The Ohlin Lectures, 2008

Offshoring in the Global Economy

Lecture 1: Microeconomic Structure

Lecture 2: Macroeconomic Implications

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Lecture 1: Microeconomic Structure

Introduction

Bertil Ohlin, building on the pioneering contributions of Eli Heckscher, wrote shortly after the first golden age of trade, lasting from about 1890 to the beginning of World War I. That period saw dramatic improvements in transportation, such as the steamship and railroads, as well as wireless communication, that greatly facilitated increases in international trade. It is no surprise that Heckscher and Ohlin were led to modify the assumptions of the Ricardian model of trade, and suppose that technologies would spread quickly between countries while resource endowments were the domestic constraint. Their ideas ushered in a new era of trade theory that dominated post-war academic work.

We are arguably now in a second golden age of trade, which like the first, has relied on declines in costs of transportation, such as the container ship, as well as communication, with developing countries leapfrogging to fiber optic cable and cellular telephone services at costs lower than in advanced economies. These costs have now fallen so much that it is possible to break apart the production process, with various stages occurring in different countries. This is the idea of "fragmentation," as Ronald Jones (2000) referred to it in his Ohlin Lecture a decade ago. There are innumerable examples of this fragmentation of the production process, which is alternatively described as "foreign outsourcing," or simply "offshoring", the term that has become popular and that I shall use.

This new feature of globalization means that the spread of technology is even more rapid than in the time of Heckscher and Ohlin. The ability to utilize labor in other countries suggests that domestic resources are no longer the binding constraint on international trade. The speed with which instructions and designs can be transmitted overseas further suggests that these activities need not occur in the same country as production, but that firms can truly search the global economy in order to minimize costs. We might expect, therefore, that a new paradigm is needed to describe this second golden age of trade.

Or is it? Is the Heckscher-Ohlin (HO) model – in all its manifestations – sufficiently rich to guide our understanding of offshoring, or does it leave out some critical elements? That will be an organizing theme for my lectures. To answer this question we might look first at the microeconomic structure of the models being used. I use the term "microeconomic structure" in the same sense as Ronald Jones in his classic 1965 article ("The Structure of Simple General Equilibrium Models"), to refer to features like the number of goods included in the model, the number of factors, whether we are treating world prices as fixed or not, and so forth. It will turn out that these simple assumptions make a huge difference to the results obtained. To see this, we can look at the writings of trade economists in this area.

I will start with the debate between Edward Leamer (1994) and Paul Krugman (2000) that took place in the mid-1990s, focusing on the issue of whether technology or trade explained the change in wages in the U.S. These scholars used differing assumptions on the microeconomic structure, as I will discuss, and therefore reached quite different conclusions. But it is noteworthy that neither Leamer nor Krugman arrived at a satisfactory explanation for the change in wages that occurred in the 1980s. During this decade there was a pronounced shift in the pattern of wages earned by workers in the United States and other countries: relative wages shifted towards more-skilled workers, so that a "wage gap" developed between those with higher and lower skills. The Stolper-Samuelson Theorem would lead us to expect that the movement in world prices could have such an impact on factor prices, but Leamer (1998) rejects that explanation for the 1980s. Alternatively, factor-content calculations might explain the fall in low-skilled wages as due to increased imports in the U.S., especially by developing countries, but Krugman also finds that this explanation is insufficient. Both these negative findings create puzzles that can and should be addressed by later research.

Leamer and Krugman both used very simple versions of the HO model, essentially relying on two goods and two factors. My own work with Gordon Hanson (1996, 1997, 1999) adopts instead a Heckscher-Ohlin structure with a continuum of goods. In that case, it turns out that the patterns of wage changes in the 1980s are entirely consistent with international trade, and in particular, the changes in prices are consistent with the changes in wages. So Hanson and I address the Stolper-Samuelson puzzle raised by Leamer, at least for the 1980s. But the story for the 1990s is quite different. There has continued to be an increase in the relative wage of skilled workers in the U.S., but the relative employment of these workers in manufacturing has fallen. That finding is strongly suggestive of the offshoring of service activities, whereby the more routine service activities are sent overseas. While this is a new phenomenon in the United States, it may have applied to Sweden and other European countries for quite some time.

