Stolper and Paul Samuelson heard the HO model talk back when they stumbled on what is now called the Stolper-Samuelson Theorem:

> "It is the intention of the present paper to show that definitive statements are possible concerning the effects of international trade upon the relative remunerations of productive agencies, and more important, upon their absolute real incomes…. In the beginning we expected to do no more than delineate factors which would indicate likelihood in one direction or another, and only in the course of the investigation did we discover that unambiguous inferences were possible" Wolfgang Stolper and Paul Samuelson(1941, p 334)

Question, theories and data: We need balance

Our drift into mathematics is allowed, I think, because we do not keep the questions clearly in mind. The HO question is NOT: "Can you build a model that supports the proposition that free trade equalizes wages and rental rates of capital?"   The economics question, that Ohlin held steadfastly in the forefront, is "Would barriers to imports of labor-intensive products increase wages of unskilled workers?"

When I teach international economics, I like to write on the board at the beginning of each lecture

Questions Theories Data	Pictures Words Numbers

By this device I try to reinforce over and over two points:

- A successful conversation in Economics begins with a question, employs theoretical frameworks appropriate to the questions and then taps into a variety of data sets that can help select among the frameworks and fill in the gaps in the frameworks that econometricians call "parameters."
- An influential data analysis needs figures that display the data, numbers that summarize the data, and stories that memorialize the findings.

Balance is what we need.

What questions does economics ask?

Our first order of business before building a model is to get clear exactly what we want the model to do. To help decide the goal of our modeling I pose a question: "Why is the discipline of Economics sliced the way it is?" Why do we have macroeconomics, international economics, labor economics, and industrial organization?" The History discipline is divided temporally and geographically. At UCLA, one can study Western Civilization from A.D. 843 to 1715, or Africa, 1945 to Present. In Sociology the undergraduate core courses are Interactions, Institutions and Social Processes, and Power and Inequality. If Economics were sliced in that manner, we might have courses on Markets, Hierarchies, Firms and Families.

Economics is sliced the way it is because, while the other Social Sciences are mostly descriptive, Economics is fundamentally prescriptive – offering policy advice about how governments should intervene in the economic system. We slice our discipline by the policy tools we study. Labor economics deals with the design of interventions in the labor markets – minimum wages, training and education subsidies, professional certifications and so on. Macroeconomics is about the design of intervention in the credit markets – government buying and selling bonds and foreign currencies, and minimum reserve requirements for banks. Industrial organization is about the design of the rules for competition – anti-trust, and patent protection. International economics is about the special interventions that governments undertake at the border – controlling the cross-border flows of people, products and contracts.

To do it right, we need to keep our eyes firmly fixed on the goal. The primary goal should not be to amuse each other with mathematical complexities. It should not be to study how trade in products has evolved and how changing trade patterns are correlated with changing global inequality. The primary goal should be to design policy interventions – policies that are intended to help achieve social objectives most notably the highest level of well-being for the most number of people. What I think should be a secondary goal is understanding for the sake of understanding. While mathematical theory and complex data analyses may be steps to the primary or secondary goals, they are not ends by themselves. As Hal Varian(1996, p. 238) has put it: "..economics is a *policy science* and, as such, the contribution of economic theory to economics should be measured on how well economy theory contributes to the understanding and conduct of economic theory." We forget this at our peril.

Thus to evaluate the Heckscher-Ohlin framework, we must be clear about its policy implications. What advice does the HO framework have for governments desirous of assuring the highest level of well-being for the most number of people? Is this advice so transparent that we don't need the model to suggest it? If not transparent, is the advice compelling or is it fantastical? Are there any data that support the policy recommendations of the HO model?

General equilibrium is potentially important

In addition to the scope of policy interventions, International Micro economics is distinct in its emphasis on "general equilibrium." With some notable exceptions, most of what economists believe comes from the study of markets in isolation.[7] The jargon for this is "partial equilibrium" modeling, which implicitly or explicitly takes as fixed many other elements in the economic system. For example, the usual supply and demand framework takes as given the prices of other products. But a tax on a particular product can unleash a complex response in the rest of the system, making partial equilibrium thinking misleading. That is where general equilibrium International micro economics enters the conversation. It assures that we are thinking more broadly about the consequences of a tariff on the imports of a product than the usual supply and demand model allows. But don't be confused by the word. "General" doesn't mean "everything." Still held fixed are demographics, motivations, institutions, technologies, abilities, infrastructure, and countless other items.

Those who established the intellectual traditions in international economics can stand up with great pride in their discoveries of the startling consequences of general equilibrium thinking. Once exposed to the general equilibrium logic of the Factor Price Equalization and the Stolper-Samuelson Theorem, few economists would carry out a policy exercise using strictly partial equilibrium thinking.

Summary: Bastiat Advice

We can summarize this discussion by channeling the spirit of Frederic Bastiat(1848) who in the parable of the broken window as a fiscal stimulus made the important distinction between the seen and the unseen, and warned about the unintended consequences of government spending. Here is his advice

> "There is only one difference between a bad economist and a good one: The bad economist confines himself to the visible effect; the good economist takes into account both the effect that can be seen and those effects that must be foreseen."

This is anticipating by almost a century Keynesian macro economics that deals exclusively with the seen of government spending or tax cuts and ignores the many unseen effects that operate through the bond market, through the product markets, and through intertemporal budget constraints. For example, the Obama $787 billion stimulus package is lowering the US national savings, making it more difficult to take care of

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[7] One important exception is macroeconomics, which considers the interaction between markets for bonds, products and labor.

future retirees, and by increasing the borrowing from foreign lenders is increasing the pressure on the US dollar, threatening a lender revolt and a forced depreciation that has serious inflationary consequences and that even calls into question the dollar as the global reserve currency.

International micro economists can stand up tall and proud in response to Bastiat's challenge, since the general equilibrium thinking that we do is all about the unseen.

While I loudly applaud Bastiat's sentiment, I would add of some Bastiat advice of my own:

> "A good economist knows the difference between the mathematical properties of a model and its messages; a mathematician doesn't know that a model has messages."

> "A great economist knows the circumstances in which an economic model is useful and the circumstances in which it is not; a mediocre economists thinks a model applies in all circumstances."

> "The best economists are multilingual. They can speak graphs, words, algebra and numbers, and they use the language best suited to the task."

The Math, the Stories and the Messages of the HOS framework

A Simple Demonstration of the Three HOS Theorems

It is very instructive to review the evolution of the language that has been used for discussing the Stolper-Samuelson Theorem, the Factor Price Equalization Theorem and the Rybczynski Theorem, but first let's get a firm handle on what the results are all about in the clearest most direct way that I know. Let's concentrate here on the 2-good 2-factor model and deal with dimensional issues later. The goal here is not to dazzle with mathematics, but to use math as a language when it is the best available, to use graphs when they work better, and to surround the words and graphs with illuminating and memorable words. The goal is to get the messages of the models and to make as clear as possible what is a mathematical property and what is a message.

Factor Price Equalization

Both the FPE and the SS theorems come from the set of zero profit conditions that equate the prices of goods to their costs of production. In the two-good two-factor case with fixed input/output ratios, we can write these zero profit conditions as

$$p_1 = A_{L1}w + A_{K1}r$$
$$p_2 = A_{L2}w + A_{K2}r$$

where p_i is the product price of sector i, i=1,2, w is the wage rate and r the rental rate of capital, and A_{ji} is the input of factor j used to produce one unit of product i. "Usually" this system can be inverted to find positive values of the factor rewards as a linear function of the product prices. Hey, that's the FPE result! We don't need to know the supplies of capital and labor to solve for the factor prices.

FPE: The Factor Price Equalization Theorem. Countries that produce the same mix of products with the same product prices and the same technologies have the same factor prices, regardless of their factor supplies.

A weaker theorem that does not make assume identical technologies is FPI.

FPI: The Factor Price Insensitivity Theorem. With product prices assumed fixed, changes in the country's labor or capital supply have absolutely no effect on wages or the return to capital.

We only need FPI not FPE to establish conditions under which native wages are not affected by immigrants.

We will see below that Ohlin didn't think that FPE was worthy of serious consideration. Here is a summary of what I speculate is his position. Note this is an idea, not a theorem.

Ohlin-FPC: The Ohlin Factor Price Convergence Idea: International trade favors the abundant factors by increasing their market opportunities, and works to the disadvantage of the scarce factors, by increasing their competitors. The gains from trade are usually great enough that even the scarce factor benefits.

The Rybczynski Mechanism

Under the assumptions of FPI, it can be said that wages are set by external competitiveness conditions. The external margin completely determines wages. The internal margin doesn't matter at all. Or to put it most provocatively: In an open economy with product prices set in global markets, the derived demand for labor is infinitely elastic.

When I described the result in this way at a paper presented at the AEA meetings many years ago, my discussant, a devout partial equilibrium thinker, excoriated me for saying something known by every decent economist to be completely false. To make this point he used so much time I had no opportunity to reply. Here is my reply: It's silly to take any theory literally. A theory has mathematical properties and it has messages. You have focused on the mathematical property and have completely missed the message.

But what is the message? If we stopped with the mathematical proof of FPE, we would have done the math but not the economics; we would have established a valid but not necessarily a useful result since the why of FPE would remain a complete mystery. Why on earth would the demand for labor be infinitely elastic??? What are the real circumstances in which this makes any sense?

The why of FPE is answered by the Rybcynski Theorem:

The Rybczynski Theorem: An increase in the supply of labor causes a more than proportionate increase in output of the labor-intensive good and a reduction in the output of the capital-intensive good.

Like the other two theorems, this one is quite inconsistent with partial equilibrium thinking which would surely lead economists to think that a larger country, with more labor, would produce more of both goods absent price changes. Actually, this is the case for the Ricardo-Viner general equilibrium model with sector-specific capital. With mobile capital, it is this amplification result that underlies the Factor Price Insensitivity Result. In response to an increase in the supply of labor, the economy moves just enough capital into the labor intensive sector to keep labor fully employed at the same wage rate.

That's the mechanism. That's the message. A small open economy with fixed product prices can absorb increases in labor by a shift in output in favor of the labor-intensive product. A closed economy that moves in the same direction would experience a decline in the price of the labor-intensive good, setting off the Stolper-Samuelson effect – lower real wages.

The Rybczynski Theorem comes from the labor market equilibrium conditions that equate the fixed supplies of factors to their usage in producing the outputs.

$$L = A_{L1}q_1 + A_{L2}q_2$$
$$K = A_{K1}q_1 + A_{K2}q_2$$

where K and L are the supplies of capital and labor, and q_i is output of sector i. What this simple system of equations implies is that the increase in the labor force is absorbed in a most remarkable way, by actually reducing the output of the capital intensive sector. This could be demonstrated algebraically, but for classrooms where I want to leave the greatest and longest lasting imprint on the student's brains, I prefer a graph.

First the algebra, which is pretty good. Algebraically, the Rybczynksi Theorem is a simple property of weighted averages. The overall labor to capital ratio is a capital-weighted average of the fixed labor/capital ratio in the two sectors
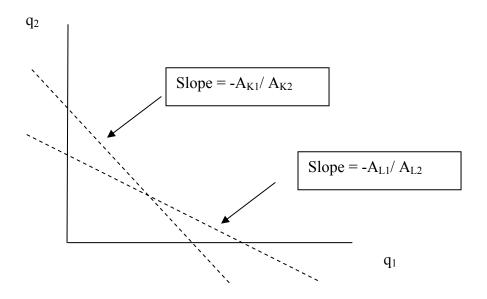
$$\frac{L}{K} = \frac{L_1 + L_2}{K_1 + K_2} = \frac{K_1(L_1/K_1) + K_2(L_2/K_2)}{K_1 + K_2}$$

The only way this weighted average can increase to keep up with an increase in L/K is by putting more weight on the labor-intensive sector and less on the capital-intensive sector, thus a shift of capital toward the labor-intensive sector and *less* output of the capital-intensive sector. This shift in capital causes an amplification effect with the proportional increase in the output of the labor intensive sector exceeding the proportional increase in

the labor force. The reason for this amplification effect is that the labor-intensive sector receives all the increment in the labor force and then some, as capital moves from the capital-intensive sector to the labor-intensive sector. The implied proportional increase in the labor force in the labor intensive sector is greater than the proportional increase in the labor force overall, because the latter has a larger denominator.

Though the algebra is pretty good, it is not so memorable as the graph, Figure 1, with outputs on the axes. The labor and capital market equilibrium lines drawn in Figure 1, have the slope of the labor constraint equal to $-A_{L1}/A_{L2}$ and the (steeper) slope of the capital constraint equal to $-A_{K1}/A_{K2}$.   The condition $A_{K1}/A_{K2} > A_{L1}/A_{L2}$ can be rewritten to create an order of the capital intensities $A_{K1}/A_{L1} > A_{K2}/A_{L2}$ in other words, as drawn, sector one is the capital intensive sector.

Figure 1   **Production Possibilities With Fixed Input Technologies**
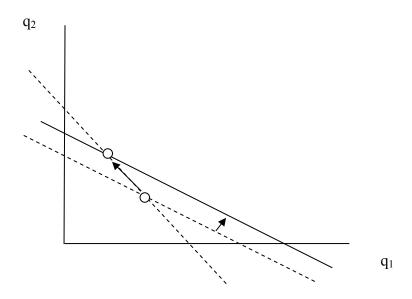

Next in Figure 2 we can relax the labor market constraint by shifting it away from the origin, and notice what happens. The intersection of these two lines, which selects the only point of full employment of both factors, shifts along the capital constraint, selecting more of the labor intensive good *but less* of the capital intensive good. That's the mechanism of FPE. That's the economics showing up. An increase in the labor force under other circumstances would lead to an increase in *both* outputs, but for this model there is a superstrong shift in favor of the sector that uses labor intensively and absolutely away from the capital intensive sector.   The economics message here is that the country-wide derived demand for labor, with product prices fixed, is going to have a special kick to its elasticity because of the opportunity to shift capital as well as labor toward the labor-intensive sector.   That's a special insight that international economists have brought to the debate about trade and wages, one that labor economists have a hard time absorbing, maybe because we are explaining it mathematically by simply repeating the FPE theorem without explaining the mechanism. Maybe we should be saying that, given enough time to shift capital between sectors, a tradables sector with a diverse mix of

labor intensities is capable of absorbing much of an increase in the labor supply by shifting toward those sectors that are labor-intensive.

A way of expressing this would be a two-equation system, one equation that describes the output mix as a function of the factor supplies and a second that explains factor prices as a function of the factor supplies. The message of the FPE theorem is that the sensitivity of factor prices to factor supply changes is less the more sensitive is the output mix to factor supply changes. Now that's an idea that is worth looking at empirically, even though FPE does not.

Figure 2   Effect of Relaxing the Labor Constraint

The Stolper-Samuelson Theorem

Next we do the Stolper-Samuelson theorem that describes the derivative of factor returns with respect to product prices. The Stolper-Samuelson theorem identifies winners and losers from protectionism and the three-factor model has been used by Rogowski(1987) to study the formation of political coalitions. Here is the 2-factor version:

The Stolper-Samuelson Theorem: An increase in the price of the labor-intensive good cause real wages to rise and the real rental rate of capital to fall, regardless of the numeraire

The Stolper-Samuelson Theorem can also be demonstrated algebraically by studying the details of the inverse of the system of zero profit conditions:

$$\begin{bmatrix} p_1 \\ p_2 \end{bmatrix} = \begin{bmatrix} A_{K1} & A_{L1} \\ A_{K2} & A_{L2} \end{bmatrix} \begin{bmatrix} w_K \\ w_L \end{bmatrix}$$

If the matrix of input intensities is invertible, we can solve for the factor returns as a function of the product prices:

$$\begin{bmatrix} w_K \\ w_L \end{bmatrix} = \begin{bmatrix} A_{K1} & A_{L1} \\ A_{K2} & A_{L2} \end{bmatrix}^{-1} \begin{bmatrix} p_1 \\ p_2 \end{bmatrix} = \left(A_{L1} A_{L2} \left(\frac{A_{K1}}{A_{L1}} - \frac{A_{K2}}{A_{L2}} \right) \right)^{-1} \begin{bmatrix} A_{L2} & -A_{L1} \\ -A_{K2} & A_{K1} \end{bmatrix} \begin{bmatrix} p_1 \\ p_2 \end{bmatrix}$$

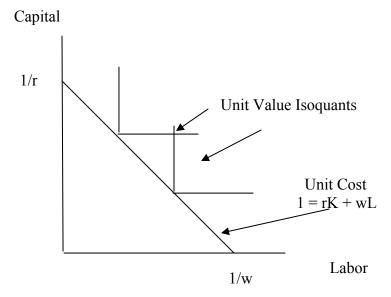From this we can extract the derivative with respect to p_1 and the percent change

$$d \begin{bmatrix} w_K \\ w_L \end{bmatrix} / dp_1 = \left(A_{L1} A_{L2} \left(\frac{A_{K1}}{A_{L1}} - \frac{A_{K2}}{A_{L2}} \right) \right)^{-1} \begin{bmatrix} A_{L2} \\ -A_{K2} \end{bmatrix}$$

$$\begin{bmatrix} dw_K / w_K \\ dw_L / w_L \end{bmatrix} / (dp_1 / p_1) = \begin{bmatrix} A_{L2} p_1 / (A_{L2} p_1 - A_{L1} p_2) \\ -A_{K2} p_1 / (-A_{K2} p_1 + A_{K1} p_2) \end{bmatrix} = \begin{bmatrix} 1/(1 - (A_{L1} p_2 / A_{L2} p_1)) \\ 1/(1 - A_{K1} p_2 / A_{K2} p_1) \end{bmatrix}$$

From these two expressions we can read the Stolper-Samuleson theorem; If sector one is capital intensive, an increase in the price of the capital-intensive good causes a more-than proportional increase in the rental rate of capital and a reduction in the wage rate of labor.
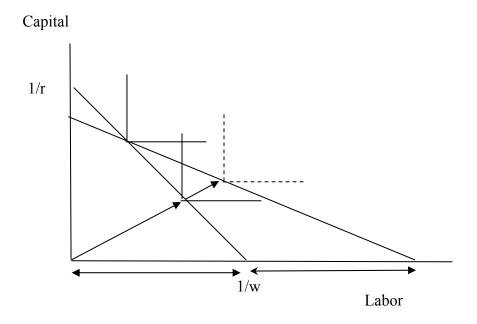
But to get inside a student's head, I much prefer the Lerner-Pearce diagram illustrated in Figure 3. Here we have two unit-value isoquants – combinations of capital and labor needed to produce a unit value of the good. We also have the unit cost line – combinations of capital and labor that cost one unit of value. The fact that we have a "kissing" equilibrium with the two unit value isoquants just kissing the unit cost line is what we need to assure efficiency and zero profits. Confirm that there is only one line that can be kissed by both isoquants at the same time and thus only one unit cost line consistent with the production of both goods. From this unique unit cost line, we can read the value 1/w from the labor vertex and 1/r from the capital vertex. There we have FPE again!

Figure 3   Lerner-Pearce Diagram

Capital

Next we need to explore the effect of a fall in price of the labor intensive good, illustrated in Figure 4 with a shift outward of the labor-intensive unit-value isoquant reflecting the fact that at a lower price it takes more capital and labor to produce a unit value. The effect of this product price change on factor prices is found by drawing a new unit-value isoquant and seeing how the intersections with the axes change. The intersection on the vertex axis is closer to the origin, signifying a fall in $1/r$ and a rise in r the nominal return. Thus the real return to capital increases regardless of which good is the numeraire, partly because of a higher r and partly from the fall in the price of labor-intensive good. It is clear that the wage rate falls, and therefore the real wage rate declines using the capital-intensive good as the numeraire because it has a fixed price. It's not so simple if the labor-intensive good in the numeraire because its price has fallen as the wage has fallen. It's a question which wins the race. Can you see that the way the unit cost line is pivoting around the capital-intensive isoquant the wage rate moves more than the labor-intensive price? The diagram is set up so that the wage rate falls by a factor of two, $1/w$ doubles, but the percentage change in price found by comparing the length of the second arrow with the first, is much less than 100%. Can you see this? That's the amplification result.

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Figure 4   Stolper-Samuelson Effect of a Fall in the Price of the Labor Intensive good
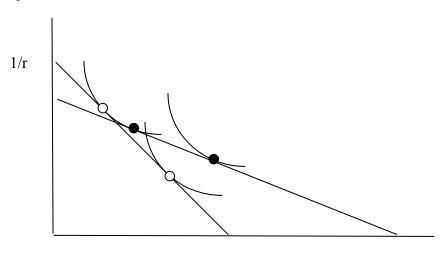
Capital

1/r

1/w

Labor

Most authors explain SS with a story about labor-deepening as a consequence of a fall in the price of the labor intensive good, labor-deepening that must cause a decline in the marginal product of labor in both sectors and a fall in the real wage rate regardless of the numeraire.   You can see this in Figure 5 which allows variable input intensities. The response to the fall in the price in the labor intensive good is a higher labor/capital ratio in both sectors. But the point of first doing the fixed intensity case is to make clear that the *intra*-industry labor-deepening is a second order effect. The first order effect is the *inter*-industry effect illustrated with fixed input intensities in Figure 4.   Deardorff(1994, p20) is very much in the mainstream when he offers a proof of SS that requires variable input intensities but he is not in the mainstream when he apologizes in a footnote "Actually, this shift in resources is not crucial to the theorem, though it does aid the intuition." But that is intuition only about the second order effect, which leaves the first order effect a complete mystery. The "intuition" that comes from the labor-deepening idea helps the math, but leaves the economics dangling. Why is it that wages change when the capital intensities do not change at all?? Raising this rhetorically from an apology to a criticism, Flam and Flanders(2002p.182-183) complain that most of Ohlin's thinking applies to a fixed-coefficient model: "Ohlin's neglect of factor substitution in the framework of factor price equalization is puzzling, since he was aware of it and its consequences for the factor and goods markets. (and explicitly refers to it on page 112 of The Theory of Trade)." On the contrary, I say, Ohlin deserves to be celebrated not criticized, and Deardorff is correct to apologize, since it is completely misleading to suggest that the Stolper-Samuelson Theorem or anything else of interest in the HO framework depends on variable input intensities.   The assumption of variable input intensities makes the graphs better, though the math harder, but it distorts the message. *The HO framework derives it meaning completely from the movement or mobility of the*

factors between sectors. The framework offers a Bastiat warning – what must be foreseen when making trade policy are the consequences of the movement and/or mobility of the factors of production between sectors.
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Figure 5   Stolper-Samuelson Effect : Variable Input Intensities

Capital

Labor

Three HO Stories

As has been discussed above, many authors do not do a very good job explaining the economics behind these three theorems in simple stories. Here is my attempt. This is relying on the idea that an economy behaves like a computer algorithm seeking the new solution to the factor market equilibrium conditions and zero profit conditions when the supply of labor increases or product prices change. Here is how it might operate.

The Story of the Rybczynksi Theorem

Both the Rybczynski Theorem and the Factor Price Equalization Theorem deal with the consequences of changes in the supply of factors which I will take for purposes of exposition to be an increase in the labor force.   The Rybczynski Theorem deals with consequent changes in outputs (away from the capital-intensive sector) and the Factor Price Equalization Theorem deals with consequent changes in factor rewards (none). Here is the story of the effect of a migrant inflow on outputs.   Keep in mind that we are holding fixed the ratios of inputs to outputs, and can determine changes in outputs directly from changes in inputs.

New workers seeking jobs offer to do the work for less.   That creates profit opportunities in both sectors, but to realize that profit both sectors seek to expand and try to acquire more capital to do so. But capital is fixed and one sector must lose and the other gain.

The labor intensive sector is able to outbid the capital intensive sector because on a per unit of capital basis, the savings from the reduced wage rate are greater in the labor-intensive sector. There is accordingly a transfer of capital from the capital-intensive sector to the labor-intensive sector.

That's pretty much the end of the SS story. The capital intensive sector loses capital and therefore contracts. The labor-intensive sector gets all the new workers plus some from the capital-intensive sector as well. Even without the workers from the capital-intensive sector, the proportional increase in the workforce in the labor-intensive sector is greater than the overall proportional increase in labor because, since the capital-intensive sector employs some of the workers, the labor-intensive sector has a smaller base against which to compare the increase in workers. Thus the labor-intensive sector expands by a percentage amount that exceeds the percentage increase in the labor force.

The key idea here is that with the expansion of the labor force and an incipient/temporary reduction in wages, the labor-intensive sector can outcompete the capital intensive sector for the existing capital, which means less capital for the capital intensive sector, and consequently the labor intensive sector gets all the new workers and then some. This has nothing to do with labor-deepening in either sector.

The Story of The Factor Price Insensitivity Theorem

What about FPI? What happens to wages if the labor force increases? I have to warn you that this story is a not very disguised version of the math. As explained in the paragraphs above, the expansion of the labor-intensive sector in response to an increase in the labor-force and a temporary reduction in the wage rate is accomplished by bidding capital away from the capital-intensive sector, which can only be done with offers of higher returns to capital. This initial change in factor prices is what we might expect to be the response to an increase in the labor force: lower wage rates and a higher return to capital. But this initial response cannot last long since it will create different profit opportunities in the two sectors. The percentage change in costs in sector i is $\theta_{Li}(dw/w) + \theta_{Ki}(dr/r)$ where θ is an earnings share, and, per the narrative so far, dw/w<0 while dr/r>0. Let's assume that the initial "trial" factor prices are chosen to prevent changes in costs in the labor intensive sector, sector one, thus: $\theta_{L1}(dw/w) = -\theta_{K1}(dr/r)$. Whatever are these initial proposed changes in factor rewards, they create problems in sector two which has an increase in costs since it is more dependent on capital than on labor:

$$\theta_{L2}(dw/w) + \theta_{K2}(dr/r) = -\theta_{L2}\theta_{K1}(dr/r)/\theta_{L1} + \theta_{K2}(dr/r)$$

$$= \theta_{L2}\left(\frac{\theta_{K2}}{\theta_{L2}} - \frac{\theta_{K1}}{\theta_{L1}}\right)(dr/r)$$

Back to the story, the initial lower *w* and higher *r* have created profit opportunities in the labor-intensive sector and negative profits in the capital intensive sector, and capital and labor are being drained from the capital-intensive sector. Once all the new workers have found jobs in the labor-intensive sector, the further expansion of the labor-intensive

sector faces a problem – what is released from the capital-intensive sector has more capital relative to labor than can be employed in the labor-intensive sector. With capital redundant the labor-intensive sector cuts back on it's offers to capital, enough to allow the sector to break even, given the advantage it has gained from lower wages. But this still leaves the capital-intensive sector making negative profits, and unusable capital floods into the labor intensive sector. It is only when the rental rate and the wage rate return to what they were that the unwanted movement of factors between the sectors ceases.

The Story of the Stolper-Samuelson Theorem

The first response to a 10% price reduction of the labor-intensive good might be a 10% across-the-board reduction in both the wage rate and the rental rate of capital in the labor-intensive sector, just enough to keep the sector breaking even. These factor price reductions create profit opportunities in the capital-intensive sector, which attempts to expand by hiring labor and capital away from the labor-intensive sector, in the proportion appropriate to its capital-intensive technology. Faced with this new competition for it's inputs, the labor-intensive sector renegotiates the contracts. The relatively large amount of losses of its capital to the capital-intensive sector causes idleness of some of the labor that remains in the labor-intensive sector. In an attempt to maintain it's capital and prevent the idleness of workers, the labor-intensive sector renegotiates its contracts putting all the burden on labor: now 0% reduction for capital but 15% reduction in labor wage rate, just enough to allow the sector to break even. So what, responds the capital-intensive sector, that reduced wage rate still creates a profit opportunity, and it responds as before by trying to expand, leaving the labor-intensive sector in the same place with idle workers. In response, the labor-intensive sector renegotiates once more, this time with a 5% *increase* in the offer to capital and a 20% reduction in the offer to labor. This is just enough to allow the labor-intensive sector to break even, and just enough to prevent to the capital-intensive sector from experiencing any profit opportunities. Thus the SS result – the fall in the price of the labor intensive good causes an absolute and real increase in the compensation of capital and an absolute and real reduction in the compensation of labor, regardless of the numeraire.

While the Rybczysnki theorem is about the actual movement of capital between sectors with different capital intensities, the Stolper-Samuelson Theorem is about the threat of movement of capital that would leave part of the labor force idle.

Mathematical reasoning and the Heckscher-Ohlin Framework

Armed now with some understanding of the what and the why of the three basic theorems of the 2 by 2 HO framework, we can take a look at how the literature on the HO model has evolved.   There has been a huge increase in mathematic rigor, and an increase in mathematical rigor mortis.   That's my way of saying I cringe when I hear it asserted that Samuelson offered a "rigorous" proof of the Stolper-Samuelson Theorem.   First because he didn't, but most importantly because that is not the goal.

Like most economists of his day, Ohlin could be read by many (well educated) Moms and Dads. Ohlin's literary deductions had a ring of truth to them, but the establishment of their logical validity depended very much on the mathematics introduced into Economics by Paul Samuelson in the 1940s. Samuelson's use of mathematical language seems like a great leap forward, but the validity of a deduction is only a small step in the Economics search for understanding, and the mathematics is leading us astray if it seduces us into thinking that validity is an end in itself, as it is in mathematics. To put it provocatively, Olin was suggesting something useful, not necessarily valid; Samuelson was offering something valid, not necessarily useful. Which do you prefer?

The editors of the American Economic Review in 1941 had a preference. Managing editor Homan(1941) in rejecting the manuscript writes on behalf of himself and editor Professor Ellis, "We both agree that the article is a brilliant theoretical performance, and since we wish to have from time to time good and substantial theoretical articles in the Review, we very much dislike to reject it. On the other hand, we agree that it is a very narrow study in formal theory, which adds practically nothing to the literature of the subject with which it is nominally concerned." Ouch.

Krugman(1994,p277) has a different preference: "In other words, Stolper-Samuelson showed that it was not enough to be a reasonable, well-spoken, thoughtful person to be a competent economist; unless you understood how to make and use formal general equilibrium models, you were going to be in danger of being purely and simply wrong about very basic issues." Ouch again. Or did Krugman mean "in danger of being purely and simply wrong about the properties of toy mathematical models that bare some unstated relationship to the ideas at risk."

In his masterful and well-worth-reading Ohlin lectures. Krugman(p.5) offers an even stronger version of "I model, therefore I think":

> "So what is it that makes some ideas acceptable, while others are not? The answer – which is obvious to anyone immersed in economic research yet mysterious to outsiders – is that to be taken seriously an idea has to be something you can model. A properly modeled idea is, in modern economics, the moral equivalent of a properly surveyed region for eighteenth-century mapmakers." Krugman(1995) p. 5

I am startled by this simile that makes the facts collected painstakingly by a surveyor before the map is drawn "morally equivalent" to a theoretical model scribbled on a chalk board in an economist's office, a model that may make the smallest possible reference to the facts. I am at a loss to understand what Krugman means by either "morally" or "equivalent." Where is the role in Krugman's world for the economist who "surveys the landscape" and organizes the facts? And I am reminded of a quotation that I carry in my briefcase:
"Fondly we think we honor merit then,
When we but praise ourselves in other men."
 -- Alexander Pope

But Krugman is surely the best economics writer of his generation, sprinkling insightful words with simple and memorable algebra. He is clearly not a mathematician and does not feel the need to impress with unnecessary jargon. He is a superb writer, finding the simplest and clearest way to make his points, whether he is using Algebra or Economics. His students are not being forced to learn a language they cannot master. He can be read by the Moms and Dads of today. His problem is that he is such a superb expositor that we and he have come to believe what he says. That's my way of expressing annoyance over his position in the trade and wages debate. (Leamer(1994))

Samuelson not surprisingly also preferred his way of thinking, and in the end won out over Homan and Ellis. Writing a few years later, he begins on page 163 of Samuelson(1948) with a nod to Heckscher and Ohlin:

> An important addition to this classical doctrine of factor-price equalisation has been supplied by Professor Bertil Ohlin. In his weighty *Interregional and International Trade* (1933), Ohlin has developed the highly interesting result that (1) *free mobility of commodities in international trade can serve as a partial substitute for factor mobility* and (2) *will lead to a partial equalisation of relative (and absolute) factor prices*. This important result, which we may call the Ohlin–Heckscher theorem, since Ohlin attributes it to a 1919 Swedish article by Professor E. F. Heckscher, has some foreshadowings in the literature of the last century [1]; but not until the highly original work of Ohlin was it made a central part of the theory of international trade.