To explain this new form of offshoring, I will appeal to the recent work of Gene Grossman and Esteban Rossi-Hansberg (2008a), emphasizing what they call "trade in tasks." They present their model of offshoring as a new paradigm, so we should examine how it differs from my earlier work with Hanson and therefore from a many-good Heckscher-Ohlin model. I will argue that in the case of offshoring the tasks performed by low-skilled labor, the results obtained by Grossman and Rossi-Hansberg (2008a) are broadly similar to those in my earlier work with Hanson; and furthermore, the differences between us and them echo some of the same issues of microeconomic structure that arose in the debate between Leamer and Krugman.

However, when we consider instead the offshoring of tasks that use *high-skilled labor*, like service tasks, then their framework can provide results that are quite different from my earlier work, but consistent with the recent empirical observations for the U.S.

I will conclude my lecture today by returning to the puzzle raised by Krugman: why the factor-content calculations are not able to explain the pattern of wage changes in the United States. In his very recent paper for the Brooking Institution, Krugman (2008) speculates that the failure of the factor-content approach may be due to aggregation bias: computing factor contents at an aggregate level that hides their true magnitudes. I will confirm this idea, and present some new calculations of the factor-content of trade for the U.S. These calculations confirm the relevance of the Heckscher-Ohlin model even in the presence of offshoring, and the continued relevance of that model to the trade in the global economy today.

Evidence from U.S. Manufacturing

Let me begin with offshoring and its impact on wages in the United States. In Figures 1.1 and 1.2, I use data from the manufacturing sector to measure the wages of “nonproduction” relative to “production” workers. As their name suggests, nonproduction workers are involved in service activities, while production workers are involved in the manufacture and assembly of goods. These two categories can also be called “non-manual” versus “manual”, or “white collar” versus “blue collar.” Generally, nonproduction workers require more education, and so we will treat these workers as skilled, while production workers are less skilled.

In Figure 1.1, we see that the earnings of nonproduction relative to production workers moved erratically from the late 1950s to the late 1960s, and from that point until the early 1980s, relative wages were on a downward trend. It is generally accepted that the relative wage fell

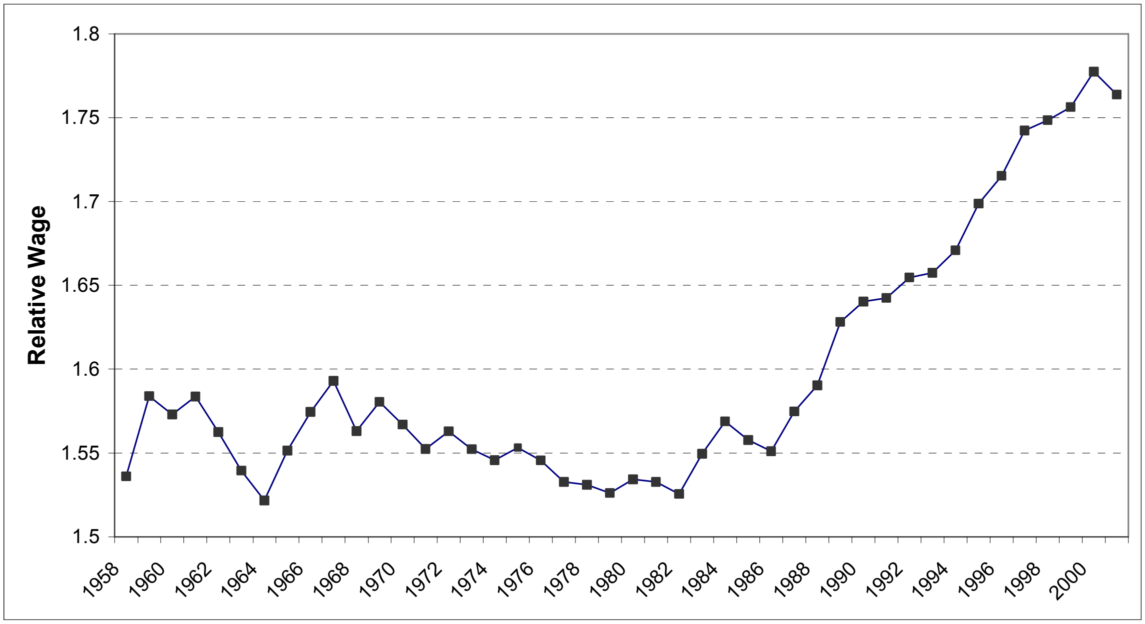

Figure 1.1: Relative Wage of Nonproduction/Production Workers, U.S. Manufacturing

Source: Updated from National Bureau of Economic Research productivity database.

during this period because of an increase in the supply of college graduates, skilled workers who moved into nonproduction jobs. Starting in the early 1980s, however, this trend reversed itself and the relative wage of nonproduction workers increased steadily to 2000, with a slight dip in 2001. The same increase in the relative wages of skilled workers has been found for other industrial and developing countries.

Turning to Figure 1.2, we see that there has been a steady increase in the ratio of nonproduction to production workers through the end of the 1980s, but then a fall in the 1990s. The increase in the relative supply of workers can account for the *reduction* in the relative wage of nonproduction workers through the 1970s, as shown in Figure 1.1, but is at odds with the *increase* in the relative nonproduction wage during the 1980s. The rising relative wage should have led to a shift in employment *away* from skilled workers, along a demand curve, but it did not. Thus, the only explanation consistent with these facts is that there has been an *outward shift* in the demand for more-skilled workers during the 1980s, leading to an increase in their relative employment and wages, as shown in Figure 1.3.

What factors can lead to an outward shift in the relative demand for skilled labor? Such a shift can arise from the use of computers and other high-tech equipment, or *skill-biased technological change.* Researchers such as Berman, Bound and Griliches (1994) argued that such technological change was the dominant explanation for the rising relative wage of skilled labor in the United States, and other countries. Their reason for rejecting international trade as an explanation was the finding that the majority of the increase in the manufacturing wage and employment of non-production workers was caused by shifts *within* industries, and not by shifts *between* industries. That is, the outward shift in relative demand being illustrated in Figure 1.3 applied to many individual industries, as well as in the aggregate. In their view, that ruled out the