But four pages later on page 167 of the same paper, Samuelson(1948) reveals his true feelings:

V. Proofs in Ohlin

When we turn to Ohlin's book, matters are even less satisfactory. Ellsworth at least meets the question head-on, while Ohlin—like a murderer who returns again and again to the scene of his crime—repeatedly comes back to the point only to leave it elusively hanging in air. There is almost something Freudian in the vehemence with which he asserts the proposition to be true and with which he employs the phrases " clearly," " of course," "obviously," "as a matter of fact," and similar phrases —as if subconsciously he is really a little uneasy about the proposition's validity.

At one point he even goes so far as to say, " It is not worthwhile to analyse in detail why full equalisation does not occur; for, when the costs of transport and other impediments to trade have been introduced into the reasoning, such an equalisation is in any case obviously impossible " (pp. 38–39).

This is hardly cricket. The question is not whether imperfect mobility of goods leads to perfect factor-price equalisation, but whether perfect goods mobility does so.

Actually, in more than half a dozen places, primarily in Chapter II, Ohlin definitely asserts the impossibility or improbability of complete factor-price equalisation, usually as if the proposition were so obvious as to require little explanation.

A sentence like the following from (Ohlin,p.38) quoted by Samuelson(1948) must surely have been driving the young mathematician completely over the edge.

Such a result is, however, almost unthinkable and certainly highly improbable.

No mathematician would ever say that a theorem is almost unthinkable and certainly highly improbable. The mere statement of the theorem makes it thinkable and whatever the theorem says, it is either true, false, or not yet decided. But could an economist convey his disinterest in the factor price equalization idea by saying with literary flourish that complete factor price equalization is almost unthinkable and certainly highly improbable?

Samuelson, perhaps more than any other economist, was responsible for the introduction of mathematics into economics, first as a language and later a value system. In his forward to Flam and Flanders(1991) Samuelson remarks on how easy it was for his training in mathematics and physics to win him acclaim in economics[8]

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[8] Quoted in Findlay(1995, p7)

Already in 1924 Ohlin has melded Heckscher and Walras. But neither then, nor in 1933 and 1967, did Ohlin descend from full generality to strong and manageable cases – such as two factors and production and two or more goods. What a pity. Not only did Ohlin leave to my generation these easy pickings, but in addition he would for the first time have really understood his own system had he played with graphical versions.

The Evolution of the Language

While Samuelson's generation may have had the easy pickings, success breeds excess and each successive generation has raised the linguistic entry barriers. We can experience the powerful effect that Samuelson has had on our language by tracing how much even Samuelson's language has changed, beginning with Stolper and Samuelson(1941) . Below is part of Stolper and Samuelson's(1941, p 65-66) "proof" not of the Factor Price Equalization Theorem but the closely related Stolper-Samuelson Theorem that asserts that a reduction in the price of the labor-intensive good (watches) causes a reduction in real wages regardless of the numeraire. Read the proof carefully, compare it to my SS story and tell me what you think.

(1) The introduction of trade will shift production in the direction of the good with "comparative advantage." According to the Ohlin analysis—even though he would not employ the previous term—this will be wheat which uses much of the abundant factor. Its production will expand, and part of it will be exported, while watch production will contract, and part of the watch consumption will be satisfied by imports. This shift in production will be accompanied by a transfer of *both* labour and capital from the watch industry to the wheat industry. But by a reduction in the production of watches more labour will be set free than can be re-employed at the same rates in the production of wheat. This is because the amount of capital released, while sufficient to employ a worker in watch production, is insufficient to employ him in wheat growing at the old wage rate. Hence wage rates have to go down in wheat growing, and it follows from the changed factor proportions that the real wage must also decline.

As a proof of the proposition, this is both incomplete and off target. Most importantly, these sentences reveal the critical misunderstanding that recurs often in the writings of international economists, an error that is at the heart of the disagreement between labor economists and international economists regarding the impact of trade on wages. The error comes from the emphasis on the *intra*-industry adjustments in factor intensities while the force of the FPE and the SS and the HO framework is fundamentally due to *inter*-industry adjustments. Best to understand that there is nothing in the HO framework that requires variable input intensities! To assure that I do not make this mistake, I will mostly assume that input intensities are technologically fixed.

For the moment, let's allow variable capital/labor ratios, and let's try to confirm the suggestion of Stolper and Samuelson that labor deepening in both sectors is a direct consequence of the need to employ all labor and capital, following a fall in the price of

the labor-intensive good, as suggested by the foregoing quotation. With K referring to capital and L to labor, it must be the case that the overall capital-labor ratio is a labor-weighted average of the capital/labor ratios in the two sectors:

$$\frac{K}{L} = \frac{K_1 + K_2}{L_1 + L_2} = \frac{L_1(K_1/L_1) + L_2(K_2/L_2)}{L_1 + L_2} = \frac{L_1 k_1 + L_2 k_2}{L_1 + L_2}$$

where $k_i = K_i/L_i$.   The hypothetical to which Stolper and Samuelson refer requires a shift in the output mix away from the labor-intensive sector(watches) in favor of the capital-intensive sector(wheat). They suggest that the excess labor released from watch-making must be absorbed in the wheat sector with more labor-intensive techniques, which consequently implies lower labor productivity and lower real wages.   We can almost confirm this by differentiating the expression above. With capital fixed, there can be no change in the numerator. This implies [9]

$$L_1 dk_1 + L_2 dk_2 = (k_2 - k_1) dL_1$$

With sector one being the capital-intensive wheat sector receiving labor, the right hand side of this expression is negative by assumption. For the left-hand side to be negative, at least one of the sectors must experience a decline in capital intensity, and lower real wages. Could it be that one goes up and the other down? What is missing from Stolper and Samuelson's literary argument is a clear statement of how labor-market arbitrage forces the capital-intensities to move in the same way in both sectors. But that is a small point. The big one is that another way to satisfy the equality above is with $dL_1=0$ and with $dk_1=dk_2=0$. That is the fixed proportions case.   The Stolper-Samuelson Theorem applies also in the case in which input intensities are fixed, and the economics of the theorem is not fundamentally about changes in productivities that come from changes in input intensities within industries.

Worst of all, the proof is off-target in referring to factor-market equilibrium conditions when the Stolper-Samuelson result is really about zero profit conditions, as discussed above.
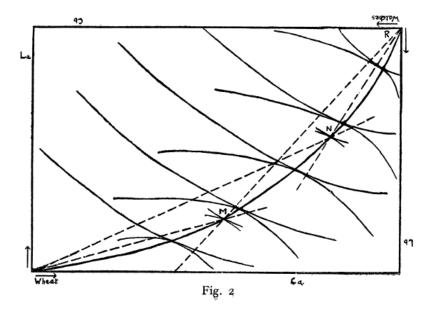
Though Stolper and Samuelson didn't seem to get the words-only demonstration right, they also use the Edgeworth-Bowley diagram below (p67), which they introduce with faint praise as an "illustration" (p66).   This diagram could be used to support the idea that the capital-intensities in the two sectors must move together, and thus to make the argument whole.
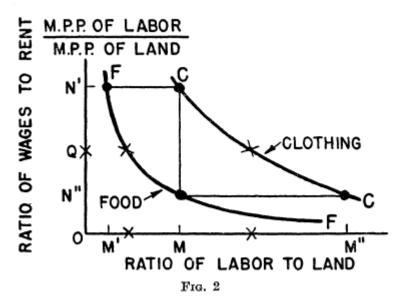
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[9] $0 = d(L_1 k_1 + L_2 k_2) = L_1 dk_1 + L_2 dk_2 + k_1 dL_1 - k_2 dL_1$
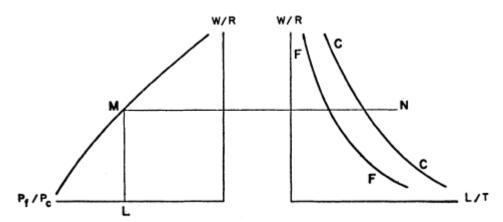
DIAGRAMMATICAL TREATMENT
It may be useful to illustrate the above arguments graphically.

Fig. 2

Perhaps because the words didn't work so well in Stolper and Samuelson(1941), Samuleson(1948) switched to the graph below to make his first try at the Factor Price Equalization Theorem. Here we can see clearly that what was missing from the Stolper-Samuelson words – the fact that the capital-intensities in the two sectors must move together if they have the same factor prices. But frankly, this diagram is not up to the task of demonstrating the FPE.; the diagram allows countries with different factor supplies to have the same factor prices, but it doesn't compel it. So in 1948, the result is still not satisfactorily established.

FIG. 2

In his "Once Again" paper, Samuelson (1949, p. 188) adds the missing piece of information with another diagram placed on the left, that connects the relative price of goods with the relative price of factors. Here on the left we see the FPE – corresponding to any goods price ratio is a unique factor price ratio.

To confirm that there is such a relationship, Samuelson(1949 pp. 181-197) turns to mathematics, counting equations and unknowns:

> Now these are two equations in the three variables $\frac{L_f}{T_f}$, $\frac{L_c}{T_c}$, and $\frac{P_f}{P_c}$. If we take the latter price ratio as given to us by international-demand conditions, we are left with *two* equations to determine the *two* unknown factor proportions. This is a solvent situation, and we should normally expect the result to be determinate.

Samuelson of course knew that counting equations assures neither the existence nor the uniqueness of a solution. Faced with this annoying difficulty, he (1949,p191) explains that multiple equilibria are almost unthinkable and certainly highly improbable:

> But a purist might still have doubts: "How do you know that these two equations or schedules might not twist around and intersect in multiple equilibria?" Fortunately, the answer is simple and definite. On our hypothesis, any equilibrium configuration turns out to be absolutely unique. We may leave to a technical footnote the detailed mathematical proof of this fact.[2]
>
> [2] The Implicit Function Theorem tells us that two suitably continuous

Actually, Samuelson did not get the mathematical proof of the factor-price equalization theorem correct, since he did not deal adequately with the possibility of "factor-intensity

reversals." Gale and Nikaido(1965) set the record straight, mathematically speaking, but offered little advice about the economics meaning of the math.

On his third try, Samuelson(1953,p.3) clearly refers to the efficiency and zero profit conditions that are the foundation of both the Stolper-Samuelson Theorem and the Factor-Price Equalization Theorem. Notice how the notation now seems more formidable.

> 5. If competition is perfect, and if factors are perfectly mobile between industries within a region, then equilibrium requires that the *value marginal productivity* of a factor (which is the good's price times $\partial X_i / \partial V_{ij}$) must be equal in every line where it is actually used, this common value being its market wage. Denoting commodity prices by $p_1, \ldots, p_n$ and factor prices by $w_1, \ldots, w_r$, we have as our conditions of equilibrium :
>
> $$w_j \geqq p_i \partial X^i (a_{i1}, \ldots, a_{ir}) / \partial V_{ij} \quad (i = 1, 2, \ldots, n) \text{ and } (j = 1, 2, \ldots, r) \quad \ldots \ldots (2)$$
> $$p_i \leqq a_{i1} w_1 + a_{i2} w_2 + \ldots + a_{ir} w_r \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2)'$$

Here for your amusement is some "prose" taken from the appendix to Samuelson(1953).

> Theorem : If $(p_{n+1}, \ldots, p_{n+r})$ are all given, then subject to the relations,
>
> $$p_i = \sum_1^{n+r} a_{ij} p_j \qquad\qquad (i = 1, 2, \ldots, n)$$
>
> $$x^i (a_{i_1}, \ldots, a_{in}, \ldots, a_{i, n+r}) = 1.$$
>
> there exists one or more sets of best a's that will give a minimum cost $p_k = A^k$ of any one specified k good ; this minimum cost can be written as a continuous function $A^k (p_{n+1}, \ldots, p_{n+r})$, homogeneous of the first order and subject to the " generalised law of diminishing returns." Furthermore, a set of all the a's that minimises unit costs of one good will also minimise the cost of *each* other good. Where unique partial derivatives happen to be defined, Wong-Viner considerations require :
>
> $$\left[\partial A^i / \partial p_{n+j} \right] = \begin{bmatrix} 1-a_{11} & -a_{12} \cdots & -a_{1n} \\ -a_{21} & 1-a_{22} \cdots & -a_{2n} \\ \cdot & \cdot & \cdot \\ -a_{n1} & -a_{n2} \cdots & 1-a_{nn} \end{bmatrix}^{-1} \begin{bmatrix} a_{1, n+1} \cdots a_{1, n+r} \\ \cdot \\ \cdot \\ a_{n, n+1} \cdots a_{n, n+r} \end{bmatrix} \quad \ldots (5.1)$$
>
> which will be the product of two non-negative matrices, and its rank can never exceed r.

The final stop down memory lane is Chipman(1969) This is now pure mathematics without a hint of economics.

(1) *The univalence problem.* g is locally univalent (one-to-one) in a neighborhood $N(w^0)$ of w^0 if $g(w) = g(w')$ implies $w = w'$ for all $w, w' \in N(w^0)$. It is well known that a sufficient condition for this is that the Jacobian determinant be nonvanishing at this point, i.e., $|g'(w^0)| \neq 0$.[2] However, even if $|g'(w)| \neq 0$ for all w, g need not be globally univalent. Even Samuelson's stronger condition [11, (16)] that the successive principal minors of $g'(w)$ be nonvanishing was shown by Nikaidô [10] to be insufficient. McKenzie [9] has shown that the condition $|g'(w)| \neq 0$ is not sufficient, even when the properties of concavity and homogeneity of g are taken into account. Gale [4] has shown, however, that a sufficient condition for the global univalence of g is that $g'(w)$ have all its principal minors positive; Nikaidô [10] has strengthened this to allow for the principal subminors (other than $|g'(w)|$ itself) to be non-negative.
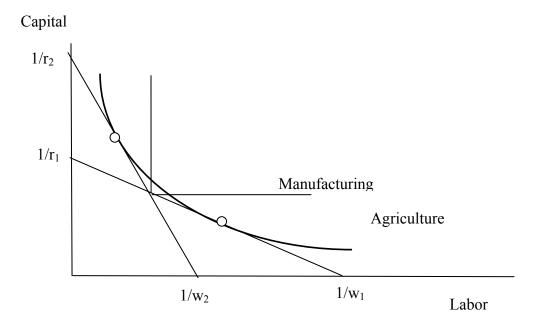
Factor-Intensity Reversals

This quotation from Chipman is referring in its mysterious way to the problem of factor-intensity reversals. Chipman's language is all about mathematical properties of the model and nothing about the message of the model. It tells us nothing whatsoever about the circumstances in which the property might be relevant. There is a way to get the message. Figure 6 is a Lerner-Pearce diagram with a plausible example of a factor intensity reversal. The equipment that is used in manufacturing pretty much fixes the capital/labor ratio which is illustrated with the right-angled unit value isoquant, but agriculture allows a wide range of labor intensities from peasant subsistence farming on small plots of land to American agribusiness. That broad set of capital/labor ratios in agriculture supports *two* different equilibria. The low wage equilibrium with wage w_1 and capital rental rate r_1 has manufacturing and labor-intensive agriculture, while the high wage equilibrium with wage w_2 and capital rental rate r_2 has manufacturing and capital-intensive agriculture.