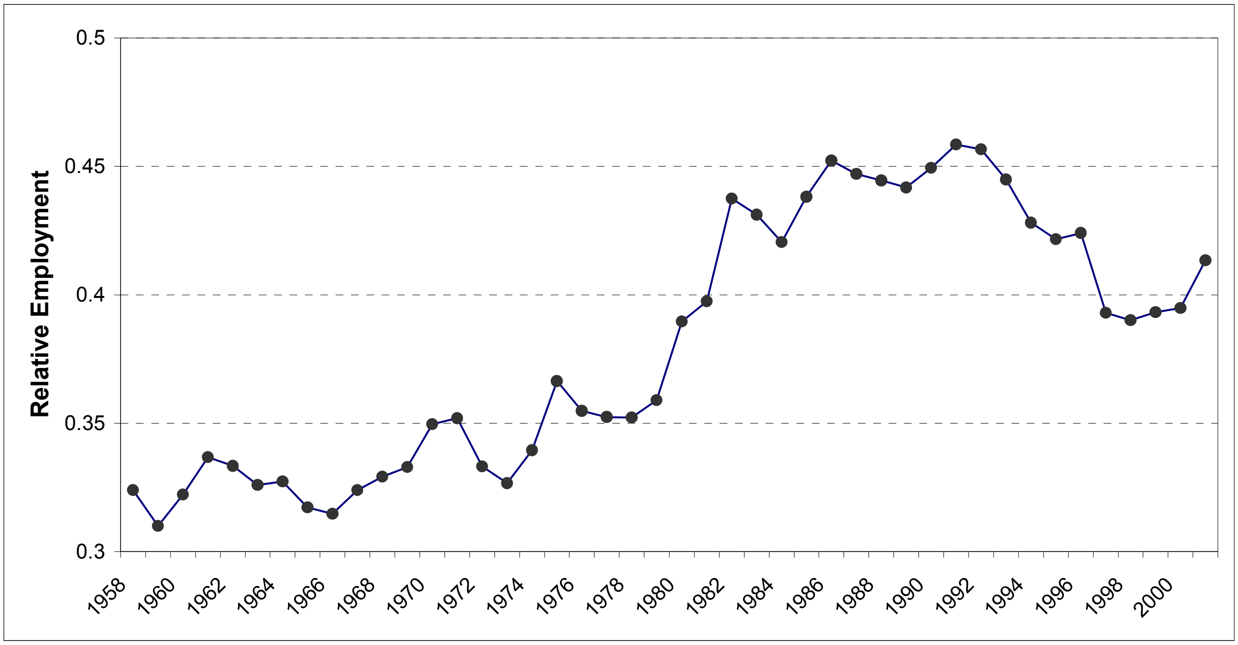

Figure 1.2: Relative Employment of Nonproduction/Production Workers, U.S. Manufacturing

Source: Updated from National Bureau of Economic Research productivity database.

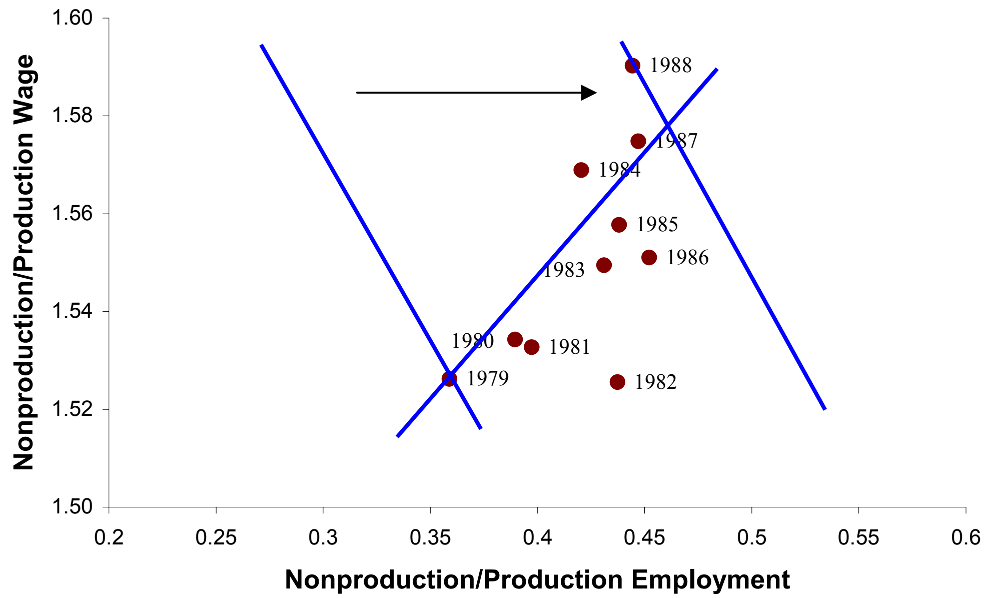

Figure 1.3: Nonproduction/Production Workers, 1980s

Source: National Bureau of Economic Research productivity database.

Heckscher-Ohlin model as an explanation, since in that model they expected to see a shift between industries instead of within industries.

Their findings for the United States were reinforced by the work of and Berman, Bound and Machin (1998), who looked at cross-country data. They found that the same shift towards skilled workers in the U.S. also occurred abroad. That again appeared to rule out the Heckscher-Ohlin model as an explanation, because in that model we expect wages to move in opposite directions between countries when comparing autarky to free trade, as factor price equalization occurs. Instead, the evidence was that wages were moving in the same direction – with an increase in the relative wage of skilled workers.