Do you perceive that I have just described factor intensities in a way that allows you to get the economic message, if there is one? On reflection, do you, like me, come to the conclusion that there is no message here, beyond what is already embodied in the multi-cone model? Can you point to a single empirical study that even mentions factor-intensity reversals?

An alternative multi-cone model might have three agricultural products ranked in order of capital-intensity: fruits and vegetables, livestock, and cereals and grains. Having thus described the change in factor-intensity as actually a change in product, do you start to wonder if there is enough scope for substitution between capital and labor in any *specific* product to warrant attention to factor-intensity reversals as a reason for non-FPE? Standardization and mechanization of manufactures leaves little scope for variability of input intensities. And hand-made items are not the same products, are they? Maybe non-traded service work including construction is where the scope for substitution of capital for labor is greatest, but that does not create the non-FPE anomaly because there is no product market arbitrage that equates the price of a road in India to the price of a road in Germany.

I am not sure, but I am pretty suspicious that there is no message here; it's only a mathematical property.

Figure 6   Factor Intensity Reversal

Ohlin's Models

Flam and Flanders(2002) and Baldwin(2008) and others make it clear that Ohlin was quite explicit in his rejection of the simple 2 by 2 model that allowed Samuelson to prove the SS and FPE theorems, and that now allows most students mistakenly to accept these theorems as symptomatic of the framework generally.

Here is a passage from Ohlin's *The Theory of Interregional* trade quoted in Flam and Flanders (2002, p 184), referring to the "multi-cone" equilibrium, next to be discussed.

> …. As mentioned, a free exchange of goods tends to give the same result and might also do so, under certain conditions. What are these conditions, or the other way around, what generally prevents this tendency from being fully realized?
> It is difficult to find a general answer to this question. On the most profound level, there is probably a certain disproportion in the distribution of the factors of production and their use in production that prevents the same outcome as when the factors of production were mobile, whatever the location of production. The exchange of goods can only create a situation where one type of good will be produced here and another there, that is, that each good is produced

in that or those places where the most favorable of the existent combinations of factors is to be found.

Here is a passage from *The Theory of Trade* quoted in Flam and Flanders (2002, p 184). This explicitly refers to factor supplies and product demand as determinants of the multi-cone equilibrium. There is also a reference to technological differences in the factor intensities associated with economies of scale.

It is difficult to give a precise meaning to the conditions for complete equalization of the prices of factors of production. The closest one could come, it seems, would be that there must be a specific relationship between (1) the technical characteristics of the goods and the factors of production, including the limited divisibility of labor (ie economies of scale), (2) the supply of the factors of production, (3) the nature of demand.

Let's memorialize Ohlin's words in some Lerner-Pearce diagrams. The point is not to change the content of the words, but to help us remember them. Here are three reasons why full factor price equalization would not occur:

1. Product market specialization that limits the arbitrage opportunities created by factor price differences. (A multi-cone model.)
2. Technological Differences
3. Trade Costs that Limit Arbitrage in the Product Market

Let's make Lerner-Pearce diagrams that illustrate each of these.

Parenthetically, it cannot come as a surprise that there are models in which full factor price equalization does not occur, and it not a surprise to read Samuelson's(1971) demonstration that the Ricardo-Viner model does not produce complete factor price equalization, but it is a surprise that the title of Samuelson's paper is "Ohlin Was Right." That is hardly the issue. Both Samuelson's FPE and Ohlin's non-FPE are "right," meaning valid conclusions from candidate models. The issue is not validity; the issue usefulness.

A Two-Cone Equilibrium Without FPE

Are you mystified by the "cone" in the title of this section? We need to have a name for the regions in factor space that select different equilibria. What shall we call the region between the two expansion paths in the 2x2 model? It has become traditional to call it a cone, as a mathematician might. More precisely, it is the interior of an infinite cone. Actually, it is the interior of an infinite pyramid(A cone has a circular base). Nevermind, we will call it a cone of specialization.

Figure 7 depicts pretrade equilibria of two isolated countries each producing three goods. This is a Lerner-Pearce diagram illustrating unit value isoquants and unit cost lines, which are different in the two countries because neither product prices nor factor prices

are equalized.   A capital abundant country depicted with solid lines has cheap capital-intensive goods (unit value isoquant farther from the origin) and a low rental rate of capital (intersection with capital vertex farther from the origin.) A labor abundant country has cheap labor intensive products and a low wage rate of labor. The middle product is treated as the numeraire with the same price in both countries.

Figure 7   Pretrade Equilibrium: 3 Goods and 2 Factors
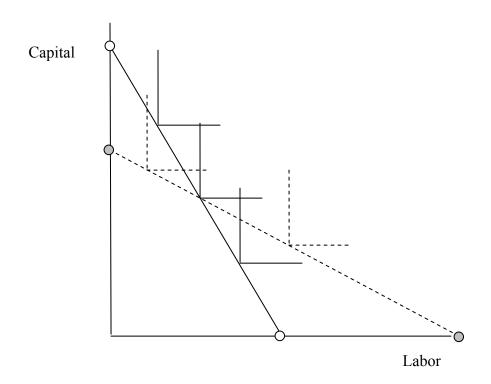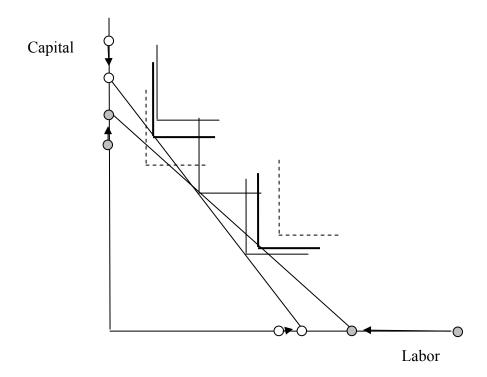

Capital

Labor

Figure 8 depicts a free-trade partially-integrated equilibrium with product prices equalized, but with differences in factor prices. Here the empty and shaded circles from Figure 7 are retained as are the original unit value isoquants. The new unit value isoquants drawn with heavy lines. These two heavy unit value isoquants lie between the two pretrade unit value isoquants to reflect the compromise prices in the integrated equilibrium.   This assumed price movement has not been enough to allow the unit value isoquants to all lie on the same line and full factor price equalization has not occurred. Here there are two cones of specialization, a low-wage cone for the country abundant in labor and a high-wage cone for the country abundant in capital. The labor-abundant countries produce a labor-intensive mix of tradables; the capital-abundant countries produce a capital-intensive mix of tradables.

The arrows on the axes show the tendency toward factor price equalization, exactly as Ohlin described.   The critical aspect of this equilibrium is that the labor abundant country is the only producer of the labor-intensive good and the capital abundant country is the only producer of the capital-intensive good.   With fixed input technologies and each country producing just two goods, the global outputs are not price dependent – the

two Rybczynski systems determine the output levels completely. The Ohlin equilibrium depicted in Figure 8 is thus reliant on the assumption that global demand for the two extreme products can be "easily" satisfied from the single source.   This is more likely the more extreme are the factor supplies in the two countries, since an increase in labor in the labor abundant country causes a more than proportionate increase in output of the labor-intensive good while an increase in capital in the capital-intensive country produces a more than proportionate increase in the capital-intensive good, making specialization more likely. If you have the desire, you can add to the model a demand side that will allow you to solve explicitly for the conditions under which this two-cone equilibrium emerges. It will produce some precise mathematical expressions, but no new messages. Here is a precisely (economically speaking) vague (mathematically speaking) way of saying it. The multi-cone equilibrium requires a distribution of factor abundance ratios weighted by country size that is broad compared with the distribution of input intensity ratios. (This is the point where some empirical work has to kick in. Theory has gone as far as it can go.)

Figure 8   Posttrade Equilibrium: 3 Goods and 2 Factors

Technological Differences: Trade Causes Factor Price Divergence

If countries before trade have technological differences, then trade can cause divergence of factor prices. Figure 9 illustrates a hypothetical pretrade equilibria of two countries one with superior technology in the capital intensive good. That superior technology is exactly offset by a lower price, keeping the two unit value isoquants identical in both countries. This allows *pre-trade factor-price equality*.

In the post-trade equilibrium depicted in Figure 10 the unit value isoquant in the capital-intensive sector for the two countries has moved in opposite directions, because the price of the capital-intensive good has increased in the technologically superior country which began with low price but the price has fallen in the backward country where the pretrade price was high. Now the backward countries have two possible cones of specialization. A labor-abundant backward country produces the two labor-intensive goods, experiences no change in the nominal wage or the nominal rental rate of capital, but benefits from cheaper capital –intensive goods. Thus trade has increased earnings of both factors. A capital-abundant backward country specializes in the two more capital-intensive product and experiences the Stolper-Samuelson effect of a fall in the price of the capital-intensive good: A higher wage rate and a lower return to capital in both nominal and real terms. The advanced country that experiences an increase in the price of the capital-intensive good specializes in the extreme products, has a Stolper-Samuelson effect of a rise in the price of the capital-intensive good: A lower wage rate and a higher return to capital in both nominal and real terms.

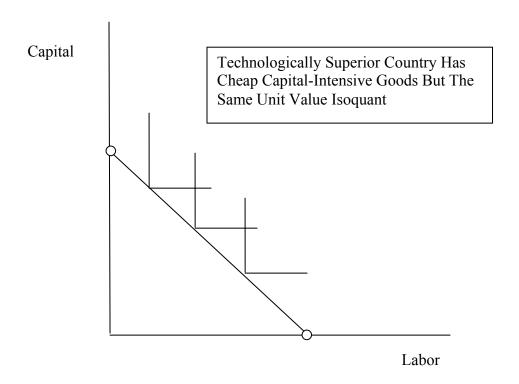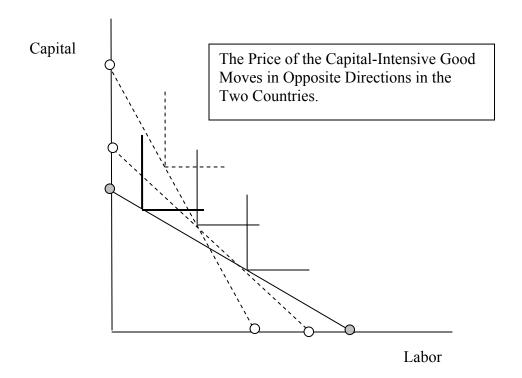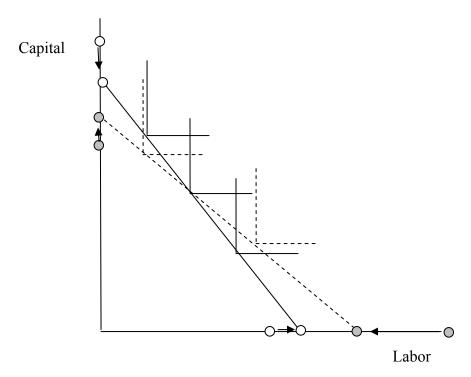**Figure 9**   **Pretrade Equilibrium: FPE with Technological Differences**

Capital

Technologically Superior Country Has Cheap Capital-Intensive Goods But The Same Unit Value Isoquant

Labor

Figure 10   **Post-Trade Equilibrium: FPE with Technological Differences**

Capital

The Price of the Capital-Intensive Good Moves in Opposite Directions in the Two Countries.

Labor

37

Trade Costs Limit FPE

The costs of exchanging products internationally limit product market arbitrage, and persistent product price differences leave persistent differences in factor market rental rates. You can see this in Figure 11 which illustrates what "encumbered" trade does to the pretrade equilibrium depicted in Figure 7. Just like Ohlin said – factor prices converge, but do not equalize.

Figure 11   **Post trade Equilibrium With Trade Costs**

Aside from the absence of FPE, the trade costs imply that the derived demand for labor varies from neighborhood to neighborhood. A European labor demand curve awards to labor a scarcity value that is not present in labor-abundant Asia. On the other hand, the correspondingly high return on capital in Asia should encourage capital formation and more rapid growth.

Dimensionality

Flat figures on manuscript pages are good for two-dimensional figures, not so good for 3, and pretty hopeless for 4 or more. However, I am pretty sure that the *economics* of higher dimensional models stops at the 3-factor n-good model discussed graphically in Leamer(1987). Whatever messages that might come from higher dimensional models are blurred to incoherence by the impossibility of sensibly counting the number of factors and the number of goods. But let's make sure we can do the mathematics. It's kinda fun.

The Heckscher-Ohlin-Vanek Model (HOV)

A general model with n products and m factors can be written in terms of the vectors and matrices that disguise the dimensions altogether, which is why the math doesn't depend on the dimensions, though it depends very much on whether the number of factors of production is greater than, equal to or less than the number of products. Here is the notation:

q = n×1 vector of outputs
c = n×1 vector of consumption
p = n×1 vector of output prices
v = m×1 vector of factor supplies
w = m×1 vector of factor supply rental rates
A = m×n vector of factor intensities, inputs per unit of output.

With this notation, we can write the two conditions that drive the results as inequalities:

Factor Market Equilibrium Conditions

$$Aq \leq v$$

Non-negative profit conditions

$$A'w \leq p$$

To make this model really sing, we need to add a neutral demand side that allows trade to replicate the production side. Vanek's(1968) assumption of identical homothetic tastes does the job perfectly. That by the way is math-speak for the assumption that budget shares are not income dependent, and facing the same global prices, everyone has the same shares.

Consumption

$$c = s\, q_W$$

The Even Model m = n

Working first with the even case with equal numbers of factors and goods, and with A assumed to be invertible, we can invert the factor market equilibrium conditions and the zero profit conditions to solve for the output vector and the wage vector:

Rybczynksi system: $\mathbf{q}=A^{-1}\mathbf{v}$
Stolper-Samuelson system $\mathbf{w} = A'^{-1}\mathbf{p}$

Because of the linearity of the Rybczynksi system, global output does not depend on where the factors reside

$$\mathbf{q_w}=\Sigma\,\mathbf{q} =\Sigma\,A^{-1}\mathbf{v} =\ A^{-1}\mathbf{v_w}$$

Finally, with identical budget shares, international trade, which is the difference between production and consumption, can be written as

$$t = \mathbf{q} - \mathbf{c} = A^{-1}\mathbf{v}\text{-s}\,A^{-1}\mathbf{v_w} = A^{-1}(\mathbf{v}\text{- s }\mathbf{v_w})$$

Thus the output vector is A^{-1} times the factor supply vector, and trade is A^{-1} times the "excess factor supply" vector $\mathbf{v}$- s $\mathbf{v_w}$, and in that sense trade inherits the properties of the production side of the model, with the demand side neutralized.

Mathematically, that is the end of the story. It doesn't matter if $n=m=2$ or $n=m =10$ or $n=m =1000$. The equations apply to any dimensionality. Factor price equalization is a direct consequence of the equation linking prices to wages, independent of the factor supply. While the mathematics works, the economics of the SS theorem deteriorates substantially when n goes from 2 to 3, and the economics pretty much evaporates when n is greater than 3. In the two-dimensional case, there is a simple algorithm for determining which factor gains and which factor loses, basically because the inverse of a positive matrix has only two possible sign patterns, with one sign on the diagonal and the other sign on the off-diagonal, which pattern depending on the determinant which in turn is determined by the ordering of the capital intensities in the two sectors.   In the three dimensional case, explored graphically in Leamer(1987), the algorithm for identifying winners and losers gets more complicated. For higher dimensional cases, all that is "known" is Eithier's friends and enemies result: In every row and column of the inverse of a positive matrix there must be at least one nonnegative number and at least one nonpositive number. In other words, a tariff on one imported good is sure to raise the earnings of one factor and lower the earnings of another.