And it was not just labor economists who feel that skill-biased technological change is the dominant reasons for the shift in labor demand toward more-skilled workers. That explanation is favored, for example by the eminent economist Jagdish Bhagwati. Writing in the *Financial Times* last year, he states that:[1]

> The culprit is not globalization but labour-saving technical change that puts pressure on the wages of the unskilled. Technical change prompts continual economies in the use of unskilled labour. Much empirical argumentation and evidence exists on this.

For the empirical evidence, Bhagwati cites Paul Krugman and myself, as well as the labor economists George Borjas and Larry Katz. In fact, I will argue that my own views have always favored a trade-based explanation, and that the views of Krugman and others may be changing. But before making these arguments it is best to go back to the beginning of the debate on trade and wages, to examine the initial response of trade economists to the idea that skill-biased technological changes was the dominant explanation.

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1 Jagdish Bhagwati, "Technology, Not Globalization, is Driving Wages Down", *Financial Times,* January 4, 2007, p. 11.

Factor-bias versus Sector-bias of Technological Change

Edward Leamer (1994, 1998) was among the first trade economist to respond. He rejected the claim that skill-biased technological change could explain the shifts in wages for the United States because, in his view, the factor-bias of technical change is not important: only the *sector-bias* matters. To make this argument, he starts with the zero profit conditions for industries i = 1,…,N, which are:

$$p_i = \sum_{j=1}^{M} a_{ij} w_j , \qquad i = 1,\ldots,N.$$

Differentiating these and allowing for exogenous changes in the factor requirements a_{ij}, we obtain:

$$\hat{p}_i = \sum_{j=1}^{M} \theta_{ij}\hat{w}_j + \sum_{j=1}^{M} \theta_{ij}\hat{a}_{ij} , \qquad i = 1,\ldots,N.$$

The second term above is the negative of total factor productivity growth, which is:

$$TFP_i \equiv \hat{y}_i - \sum_{j=1}^{M} \theta_{ij}\hat{x}_{ij} = -\sum_{j=1}^{M} \theta_{ij}\hat{a}_{ij} .$$

Therefore, the differentiated zero-profit conditions are stated as follows:

$$\hat{p}_i + TFP_i = \sum_{j=1}^{M} \theta_{ij}\hat{w}_j , \; i = 1,\ldots,N.$$

Now suppose that the country is small, so that prices do not change. Then it is immediate from this equation that the sector-bias of technological change, or TFP_i, will determine the change in factor prices. This argument can be illustrated quite simply in Figure 1.4, where I graph the zero-profit condition in two industries, where low-skilled labor earns the wage of w and high-skilled labor earns the wage of q. Suppose that there is technological progress affecting *either* factor in industry 2, which is skilled-labor intensive. Then that industry can afford to pay more to both

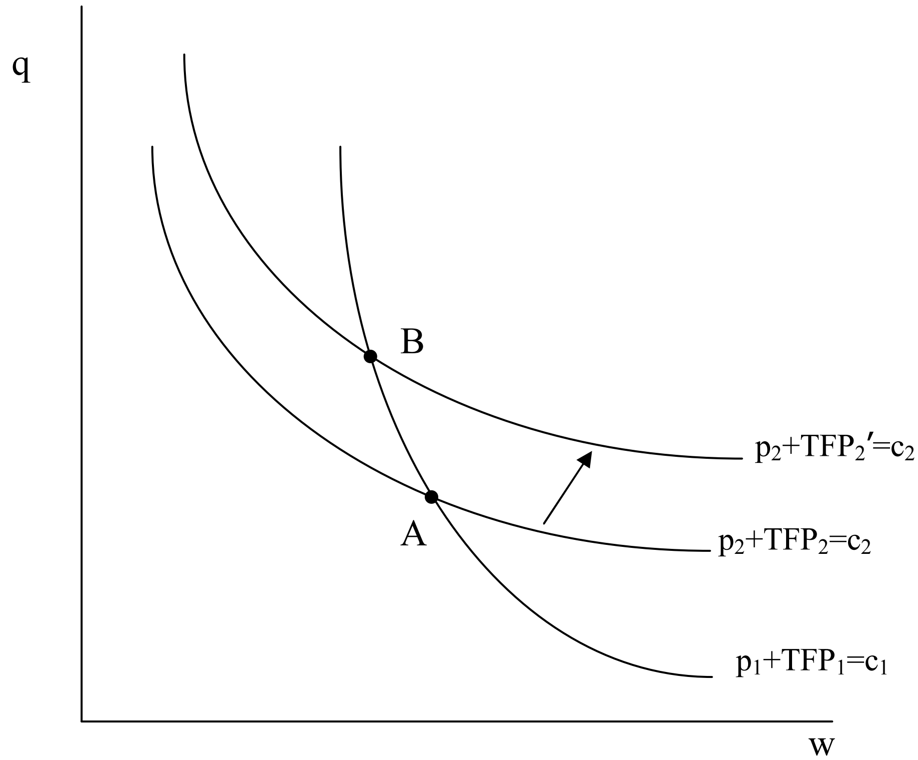

Figure 1.4: Technical Progress in Sector 2

factors, so its zero-profit contour shifts up. As a result, the wage earned by skilled labor rises and the wage for unskilled labor falls, regardless of whether the technological progress was biased towards one factor or the other. That is the point that Leamer is making.

This relationship between changes in prices and wages is called the "mandated wage equation", and is estimated as a regression of the log change in industry prices on factor shares:

$$\Delta \ln p_{it} + TFP_{it} = \sum_{j=1}^{M} \tfrac{1}{2}(\theta_{ijt} + \theta_{ijt-1})\beta_j , \qquad i = 1,\ldots,N.$$

The regression coefficients β are the "mandated" change in factor prices that are consistent with a competitive economy, and therefore consistent with the Stolper-Samuelson theorem. We interpret the Stolper-Samuelson theorem as being validated by the data provided that the estimates β of the factor-price changes are close to their true values for the economy.

When estimating this regression for the United States, Leamer and other authors[2] often find estimates of β that are quite far off the mark: they do not reflect the actual change in wages that occurred, and are quite sensitive to the data used and specification of the regression.[3] I believe there is a good explanation for why this regression does not work as well as expected, as I will describe in a moment, but first I would like to turn to the response that Krugman gives to Leamer's arguments.

Published in the Jubilee issue of the *Journal of International Economics* in 2000, but written five years earlier, Krugman argues that the sector bias of technological change matters only in a small-country model, with fixed world prices, which was the assumption that Leamer

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[2] See Sachs and Schatz (1994, 1998), as well as Krueger (1997).

[3] Nevertheless, Leamer still refers to the 1970s as the "Stolper-Samuelson decade," in the sense that that it is changes in product prices, and not total factor productivity, that are principally responsible for the change in wages.

made. Leamer is careful to qualify his results for that reason.[4] But Krugman makes an important theoretical point: if world prices are endogenously determined, and under the simplifying assumption of Cobb-Douglas preferences, then the sector-bias of technological changes completely cancels out and has no impact at all on factor prices. Instead, only the factor-bias matters, contrary to Leamer's arguments.

To illustrate this point, Krugman considers a closed economy with two sectors and two factors – skilled and unskilled labor, where we assume for convenience that preferences are Cobb-Douglas. Now suppose that either one of the sectors has Hicks-neutral technological progress: then how does that affect the relative demand for labor? The answer is not at all: Hicks-neutral progress lowers the price of that good and raises its demand by just the amount needed to leave relative factor demands unchanged. Since relative demand is unchanged, then the relative wage is also unchanged by neutral technological progress. Furthermore, this result continues to hold in a two-country HO model with factor price equalization, provided that the Hicks neutral technological shift is worldwide.

So in strong contrast to Leamer's small-country case, the sector bias of Hicks-neutral technological change does not matter at all. But the factor-bias clearly does matter: if either sector has skilled-biased technological change, for example, then the demand for skilled labor shifts out, raising its relative wage. So the large-country case puts the focus squarely back onto the skill-bias of technological change.