There is one additional important lesson of the HOV model found by premultiplying the trade vector by the matrix of input intensities:

THE HOV Equations (Heckscher-Ohlin-Vanek)

$$At = (\mathbf{v}\text{- s }\mathbf{v_w})$$

At the left are the factors embodied in trade. On the right are the excess factor supplies. This confirm's Ohlin's view that products are best thought to be bundles of factor services, and the products that are included in exports and imports are designed to export the services of factors that are abundant and to import the services of factors that are scarce, where abundance is measured by the difference between the factor supply and the factor consumed.

More goods than factors

At several points already we have tiptoed into the issue of dimensionality by exploring a model with three goods and two factors. In doing so, we learned something very interesting and potentially very important: In the two-good two-factor model with countries producing both goods, all countries are competitors, and trade has internal income distribution consequences, inevitably producing losers as well as winners. That is what Ohlin worried about – trade lowering wages in labor-scarce countries. This Samuelsonian conclusion contrasts with a Ricardian "partners" model in which each country specializes according to its comparative advantage, and trade has only winners.

An HO 3-good 2-factor model also allows a "partners" not "competitors" solution with countries producing different mixes of products. Figure 8, which illustrates the post-trade equilibrium in the two-cone case, does indicate a partial convergence of wages and rental rates, which seems to suggest that labor loses its scarcity value in the high-wage labor-scarce country, but offsetting that is a lower price for the labor-intensive products no longer produced. If these labor-intensive products comprise a large enough consumption share, then real wages can increase, even though real wages in terms of the two capital-intensive products falls, per the SS effect induced by an increase in the price of the capital-intensive good. This is something that we will need to keep alert for when we start talking about the data. To make sure we remember, let's call it the Walmart effect – lower prices of products from labor-abundant Asia raises living standards for all Walmart customers. This is a wholly advantageous terms-of-trade effect provided that we don't produce those imported products.

The case of many goods and three factors of production discussed in Leamer(1987) is the minimal HO model that allows multiple paths of development, with land abundant countries following a different path than land scarce countries. It is probably the maximal model that allows clear messages. It serves as an intellectual foundation for differences in policies toward trade among the land-abundant and the land-scarce countries, including, for example, the need to subsidize education in the land-abundant countries, which otherwise would not be prepared to move into the higher end of manufacturing when the natural resources are fully exploited.

More factors than goods

Homework problem: What are the implications of a three-factor two-good HO model?

The Four Mobilities: Objects, Organisms, Promises and ideas.

The best definition of globalization is the increased movement and mobility of objects, organisms, promises and ideas.

*** more later.

Econometric Journalism

We turn now to the empirical work that I will call "econometric journalism." The empirical literature on international trade has been extensively reviewed by Leamer(1994), Leamer and Levinsohn(1995), Helpman(1999), and most recently by Davis and Weinstein(2002) and by Baldwin(2008). I will not be offering a review here, but only some methodological comments in keeping with the theme of this essay.

We Need Better Balance

I share with Davis and Weinstein(2002) disappointment in the small impact that empirical work has had on the intellectual lives of international economists. The reasons for this are many and diverse, including ones identified by Davis and Weinstein(2002) but I am pretty sure one problem we have is imbalance. We need better balance between the three layers of the argument: the questions, the theory and the data. The profession as a whole is imbalanced in favor of theory. But most of the empirical work is also imbalanced. Some empirical studies take the theory too seriously and lose track of the questions. Others do not take the theory seriously enough and try to make do with ad hoc but inappropriate empirical models. Some studies that lack the theory layer lack as well any clear questions too. We need better balance. If we had better balance, we would do better economic fiction and better econometric journalism, and we would find ways to make our work more influential.

Theoretical econometricians are part of the problem because econometric theory presupposes that models are either true or false, and much time is spent on the hypothesis testing problem - determining a model's truthfulness. But the type I and type II errors that are really relevant when analyzing data are not rejecting a true null hypothesis or accepting a false one, but rather taking a model too seriously or not taking a model seriously enough.

A classic example of not taking a model seriously enough is Leontief's (1954) discovery that 1947 US imports were more capital-intensive than US exports, which seems hard to reconcile with an HO framework since in the aftermath of WWII the US was surely a capital abundant country. However, as I explained in Leamer(1980), Leontief did not do the HO calculations correctly, adjusting properly for the US external surplus. When done correctly, the US 1947 international trade data actually suggest that the US was capital-abundant not labor-abundant, the opposite of Leontief's inference. An example of taking the model too seriously is Bowen, Leamer and Sveikauskus(1987) who carried out a mathematically correct Leontief type of exercise using 1966/67 trade and endowment data on 27 countries. But was it economically correct? More on this below.

Are We Making Maps or Artwork?

If by "testing" we mean determining the truth value of a model, we should avoid that completely. When we "test" we measure how well the model fits the facts. One might expect a model that was inaccurate would be misleading, but that is not necessarily the case. For example, econometricians, intent on determining the truth value of the map of the freeway system might notice that freeways on the map are colored red. A small

sample of points on the real freeway system would allow them to reject the truthfulness of the map with a high degree of confidence. That, of course, misses the point. The coloring distortion is intended to increase the usefulness of the map. The right way to test the coloring of the map is by comparing the ease with which we make our journey when following a colored map compared with a black and white one. Usefulness can only be tested by use.

There is a lot that's right about the mapmaking analogy, but there is something very important that is wrong with it. Real maps are not just decorative items hung on the walls whose artistic qualities are compared one with another. Real maps promise to help us get from point A to point B in actual journeys, and if my map gets me lost while yours gets you there, I will switch to yours. In that sense, maps are tested, not for their truthfulness, but for their usefulness.

Economic maps are designed in principal to help governments get from A to B, but a valid scientific test of their usefulness requires a randomly selected "treated" group and a "control" group. This is hard to effect on human subjects and virtually impossible for countries.[10] Once in a while we stumble on a compelling natural experiment, but otherwise we draw causal conclusions from a combination of the correlations in our nonexperimental data and the stories we tell each other. Best to remember when studying nonexperimental data: Correlations are in the data, causation is in the mind of the observer.

Give us Some Graphs

Another reason that data doesn't matter is that we don't do the packaging very well. Humans have a hard time unscrambling, internalizing and remembering the messages of stories encoded with Math, but we also have a hard time unscrambling, internalizing and remembering the patterns of data encoded in tables of estimates and t-values.

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[10] There is a good chance that this vaccine will prevent swine flu. Do you mind if we flip a coin, and administer the vaccine if heads comes up, and administer a saline solution if tails comes up? There is a good chance that a tax cut could stimulate the economy and make a recession less severe. Voters in the UK and the US: do you mind if we flip a coin and have a tax cut in Britain if heads comes up or a tax cut in the US if tails occurs??

Of course real policy would never be decided randomly, but we can still take the medicine when it is needed and after the fact evaluate the outcome. But that isn't so easy either. The Obama administration enacted a $787 billion stimulus package based on Keynesian macroeconomic maps early in 2009, and the Obama economists seemed to promise that the stimulus package would keep unemployment below 8.5%. When the unemployment rate exceeded 9.5%, it wasn't from a failed stimulus, it was because the economy deteriorated much more rapidly than "anyone" expected, and if we didn't have the stimulus, the unemployment rate would have been 10.5%. In other words, the map is right, it is the ground that shifted!

Econometricians can adjust for the shifting ground by including an adequate number of control variables, but what they cannot do is to tease valid causal inferences about the effects of a stimulus program from the nonexperiment data on which we are forced to rely on. "Correlations are in the data, causation is in the mind of the observer."

When I heard a decade ago a commentator on National Public Radio explain "Humans are pattern-seeking story-telling animals." I realized immediately that's what Economics is. Thus my experience with forecasting was summarized in my recent book "Macroeconomic Patterns and Stories." The word "pattern" is a visual metaphor, referring to the way most of us process data most effectively. When I teach the analysis of data, I like to write on the board at the beginning of each lecture

> Pictures
> Words
> Numbers

An influential data analysis needs figures that display the data in a way that we can understand the main conclusions, numbers that summarize the data and support those conclusions, and stories that memorialize the findings. We are way overemphasizing complex numerical analysis – the special effects. I would like to see in every article at least one data display that conveys the message. See what you think of the displays soon to be revealed. Do they leave a lasting impression?

HO Questions

To help maintain balance, let's put firmly in the foreground the fundamental question: *"What should governments do to assure that the gains from trade are broadly shared and that the greatest benefits accrue to the most deserving?"* Here are five central ideas of the HO framework on which to build public policy:

1. Trade lowers the scarcity rents of scarce factors, and trade barriers can raise the return to scarce factors. (The Ohlin proposition vs. the SS Theorem)
2. Educational and infrastructure investments can serve as a foundation for product upgrading which can turn low-wage developing countries into partners instead of competitors, allowing gains from trade by all factors of production. (The Multi-cone model.)
3. A country with a diverse mix of tradables produced at home can absorb immigrants with a minimal impact on wages of natives. (FPI
4. A country with a diverse mix of tradables produced at home can absorb capital with a minimal impact on the return to capital. Thus the slowdown in growth that comes traditionally from diminishing marginal productivity of capital is nonexistent, or at least less severe for a small open economy. (FPI
5. Technological backwardness lowers GDP per worker overall, but can raise the return to some factors of production even as it hurts others.

Thus, for countries that rely on exports of manufactures, the public policies suggested by an HO framework are:

1. Invest in education and logistics infrastructure to attract a mix of manufacturing products that are not exported by low-wage developing countries.
2. Have a high-skill preference in immigration policies, consistent with (1).

3. Avoid inward-looking isolationist commercial policies which might help raise wages in the short-run but which will slow growth by reducing the returns to education and physical capital
4. Find ways to assure that your businesses and individuals have access to the best technologies.
    a. Welcome foreign direct investment, and make sure your workers have the education suited to the management and professional levels of these operations.
    b. Encourage international trade, especially exports, since it is only through competition that we learn how to compete.
    c. Send your children to study in the countries that are most successful economically.
    d. Encourage foreign students to attend your colleges and universities. These students in the future will help connect your economy with external opportunities, but in addition your educational institutions need to be able to demonstrate their effectiveness by attracting the best and brightest from around the globe.

Let's not forget: *successful empirical work needs to shed light on the usefulness of these policies or others like them.* The brighter the light the better, but dim is better than no light at all.

Empirical To-Do List

Now that we know the questions, let's do a little thinking about how we should study the data to help find the answers. All of the messages of the HO framework come from the fundamental idea that trade is a consequence of the uneven geographic dispersion of the factors of production. Some of the policies listed above might be appropriate if trade has another source, but as a first step maybe should look for evidence that trade is substantially influenced by factor supplies. And maybe we can find some direct evidence of the SS equations too. Here are some questions that I think need to be addressed empirically:

1. How Accurate is the HO Model?
    a. Are the HOV equations satisfied?
    b. Is Trade Correlated with Endowments?
2. Who Competes With Whom? Are There Multiple Cones?
3. Is the SS model right?
    a. Can we connect changes in prices of traded goods to changes in wages?
4. Alternative Models: How Rapidly Does the Heckscher-Ohlin Clock Tick?

On question four, we really need to pass the data through the filters of more than one framework. Though the HO assumption of perfect instantaneous factor mobility is obviously absurd, it is less absurd the longer the time interval. An obvious and interesting possibility is to attach to the HO model some adjustment process making it have a Ricardo-Viner short run and an HO long run which is something explored

theoretically by Neary(1978). Empirically we need a dynamic panel, with an investment process.

Three Partially Answered Questions

There is much to do, and very little done. In this section, I will summarize empirical work that is intended to answer three questions:

- Does the HO Model Fit the Facts?
- Who Competes With Whom?
- How Much Has Trade Affected Wages?

Does the HO Model Fit the Facts?

Factor Content Studies

The first and by far the most influential study of trade patterns using the Heckscher-Ohlin model was Leontief (1953) who found that U.S. imports in 1947 were more capital intensive relative to labor than U.S. exports. That seems startling, since in 1947 the US was surely a capital-abundant country. In our collective astonishment, we called it a "paradox," when at worst it was only a single contradictory observation. Faced with this alarming "paradox," we started desperately searching for ways to change the model that could explain it. Was it labor skills, trade barriers, natural resource abundance, capital-biased consumption, or technological differences? How sad! Leamer(1980) showed that Leontief's data imply that the US was capital abundant, if these data are filtered correctly through the HOV equations, $At = (v - s\, v_w)$, properly accounting for the substantial US surplus in 1947.   From this we should draw an extremely important methodological conclusion. We really need a clear conceptual framework as a basis for a data analysis. We need to take a framework seriously, but not too seriously. It's a difficult journey between Scylla and Charybdis.

We could not relax for long, since Bowen et. al.(1987) performed the conceptually correct calculations for many factors and many countries and found numerous "Leontief paradoxes," meaning that the signs of the two sides of the HOV equations, At, *and* $(v - s\, v_w)$, don't conform in sign. These HOV equations get the signs right at a rate that is only slightly better than monkeys flipping coins.   However, I have a sense of remorse in the choice of title for Bowen et.al.(1987): "Multicountry multifactor *tests* of the factor abundance theory."   Baldwin has taken this to the next level by choosing "The Development and *Testing* of the Heckscher-Ohlin Trade Models" as the title for his Ohlin lectures.   But theories are neither true nor false; theories are sometimes useful and sometimes misleading. What these factor content exercises really do is measure the accuracy of the HOV equations, and explore ways of changing the model to make it more accurate.   Rarely do we follow the title of Davis et al.(1997) "Using (the) data to determine when the factor abundance theory of trade works." That's what should really be the goal.

The HOV equations involve three separately measurable items: trade, t, technologies A and factor supplies v, and these "tests" measure the extent to which these three items fit

together as suggested by the HOV equations: $At = (v - s\, v_w)$. In the background are several extremely important auxiliary hypotheses

- There is only one cone: All countries produce all products.
- The technologies are the same everywhere. We can use the US input intensities A to compute the factor content of every other country's trade.[11]
- Prices of traded products are the same everywhere.
- Everyone on the global has the same homothetic tastes, including the "taste" for savings.
- Products and factors are sufficiently disaggregated that they can be taken as identical everywhere
   - High-fashion women's dresses crafted in the US are produced with the same combination of labor and capital as t-shirts and jeans sewn in Asia.
   - An acre of US Iowa farmland is the same as an acre of coffee plantations in Guatemala
   - And so on.

When the HOV equations failed to fit, there have been two reactions. Those who had a vested interest in scale economies and product differentiation as the source of trade celebrated loudly and started imagining a funeral for the HO framework. Those with a greater personal commitment to HO started looking for why the equations did not work, knowing full well that the HO framework has a domain of usefulness, even it doesn't fit perfectly the trade of every country on the globe, and knowing also that this particular "test" of an HO model involved a plethora of auxiliary hypotheses and was not a test of the much broader HO framework.   In BLS(1987) we explicitly considered nonhomothetic tastes, measurement errors and neutral technological differences (multiplying the US input intensity matrix A by different scalar for each country.) While this improved the fit, it did so by producing some pretty wild technology estimates. Trefler(1995) added home bias to the mix and got a better outcome.

It is a mystery to me how to connect these disappointing factor content studies with what is the fundamental idea of the HO framework that scarce factors lose when confronted with global competition.   Is this idea even remotely at risk when we conduct these factor content studies? I think not.

Trade and Factor Endowment Correlations

The theory $At = (v - s\, v_w)$ is highly doubtful from the get-go, especially when one considers the measurement problems. But Ohlin never said $At = (v - s\, v_w)$. What Ohlin said was $t = f(v)$, meaning that trade depends on factor endowments in some undefined way. The special case of an even model has a linear structure $t = A^{-1}(v - s\, v_w)$, which is surely something to look for, but not something to which one should make a complete commitment.   In other words, all the emphasis on $At = (v - s\, v_w)$ has the same defect of

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[11] Adrian Wood(1994) has emphasized calculations that are based on differences in factor intensities in developed and developing countries.

the mathematization of Ohlin's ideas. The HOV equations using the US input-output matrix is only a caricature.