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4 Leamer (1994, p. 14) recognizes that if technological change leads to induced changes in product prices, then the implied change in wages are impacted. He writes: "One last point. These derivatives for studying technological changes take prices as given, but, if the technological improvement is nonneutral, nonproprietary and worldwide, the increased relative supply of the technologically advantaged products is likely to be accompanied by offsetting reductions in their relative prices. An estimate of the full effect of technological change on wages would of course have to allow for these induced price changes." See also Leamer (1998, p. 182): "Thus, to do the job right, we really need a complete worldwide, general equilibrium model, input-output model. We need this to deal with second-order effects, to deal with pass-through rates, and also to determine sectoral-biased price changes induced by factor-biased technological change."

In the same article, Krugman argues that factor-content calculations from the HO model are relevant, and should be viewed as changes in effective factor endowments in terms of their impact on wages. But it turns out that when this argument is quantified, the actual change in factor contents is just too small to affect wages by anything like the amount observed. So that leaves Krugman with a puzzle, that I will return to at the end of the lecture today.

Offshoring versus Technological Change

Summing up, neither Leamer nor Krugman arrived at a satisfactory explanation for change in wages that occurred in the 1980s. But even if a simple two-good, two-factor cannot explain the shift in relative labor demand toward skilled labor, perhaps a more general specification of the Heckscher-Ohlin model can. In my work with Gordon Hanson (Feenstra and Hanson, 1996, 1997), we present a model of an industry in which there are many “activities,” denoted by z, arranged along a “value chain.” For convenience we arrange these activities in increasing order of their ratio of skilled to unskilled labor used in each activity. The structure of this model is very similar to a Heckscher-Ohlin model with a continuum of goods, as in Dornbusch, Fischer and Samuelson (1980), except that we now think of all these activities as taking place within the same industry.

Formally, we specify the unit-costs of each activity as:

$$c(w,q,r,z) = B[wa_L(z) + qa_H(z)]^{\theta} r^{1-\theta},$$

with the same technologies used in the foreign country, except that we allow the country-wide technology parameter B* to differ from B. The outputs x(z) from these activities are combined in a Cobb-Douglas fashion to produce a single, final output:

$$Y = \int_0^1 \alpha(z) x(z) dz \,.$$

We suppose that relative wage of skilled labor is higher in the foreign country, and the rental on capital is also higher:

$$\frac{q}{w} < \frac{q^*}{w^*}, \quad \text{and} \quad r < r^*.$$

Then just like the Heckscher-Ohlin model with a continuum of goods, in a trade equilibrium we will find that countries specialize in different portions of the skill continuum. Under our assumption that the relative wage of skilled labor is higher abroad, and that goods are arranged in increasing order of their skill intensity, then the ratio of the home to foreign unit-costs is downward sloping, as shown by the schedule c/c* in Figure 1.5. Foreign production – or offshoring – occurs where the relative costs at home are greater than unity, in the range [0,z'), whereas home production occurs where the relative costs at home are less than unity, in the range (z',1]. The borderline activity z' is determined by equal unit costs in the two countries:

$$\frac{c(w, q, r, z')}{c(w^*, q^*, r^*, z')} = 1 \ .$$

Using this unique borderline activity z', we can then calculate the demand for labor in each country. At home, for example, the relative demand for skilled/unskilled labor is:

$$D(z') = \frac{\int_{z'}^{1} \frac{\partial c}{\partial q} x(z) dz}{\int_{z'}^{1} \frac{\partial c}{\partial w} x(z) dz} \ .$$

It can be shown that this schedule is a downward sloping function of the relative wage. A downward sloping relative demand curve applies to the foreign country, too, where now we integrate over the activities in [0, z'). In both countries, equilibrium factor prices are determined by the equality of relative demand and supply.