The most compelling evidence in support of the HO model (I think) comes from Leamer(1984) who studies Ohlins t=f(v).[12] Leamer's(1984) first step is to aggregate the trade data to the point where a message is obtainable. He forms the ten trade aggregates reported in Table 1 created by a clustering algorithm putting into the same aggregate the products products that tend to be exported by the same countries.   Balancing accuracy with understanding, Leamer(1984) has two raw materials, four crops and four manufactures listed in Table 1.

Table 1   **Ten Product Aggregates from Leamer(1984)**

1	PETRO	Petroleum and Petroleum Products
2	MAT	Raw Materials including coal and ores
3	FOR	Forest Products, including paper
4	TROP	Tropical agricultural products including coffee, fruits, sugar and beverages
5	ANL	Animal products including meat, dairy and fish
6	CER	Cereals, tobacco and textile fibers
7	LAB	Labor intensive manufactures including apparel and footwear
8	CAP	Capital intensive manufactures including textiles, iron and steel
9	MACH	Machinery including transport equipment
10	CHEM	Chemicals

Leamer(1984) studied data from 1958 and 1975.   Trade patterns based on the 1988 data compiled by Ligang Song(19**) are reported in Table 2 and Table 3. Each of these tables reports for each country the item from this list of ten aggregates with the largest positive net exports and the most negative of the negative net exports, the former counting as an "export" and the latter counting as an "import."   For exports and imports, a second item is reported if it is at least half as large as the first. Thus for example, at the top of the list in Table 2 we find that Egypt, Libya and Venezuela exported petroleum in return for machinery imports.   Table 2 includes the countries that are exporters of the materials and the crops. Table 3 has the countries that are exporters of manufactures

You should be able to "see" the Heckscher-Ohlin framework with land, labor and capital as the factors in these trade patterns. Countries abundant in land export the raw materials and the crops in exchange for manufactures, most notably for machinery. This includes Norway, Canada, Finland Austria, Australia and **Sweden**.   A few countries export land-based products and manufactures as well, for example, Brazil and the Netherlands. Labor abundant land-scarce countries exchange clothing for machinery.   Capital abundant but land scarce countries exchange machinery and chemicals for raw materials.

Figure 12 reports net exports per worker for selected trade-dependent exporters of manufactures and Figure 13 has the same for countries with much lower levels of overall

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[12] See also: Harrigan(1995) who studies q=f(v) for OECD countries. Blum and Leamer(2004) who include distance as a determinant of trade patterns, find that being far away is a source of comparative disadvantage in manufacturing.

trade dependence per capita. (Notice the difference in the vertical scales.) Figure 12 has the countries ordered by apparent capital abundance as revealed by their trade patterns: Switzerland, Germany, Japan and Taiwan. The Swiss pictured in the top left of Figure 12 have only machinery and chemicals as positive net exports, symptomatic of a country that is land-scarce and very capital abundant. Germany has exports of CAP (textiles and steel) which is a less-advance trade pattern. In the next row are Japan and then Taiwan, with greater emphasis on the first or second of the manufactures (LAB and CAP) and less on the third and fourth (MACH and CHEM). At the bottom of Figure 12 are two advanced developed countries that export crops as well as manufactures – the Netherlands exporting dairy products and Sweden exporting softwood products. Figure 13 has two very similar countries in the top row – Korea and Italy – both of which have exports concentrated in apparel(LAB). In the next row are another pair of very similar trade patterns – France and the US – with crops and chemicals as exports. Last are China and India – with an emphasis on exports of labor-intensive manufactures

Table 2   Exporters of Materials and Crops

Largest 1988 Net Exports of Ten Aggregates From Leamer(1984)
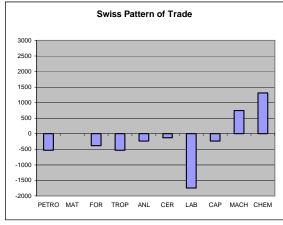(Secondary Trade Item at least half of the Major Item)

|	Exports		Imports	
	Major	Secondary	Major	Secondary
EGY	Petroleum		**Machinery**	
LIBY	Petroleum		**Machinery**	
VEN	Petroleum		**Machinery**	
INDO	Petroleum	Minerals	**Machinery**	
NOR	Petroleum	Minerals	**Machinery**	
MEX	Petroleum		**Machinery**	Cereals
UK	Petroleum		**Machinery**	
CHILE	Minerals		**Machinery**	
PERU	Minerals		**Machinery**	Chemicals
GHA	Minerals	Coffee, Fruit	**Machinery**	Chemicals
LIBR	Minerals	Coffee, Fruit	**Machinery**	
AUS	Minerals		**Machinery**	
CAN	Wood	Minerals	Clothing	**Machinery**
BURM	Wood		**Machinery**	
MALA	Wood	Coffee, Fruit	**Machinery**	Chemicals
FIN	Wood		**Machinery**	
AUST	Wood		**Machinery**	
SWE	Wood		Clothing	Petroleum
COL	Coffee, Fruit		**Machinery**	
ECU	Coffee, Fruit	Petroleum	**Machinery**	
CYP	Coffee, Fruit		**Machinery**	
COSTA	Coffee, Fruit		**Machinery**	Chemicals
ELS	Coffee, Fruit		**Machinery**	
HOND	Coffee, Fruit		**Machinery**	Chemicals
PAN	Coffee, Fruit		**Machinery**	
NIC	Coffee, Fruit		Cloth and Steel	**Machinery**
FRA	Coffee, Fruit	Cereals	**Machinery**	
SPA	Coffee, Fruit		**Machinery**	
ICE	Meat, Dairy, Fish		**Machinery**	
AFG	Meat, Dairy, Fish		Cloth and Steel	**Machinery**
NZ	Meat, Dairy, Fish		**Machinery**	
DEN	Meat, Dairy, Fish		Cloth and Steel	Wood
IRE	Meat, Dairy, Fish		Petroleum	Wood
PAR	Cereals		**Machinery**	
ARG	Cereals		**Machinery**	
US	Cereals		**Machinery**	Clothing
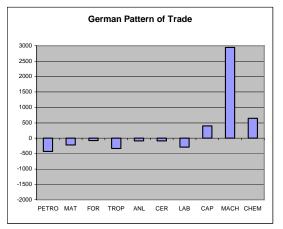
Table 3   Exporters of Manufactures
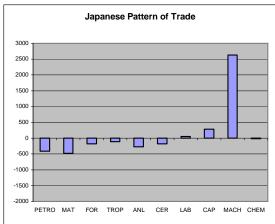
Largest 1988 Net Exports of Ten Aggregates From Leamer(1984)
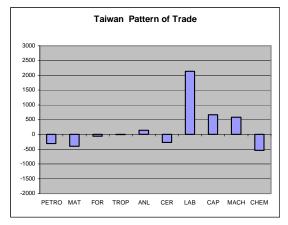(Secondary Trade Item at least half of the Major Item)

	Exports		Imports	
	Major	Secondary	Major	Secondary
JAM	Minerals	Clothing	**Machinery**	Cloth and Steel
THAI	Coffee, Fruit	Clothing	**Machinery**	
BRAZ	Coffee, Fruit	Cloth and Steel	**Machinery**	
URU	Meat, Dairy, Fish	Clothing	**Machinery**	Chemicals
NETH	Meat, Dairy, Fish	Chemicals	**Machinery**	
HONG	Clothing		**Machinery**	Cloth and Steel
CHINA	Clothing		**Machinery**	
MALT	Clothing		**Machinery**	Cloth and Steel
POR	Clothing		**Machinery**	
YUG	Clothing		**Machinery**	
GRE	Clothing		**Machinery**	
ISR	Clothing		**Machinery**	
MAUR	Clothing		**Machinery**	Cloth and Steel
PHI	Clothing		**Machinery**	Petroleum
SING	Clothing		Cloth and Steel	Petroleum
TUR	Clothing		**Machinery**	
DOM	Clothing	Coffee, Fruit	**Machinery**	
SRI	Clothing	Coffee, Fruit	**Machinery**	Cloth and Steel
INDI	Clothing		**Machinery**	
ITA	Clothing		**Machinery**	Meat, Dairy, Fish
KOR	Clothing		Chemicals	Cereals
TAI	Clothing		Chemicals	Minerals
BLX	Cloth and Steel		**Machinery**	
JAP	**Machinery**		Minerals	Petroleum
GER	**Machinery**		Petroleum	Coffee, Fruit
SWZ	Chemicals	**Machinery**	Clothing	
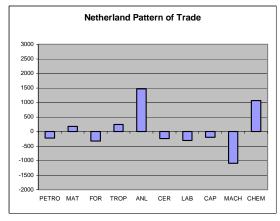
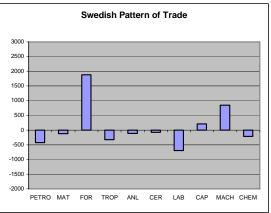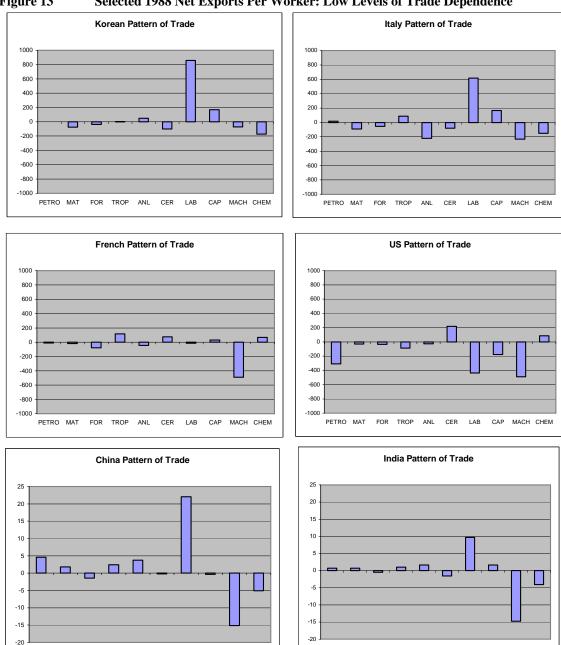**Figure 12   Selected 1988 Net Exports Per Worker: High Levels of Trade Dependence**

Swiss Pattern of Trade

German Pattern of Trade

Japanese Pattern of Trade

Taiwan Pattern of Trade

Netherland Pattern of Trade

Swedish Pattern of Trade

Figure 13   Selected 1988 Net Exports Per Worker: Low Levels of Trade Dependence

Korean Pattern of Trade

Italy Pattern of Trade

French Pattern of Trade

US Pattern of Trade

China Pattern of Trade

India Pattern of Trade

The theory that I think best fits these facts is the HO multicone model with three inputs, summarized in what I with uncharacteristic lack of humility like to call a Leamer triangle, a version of which is illustrated in Figure 14.   Here the vertices represent the three factor of production, land, labor and capital, and straight lines pointing toward one of the vertices represent a path along which the ratio of the other two factors is held fixed. The two arrow thus represent two paths of development with the ratio of land to labor fixed and with capital accumulating. Seven different products are represented by points in this figure. Along the bottom edge are manufacturing activities that use no land. In order of

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their capital intensities, first comes handicrafts, then apparel, textiles and machinery. Three ways of using the land are also depicted by points. "Logs" refers a labor-intensive way of making use of the land. In the middle is a moderately capital intensive activity – wood – and along the right-hand edge is an activity so capital intensive that the labor input is very small – paper. An alternative labeling might be "peasant farming," farms and agribusiness. These productive activities divide the space into cones of diversification, the edges of each cone comprised of one of the productive activities.

Two different development paths are represented by arrows. The path A-B-C-D-E is followed by countries that are scarce in land. The path X-Y-D-E is followed by countries abundant in land. The land-scarce countries begin in cone A by producing handicrafts, logs and wood. With capital accumulation, apparel replaces logs, then textiles replaces handicrafts, then paper replaces apparel, and finally, in cone E, machinery has replaced apparel. For the land-abundant countries, land is a redundant factor in cones X and Y, which a zero rental value. The land is first used for logs and wood, and then paper replaces logs. It is not until cone D that land has scarcity value, and capital is partially absorbed in manufacturing in textiles.

With this as the model, we can ask when would tariffs on import raise wages of workers? This requires two steps –
1. Find the product or products that are the "friends" of labor, meaning that an increase in the product price increases real wages.
2. Determine if these friends are imported or exported. (If exported, an import tariff will not raise the price.

Here is the algorithm described in Leamer(1987) for finding the friends and enemies. Consider handicrafts in cone B in Figure 14. Draw a line through the other two vertices of the triangle B, apparel and wood. Notice that this line divides the plane into a half that includes the handicrafts point and a half that excludes it. If a factor vertex is on the same side of this line as the handicrafts point, then it is a friend of handicrafts, and if on the other side is an enemy. Thus in cone B, handicrafts is the friend of labor and land, but the enemy of capital. A policy that sought to increase wages would be a tariff on imports of handicrafts, though for countries with factor endowments close to the labor vertex, handicrafts are an export item not an import item. Table 4 has the friends and enemies for all the cones, including the fact that in cone B, only handicrafts is a friend of labor. Thus a tariff on imports would have a favorable effect on wage rate only if the factor endowment in cone B only if capital and land were great enough that this country imported handicrafts. This could be a fairly slim interval close to the line connecting apparel and wood.

The friend of labor reported in Table 4 is the labor-intensive manufacture in each cone or the labor-intensive way of using the natural resource. This makes it seem pretty simple to devise some tariffs that would increase the wage rate. But one would have to be careful, since in Cone E, apparel and handicrafts are imported, but only textiles are a friend of labor. And a real economy has a vast array of very labor-intensive and not-so-labor-intensive products that have a small degree or a large degree of substitutabilty with

domestically produced alternatives. Here is my bottom line: Find a set of tariffs that could confidently increase real wages of workers is almost unthinkable and certainly highly improbable.

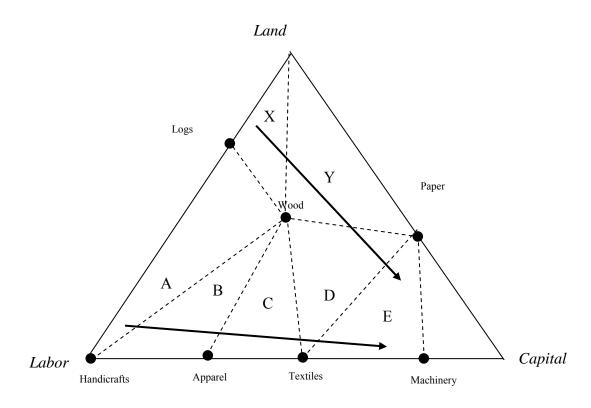**Figure 14**   **The Leamer Triangle and Paths of Development**

Table 4   **Multi-cone Friends and Enemies**

| Cone | **Friends** | | | **Enemies** | | |
	LABOR	CAPITAL	LAND	LABOR	CAPITAL	LAND
A	Handicrafts	Wood	Logs		Handicrafts Logs	Handicrafts
B	Handicrafts	Apparel	Handicrafts Wood		Handicrafts	Apparel
C	Apparel	Textiles	Wood	Textiles	Apparel	Apparel Textiles
D	Textiles Wood	Textiles Paper	Wood Paper	Paper	Wood	Textiles
E	Textiles	Machinery	Textiles Paper	Machinery	Textiles	Machinery
X	Logs	Wood			Logs	
Y	Wood	Paper		Paper		

Who Competes with Whom? Is There More than One Cone of Diversification?

One doesn't have to stray from the office in Cambridge, Mass to notice that wages are not the same everywhere.   A short drive away from the center of Boston in any direction should suffice. Regionally, The US experienced more than a century of persistent low wages in the South compared with the East, and persistent high wages in the West. Across countries, Davis and Weinstein(2002, p368) provide the graph below showing wage differences in manufacturing across OECD countries varying by a factor of five.

Figure 15   OECD Wages in Manufacturing (Davis and Weinstein)

Figure 17.1
World wages in manufacturing (in 1993 U.S.$).

These wage differences cry out for an explanation, not a proof of factor price equalization.   Could it be these are apples-to-oranges comparisons that do not control for the levels of human capital, per Krueger(1968)?   Is it compensation for the high cost of rent in cities where wages can be high because of the agglomeration economies? Is it compensating differences per the effort explanation of the intraindustry wage structure in Leamer(1999)?   Or is it that one of the assumptions of the FPE theorem breaks down, like identical technologies or non-equalization of product prices or …?   Could it be multiple cones of diversification? Is it possible that the products imported by the US from Mexico and China do not have close domestically produced substitutes, and that lower prices for the imports creates a Ricardian type gain from trade – a pure terms-of-trade effect?

The Global Labor Pool

I offer here the evidence of the multi-cone model that I think is most compelling.   Figure 16 is what I call the "global labor pool," where each country is represented by a rectangle

with height equal to GDP per capita and width equal to the population fraction. The area thus represents total GDP. Countries are sorted left to right in declining order of per capita GDP. On the left is a rectangle representing the US with a high percapita GDP and a significant population fraction. Japan has a lower per capita GDP and a smaller population fraction. On the right are the two very populous countries: India and China, that also had very low per capita GDPs.

This is a strange pool with the liquid piled up high at one end, and hardly present at the other end. What could possibly be holding up the high end? One possibility is that 2/3rds of humanity lived in inward-looking isolationist countries that prevented them from enjoying the gains from trade. "Tear down that wall" is what we told them. When they took our advice, we started rethinking it, worrying that without the barriers to trade, the pool would levelize. There would be gains from trade, of course, but the integration of those huge numbers of unskilled workers, would inevitably put downward pressure on the high end of the pool.

Figure 16   Global Labor Pool, 1980

1980 Per Capita GDP
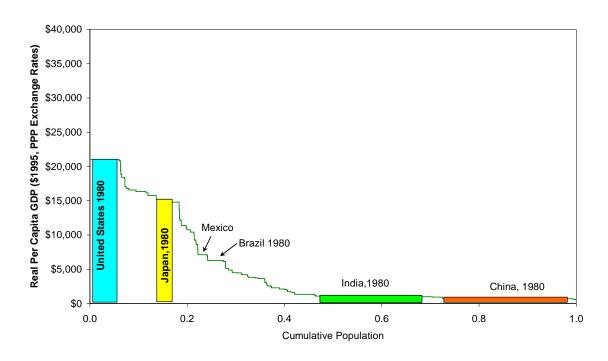
Figure 17   Global Labor Pool, 1980 and 2000
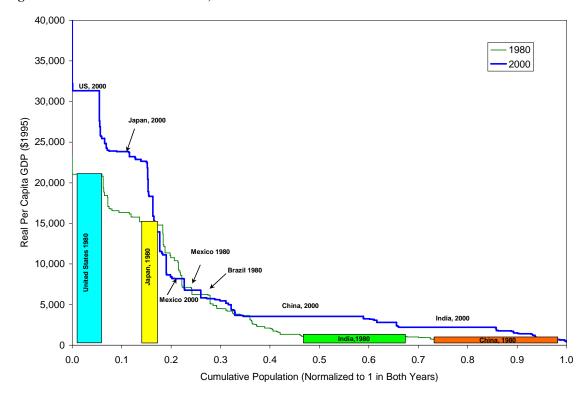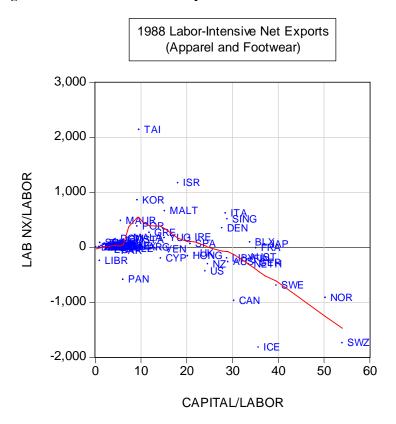
Figure 17 illustrates what actually happened between 1980 and 2000. There was enormous growth in China and India at the low end of the pool but there was also enormous growth at the high end of the pool, in the US and Japan. It was the Latin American countries in the middle of the pool that got left out.

While I am suggesting that this is evidence of the multi-cone model, I leave as a homework problem the demonstration that this change in the global labor pool can be explained with a one-cone model.

Nonlinearities

Less ambiguous evidence of the multi-cone model is the scatter diagram Figure 18 that compares a countries capital/labor ratio with it's net exports of labor-intensive products per worker. The HOV model in the single cone case suggests a straightline would be the best fitting curve through these data, with high levels of net exports at either the lowest levels of capital per worker or the highest. The best fitting curve actually has very low levels of trade for countries with capital/labor ratios less than $10,000 per worker, substantial net exports for countries with capital per worker between $10,000 and $20,000, and sharply declining values for larger capital/labor ratios. This is exactly the pattern suggested by the two-cone model with the capital intensity of labor-intensive products about $10,000.

Figure 18   **Nonlinear Net Exports of Labor-Intensive**
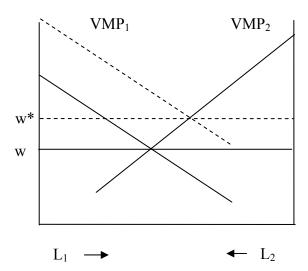
Do Falling Prices of Labor-Intensive Tradables Help Explain Wage Stagnation?

The Ricardo-Viner Model or the Stolper-Samuelson Theorem?

There is of another simple general equilibrium model used in international micro economics – the Ricardo Viner model – illustrated below. This produces results more compatible with your partial equilibrium intuition. In this model, there is specific capital fixed in each sector, and the "general" equilibrium problem is only to allocate mobile labor between the two sectors. The horizontal line segment that is the x-axis in the figure has length equal to the total labor force and each point on this interval selects an allocation of labor between the two sectors. Each sector has an initial (solid) downward sloping value-marginal-product curve and where these meet is the initial equilibrium value for the wage rate, which equates the VMP in both sectors and allocates labor accordingly. A price increase in sector one (the favored sector) increases the VMP, which creates a new equilibrium with a higher wage rate illustrated by the dotted lines. That wage increase can be seen in the figure to be less than the increase in the product price (VMP) which means that real wages decline in terms of product one but increase in terms of product two.

Figure 19   **Ricardo Viner Equilibria**

Perhaps the best way of understanding what is happening is to keep track of the capital/labor ratios. With capital fixed in each sector, the movement of workers from sector two to sector one comes with an increase in the capital/labor ratio in sector two and a reduction in sector one. Since the marginal physical product of capital is a decreasing

function of the capital/labor ratio, this straightforwardly implies exactly opposite effects: an increase in the marginal physical product of capital in the favored sector (one) but a decrease in the other sector. The price movement in favor of sector one further amplifies this result: capital in the favored sector is better off regardless of what it consumes, and capital in the other sector is worse off. For mobile labor, the result depends on what is consumed. If labor concentrates consumption on product two, where the marginal physical product of labor has increased because the same amount of capital is operated by fewer workers, then labor is better off. But if consumption is concentrated on the favored product, labor is worse off.

Thus we have:

A Ricardo-Viner Theorem: A trade impediment that increases the price of a good causes an increase in the real return to capital in the favored sector regardless of what capital consumes, and has the opposite effect on specific capital in the other sector. Mobile labor is made worse off or better off depending on whether labor's consumption concentrates on the favored sector that experiences the price increase or the other sector.

Pause a moment to think about the difference between the policy advice of the Stolper-Samuelson theorem and the Ricardo-Viner result. The former says to worry about China's effect on the prices of labor-intensive products made in the US, while the latter says to rejoice in the fact that China provides low-price goods that our unskilled workers consume. It is worthwhile to take a look at some data to help make this difference clear. Figure 20 illustrates the relative price of the PPI for textiles compared with the PPI overall. This is the kind of relative price that drives the Stolper-Samuleson effect – the relative price of labor-intensive manufactures compared with other manufactures. Notice in this figure the plateau from 1958 to 1968 and the long plateau from 1980 to 1999. These may have been periods when the Stolper-Samuelson effects were quiet. But the 25% decline in the price of apparel and textiles from 1947 to 1958, the 50% decline from 1968 to 1980 and the latest 25% decline from 1999 to 2009, if the Stolper-Samuelson theorem is right, should have come with greater declines in real wages. Then take a look at Figure 21 which illustrates real average hourly earnings of production workers in manufacturing divided by both the overall PPI and the textiles and apparel PPI. Wages relative to the textile and apparel PPI show the steady march of productivity improvements, which in our notation means ever lower input intensities A. The same manufacturing wages but divided by the overall PPI has a very different shape. Like the other series, this one is marching upward with improvements in productivity, but reaches a peak in 1972, roughly when the relative price of textiles began to fall. In 1980, wages were 27% below the trend of the period from 1947 to 1972. That gap widened a bit until 2002, after which it opened up almost to 50%. The startling thing is that these two periods of declines in real wages correspond almost exactly to the periods of sharp declines in the relative price of textiles and apparel. Is that the Stolper-Samuelson Theorem at work??

The Ricardo-Viner framework points to what workers consume, not what they produce. Figure 22 illustrates the decline in the CPI of apparel relative to other items consumed. This is broadly similar to the PPI graph, Figure 20. Figure 23 has the wages of production workers in manufacturing divided by the CPI overall and the CPI of apparel.   Here we can see the stagnating real wages for the broad consumption basket but if all you bought was apparel, the gains, especially since the early 1990s have been very substantial. This hints at the much broader finding of Broda and Romalis (2008):

> "Using household data on non-durable consumption between 1994 and 2005 we document that much of the rise of income inequality has been offset by a relative decline in the price index of the poor…. Since Chinese exports are concentrated in low-quality non-durable products that are heavily purchased by poorer Americans, we find that about one third of the relative price drops faced by the poor are associated with rising Chinese imports."

Figure 20   **Declining Producer Prices of Labor-intensive Manufactures**

Producer Price Index of Textiles and Apparel / Overall PPI
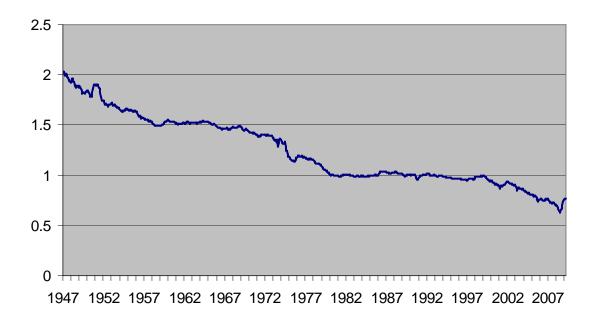
Figure 21   **Real Average Hourly Earnings of Prduction Workers in Manufacturing**

Real Wages in Manufacturing (PPI deflated)

64
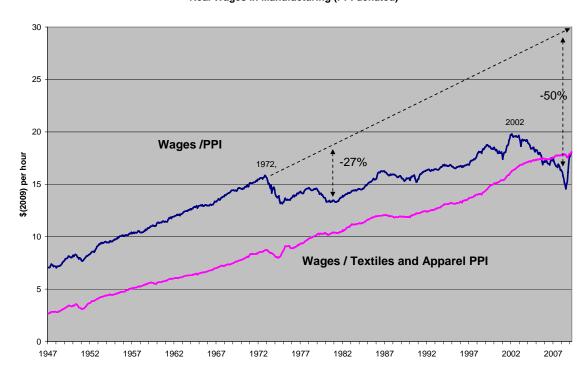
Figure 22   **Declining Consumer Price of Labor-Intensive Manufactures**
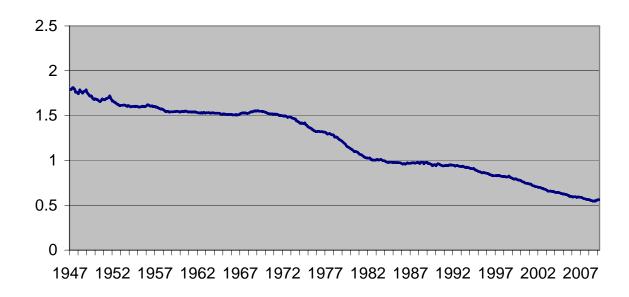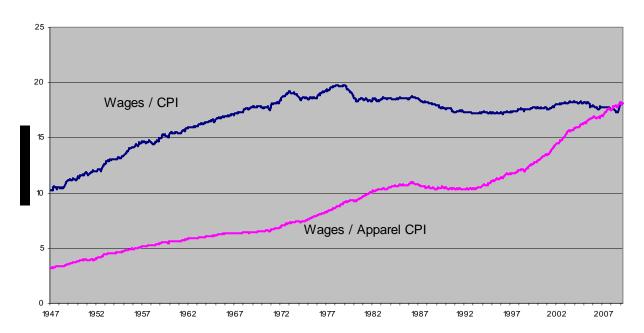
Apparel CPI / Overall CPI

Figure 23   **Real Wages Using Apparel as the Numeraire**

Real Wages in Manufacturing

Mandated Wages and the Stolper-Samuelson Equations

Figure 20 illustrates the change of price of one of many tradable products. A way to deal with a larger number of prices was suggested by Leamer(1997) who uses data on product prices, total factor productivity and industry factor shares to find the changes in wages and capital rental rates needed to maintain the zero profit conditions that are the basis of the SS theorem. Per the language in Leamer(1997) these are "mandated" wage changes.

Leamer's logic begins by differentiating a zero profit condition, $p_i = \Sigma A_{ik} w_k$, to obtain the dynamic version:

$$\textbf{Equation 1} \qquad \hat{p}_i + T\hat{F}P_i = \sum_k \theta_{ik} \hat{w}_k$$

where TFP is the part of growth of outputs that cannot be explained by growth of inputs, $T\hat{F}P_i = -\sum_k \theta_{ik} \hat{A}_{ik}$, and where $\hat{p}_i$, $\hat{A}_{ik}$ and $\hat{w}_k$ refer to percent changes in prices, input intensities and factor returns respectively, and where θ is a factor share.

Equation 1 simply says that the sum of price changes and technological changes has to be distributed among the factors to maintain zero profits. A regression of the price changes on factor shares has coefficients that are the factor price changes "mandated" by these price changes. If this regression fit perfectly we would have found exactly that wage changes needed to keep profits zero. Of course the regression doesn't fit perfectly. A regression is one way to find a compromise. The underlying assumption is that the economy also has to try to find some way to resolve the conflicts among the multiple sectors, and it does so in a way that is similar to the way a regression analysis resolves the conflict among the data points.[13]

Labor economists seem to have concluded that wages of US unskilled workers are being driven down by "skill-biased" technological change. A very interesting implication of Equation 1 is that it is the sector-bias not the factor-bias of technological change that drives wage changes. In other words, in this equation, TFP has an industry subscript but no factor subscript. This is very much in spirit of my insistence that the HO framework has its first-order effects through *inter*-industry changes not *intra*-industry changes.
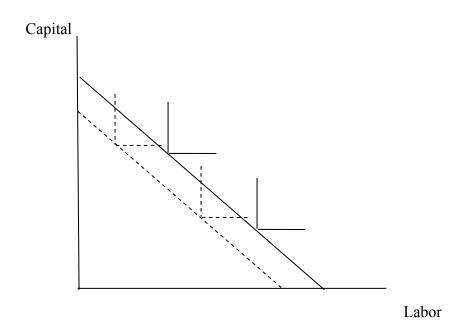
If you do not believe the algebra, Figure 24 illustrates the case of sector-neutral but factor-biased technological change. The solid lines represent the initial equilibrium and the dashed line the equilibrium after technological change. Factor-bias means that both sectors use less labor and more capital after the new technology is deployed. Sector-neutral means that both sectors have the same percentage reduction in costs, which means that the new unit-value isoquants select a unit cost line that is parallel to the first. Thus there is the same percentage increase in the returns to both labor and capital, nevermind what is the factor bias.

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[13] Weighted regression seems like a good idea

According to an HO model, factor-bias in technological change would affect factor prices if the technological changed caused sector-biased price effects. The technological shifts toward more capital intensive methods of production illustrated in Figure 24 cause a shift in output in favor of the labor-intensive sector, like an increase in the labor force. If this output change were sufficiently widespread, it would require offsetting global price changes, meaning lower prices of labor-intensive tradables, which in turn induces a SS decline in the real wage of labor.

Figure 24   Skill-Biased But not Sector-Biased Technological Change

In mentioning the possibility that factor-biased technological change might have an effect through induced price changes, this opens up Pandora's Box. The biggest problem with Equation 1 is that it explicitly includes both TFP growth and product price changes, but it is entirely silent on the relationship between the two. In order to unscramble trade from technology we need to know how they relate. It could be that technological improvements are exogenous and passed on to some extent to consumers. It is also possible that "necessity is the mother of invention" and price declines in labor-intensive goods are offset by TFP gains. Leamer(1997) uses the "pass-through" assumption

$$\hat{p}_i(t) = -\lambda \, \hat{TFP}_i$$

that the fraction λ of an improvement in TFP is passed on with lower prices and explore the implications of different pass-through rates. This can only be a working assumption until we better understand the interplay between technological change, economic liberalization, economic growth and product prices.

In other words, we are far far away from a credible disentanglement of the forces that are affecting wages, and when you hear otherwise you need to hold up a clove of garlic.

Anyway, Table 5 reports regressions taken from Leamer(1997) that explain price inflation and TFP growth with factor shares for three different decades. In the 1960s, prices tended to decline in the capital-intensive sectors, *** more here

Table 5   Regressions of Inflation and TFP Growth on Beginning-of-Period Earnings Shares
450 Four-digit SIC Manufacturing Sectors
Capital and High-wage and Low-wage Labor.

	Annualized Price Inflation			Annualized TFP Growth		
	1961-71	1971-81	1981-91	1961-71	1971-81	1981-91
Estimates						
Labor						
High-wage	3.47	6.34	5.36	-0.65	1.96	-4.89
Low-wage	2.58	4.79	5.26	1.8	-1.04	-0.14
Capital Share	-5.46	6.56	-4.14	13.75	0.61	15.68
Materials Share	(1)	(1)	(1)	(2)	(2)	(2)
Standard Errors						
Labor						
High-wage	0.45	1.03	0.98	0.54	1.1	0.99
Low-wage	1.08	1.34	1.13	1.3	1.43	1.15
Capital Share	1.51	3	2.47	1.82	3.2	2.5
Mean Dependent Variable	1.91	8.01	2.38	0.83	0.17	0.32
S.D. dependent var	2.1	5.78	2.88	1.91	3.12	2.24
S.E. of regression	1.44	2.89	2.14	1.73	3.09	2.16

(1) The materials share coefficient is set equal to the sector-specific materials inflation rate.

(2) Materials input shares are excluded because the pass-through is assumed to apply to value-added prices

Two Little Disaggregation, "Outsourcing" and Delocalization

Like it or not, the data we analyze are aggregated in ways that make it hard to see the HO forces at work. This is a genuine headache for those of us who carry out studies of the data.

If aggregation is carried all the way to a one-product model, using GDP as the single aggregate, HO thinking requires us to include relative price terms as parameters of the production function. If this seems mysterious to you, remember in the two-by-two model, GDP can be written in terms of the earnings of the factors, which depend on the technologies t but also on the product prices p:

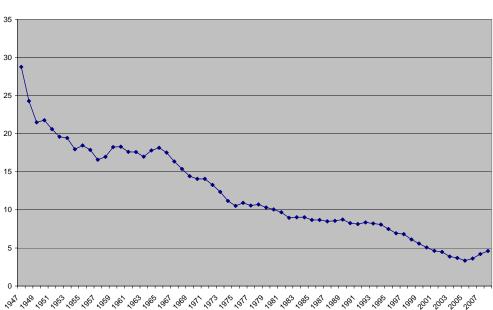$$GDP(\mathbf{p},t) = w(\mathbf{p},t)L + r(\mathbf{p},t)K$$

If one neglects the "globalization" effect on product prices the technology effect t is going to look like it is driving the outcome. It really is darn difficult, as we saw in the mandated wage regressions, to sort technological effects from globalization effects. Some disaggregation helps but most product categories include both capital-intensive and labor-intensive product, and a trade induced shift toward the more capital-intensive products is going to look like a change in technology, not a change in global competition.

Even with data highly disaggregated by industry there is still an aggregation problem. Graphs like Figure 25 that demonstrate the declining ratio of production to nonproduction jobs in apparel have been interpreted by all labor economists as evidence of "skill-biased technological" change. Their argument is that the trade effect requires lower wages for production workers, and therefore a shift toward using more of them. But since that didn't happen, it must be skill-biased technological change.

Wrong, wrong, wrong. If you think this is skill-biased technological change, please tell me exactly what happened to the sewing machines that allowed this large savings in production work compared with nonproduction work.

There is some technology in this picture, but there is plenty of globalization too. An HO model properly interpreted includes "activities" not "industries." A prominent example is the extensive literature on trade in intermediate inputs. Think of the design as an intermediate input passed on to production workers who pass the finished garments on to the marketing. Take a look at the post-trade 3-good 2-factor equilibrium in Figure 8 – here the most labor-intensive activity is not done in the high-wage capital-abundant country.

Figure 25   Ratio of Production to Nonproduction Jobs In Apparel

Apparel Production/Nonproduction Jobs

With that insight, take a look at the production and nonproduction jobs in apparel displayed separately in Figure 26 and the apparel industrial production index displayed in Figure 27. To be provocative, I have separated the time line into four intervals. From 1947 until 1966, the sector was to a large extent isolated from foreign competition, and both production jobs and non-production jobs were increasing. From 1966 to 1984, the industry reacted to increased foreign competition by moving the labor-intensive production work abroad even as the nonproduction work was increasing. That was the period of "delocalization" which is the word currently in vogue to describe this kind of trade in intermediate goods (refer to Jones??).[14] Per the model depicted in Figure 8 this maintains the high-wage solution by shipping abroad the jobs that are more cheaply done there. The next period from 1984 to 1998 is a struggle,

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[14] That's a pretty good word, but a bad one that is the most popular is "outsourcing" which fails to distinguish the boundary of a firm from the boundary of a country "Offshore outsourcing" is a mouthful, but keep in mind that the HO framework has no firms and no outsourcing

Figure 26   Production and Nonproduction Jobs in Apparel

Apparel: Production and Nonproduction Jobs
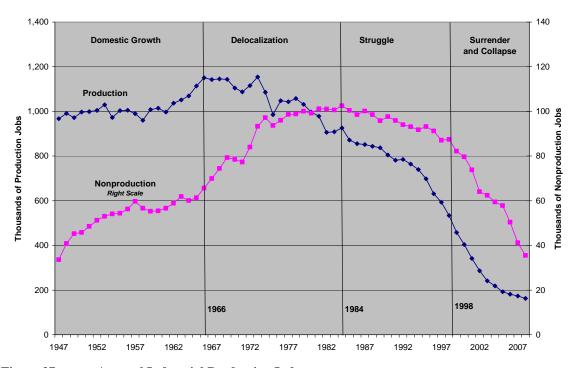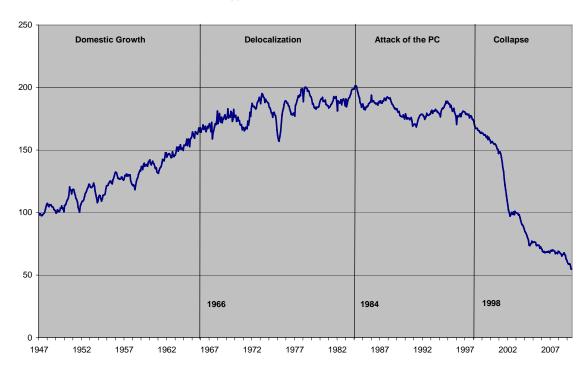
Figure 27   Apparel Industrial Production Index
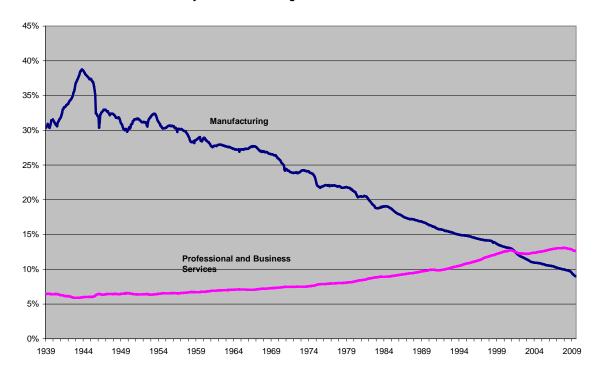
Apparel Industrial Production

Too Much Disaggregation: Business Services

Too much aggregation can cause problems, but so can faulty disaggregation. Figure 28 reveals that the falling share of manufacturing payrolls was accompanied by a rising share of professional and business services. To some extent, this is a symptom of the outsourcing of services, including legal, professional as well as clerical by manufacturing firms, making it seem that the decline in manufacturing jobs was greater than **

Figure 28   Rise of Professional and Business Services

Shares of Total Payrolls: Manufacturing and Professional and Business Services

Conclusions

Forthcoming***

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Appendix: The Heavy Duty Algebra of the Two-Cone Model

Some of you are desperate to see some algebra for the two-cone equilibrium, and I do not want to disappoint. The rest of you should ignore this appendix. Let's make this as simple as possible and use Cobb-Douglas preferences that fixes the budget shares. Suppose that products are ordered by their capital intensity with product 1 being the most capital intensive and product 3 the least capital intensive. Suppose that Country X produces the capital intensive mix of products 1 and 2 while Country Z produces the labor intensive mix of products 2 and 3. Using the notation $q = A^{-1}v = Bv$ we have

$$\begin{bmatrix} q_1 \\ q_2 \\ q_3 \end{bmatrix} = \begin{bmatrix} B_{1K}K_A + B_{1L}L_A \\ B_{2K}K_A + B_{2L}L_A + C_{2K}K_B + C_{2L}L_B \\ C_{3K}K_B + C_{3L}L_B \end{bmatrix} = \begin{bmatrix} B'_1 v_X \\ B'_2 v_X + C'_2 v_Z \\ C'_3 v_Z \end{bmatrix}$$

$$B = \begin{bmatrix} A_{1K} & A_{2K} \\ A_{1L} & A_{2L} \end{bmatrix}^{-1} = \begin{bmatrix} B_{1K} & B_{1L} \\ B_{2K} & B_{2L} \end{bmatrix} = \begin{bmatrix} B'_1 \\ B'_2 \end{bmatrix},$$

$$C = \begin{bmatrix} A_{2K} & A_{3K} \\ A_{2L} & A_{3L} \end{bmatrix}^{-1} = \begin{bmatrix} C_{2K} & C_{2L} \\ C_{3K} & C_{3L} \end{bmatrix} = \begin{bmatrix} C'_2 \\ C'_3 \end{bmatrix}$$

$$C = (A_{2K}A_{3L} - A_{3K}A_{2L})^{-1} \begin{bmatrix} A_{3L} & -A_{3K} \\ -A_{2L} & A_{2K} \end{bmatrix}$$

The earnings vector for country Z is a function of the product prices

$$w_Z = C'p = (A_{2K}A_{3L} - A_{3K}A_{2L})^{-1} \begin{bmatrix} A_{3L} & -A_{2L} \\ -A_{3K} & A_{2K} \end{bmatrix} \begin{bmatrix} p_2 \\ p_3 \end{bmatrix}$$

With outputs fully determined, we can solve for the two relative prices using the budgets shares

$$\frac{\alpha_1}{\alpha_2} = \frac{p_1 q_1}{p_2 q_2} = \frac{p_1}{p_2} \frac{B'_1 v_X}{B'_2 v_X + C'_2 v_Z}$$

$$\frac{p_2}{p_1} = \frac{\alpha_2}{\alpha_1} \frac{B'_1 v_X}{B'_2 v_X + C'_2 v_Z}$$

$$\frac{p_3 q_3}{p_1 q_1} = \frac{\alpha_3}{\alpha_1}$$

$$\frac{p_3}{p_1} = \frac{\alpha_3}{\alpha_1} \frac{q_1}{q_3} = \frac{\alpha_3}{\alpha_1} \frac{B'_1 v_X}{C'_3 v_Z} =$$

The condition of equilibrium is that the cost of producing product 1 using country Z's factor prices exceeds the price of the product $A'_1 w_Z > p_1$. This can be written as

$$A_1'C'\begin{bmatrix} p_2 \\ p_3 \end{bmatrix} > p_1$$

$$A_1'C'\begin{bmatrix} 1 \\ p_3/p_2 \end{bmatrix} > p_1/p_2$$

$$A_1'C'\begin{bmatrix} 1 \\ \left(\dfrac{\alpha_3 q_2}{\alpha_2 q_3}\right) \end{bmatrix} > \left(\dfrac{\alpha_1 q_2}{\alpha_2 q_1}\right)$$

$$\begin{bmatrix} A_{1K} & A_{1L} \end{bmatrix} C' = (A_{2K}A_{3L} - A_{3K}A_{2L})^{-1} \begin{bmatrix} (A_{1K}A_{3L} - A_{1L}A_{3K}) & (-A_{1K}A_{2L} + A_{1L}A_{2K}) \end{bmatrix}$$

$$= \frac{\left[(A_{1K}/A_{1L} - A_{3K}/A_{3L})A_{3L}A_{1L} \quad -(A_{1K}/A_{1L} - A_{2K}/A_{2L})A_{1L}A_{2L}\right]}{(A_{2K}/A_{2L} - A_{3K}/A_{3L})A_{3L}A_{2L}}$$

$$(A_{1K}/A_{1L} - A_{3K}/A_{3L})A_{3L}A_{1L} >$$

$$(A_{2K}/A_{2L} - A_{3K}/A_{3L})A_{3L}A_{2L}\left(\frac{\alpha_1 q_2}{\alpha_2 q_1}\right) + (A_{1K}/A_{1L} - A_{2K}/A_{2L})A_{1L}A_{2L}\left(\frac{\alpha_3 q_2}{\alpha_2 q_3}\right)$$

$$(A_{1K}/A_{1L} - A_{3K}/A_{3L})A_{3L}A_{1L}\frac{\alpha_2}{q_2} >$$

$$(A_{2K}/A_{2L} - A_{3K}/A_{3L})A_{3L}A_{2L}\left(\frac{\alpha_1}{q_1}\right) + (A_{1K}/A_{1L} - A_{2K}/A_{2L})A_{1L}A_{2L}\left(\frac{\alpha_3}{q_3}\right)$$

Substituting the factor supplies for the outputs we have the condition for the two-cone equilibrium

$$(A_{1K}/A_{1L} - A_{3K}/A_{3L})A_{3L}A_{1L}\frac{\alpha_2}{B'_2 v_X + C'_2 v_Z} >$$

$$(A_{2K}/A_{2L} - A_{3K}/A_{3L})A_{3L}A_{2L}\left(\frac{\alpha_1}{B'_1 v_X}\right) + (A_{1K}/A_{1L} - A_{2K}/A_{2L})A_{1L}A_{2L}\left(\frac{\alpha_3}{C'_3 v_Z}\right)$$

I am at a loss to translate this into something intelligible about factor supplies. Basically the condition requires demand relative to output in the middle sector, α_2/q_2, to be high compared with the same ratios in sectors one and three.