Suppose now that the home firm wishes to offshore more activities. The reason for this could be a capital flow from the home to foreign country, reducing the rental abroad and

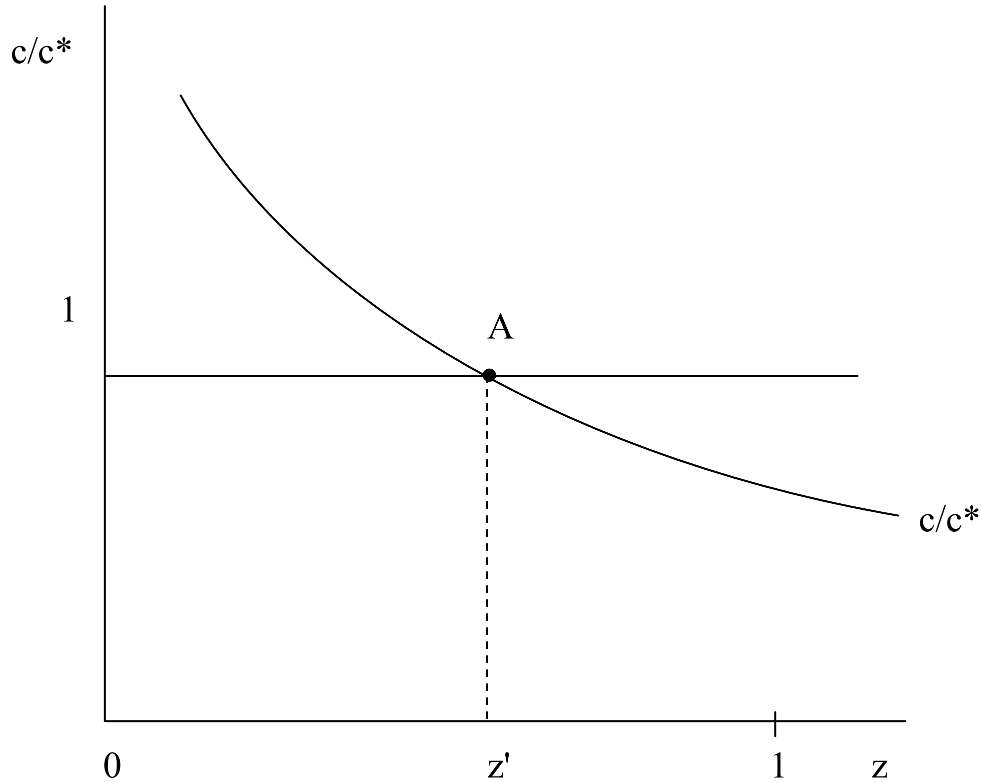

Figure 1.5: Value Chain of Production

increasing it at home; or alternatively, technological progress abroad, neutral across all the activities, but exceeding such progress at home. In both cases, the relative costs of production at home rise, which is an upward shift in the relative cost schedule. As a result, the borderline between the activities performed at home and abroad therefore shifts from the point z' to the point z*, with z* > z', as shown in Figure 1.6.

What is the impact of this increase in offshoring on the relative demand for skilled labor at home and abroad? Notice that the activities no longer performed at home (those in-between z' and z*) are *less* skill-intensive than the activities still done there (those to the right of z*). This means that the range of activities now done at home are more skilled-labor intensive, on average, than the set of activities formerly done at Home. For this reason, the relative demand for skilled labor at home increases, as occurred in the United States during the 1980s. That increase in demand will also increase the relative wage for skilled labor, as shown in Figure 1.7.

What about in the foreign country? The activities that are newly sent offshore (those in-between z' and z*) are *more* skill-intensive than the activities that were initially done in the foreign country (those to the left of z'). That means that the range of activities now done abroad is also more skilled-labor intensive, on average, than the set of activities formerly done there. For this reason, the relative demand for skilled labor in the foreign also increases. With this increase in the relative demand for skilled labor, the relative wage of skilled labor *also* increases in the foreign country. That outcome occurred in as Mexico, for example, during the 1980s, as well as in Hong Kong and other developing countries.

To summarize, this model of Feenstra and Hanson, which borrows the structure of the Heckscher-Ohlin model with a continuum of goods, gives an explanation for the increase in the relative demand for skilled-labor that was observed across countries during the 1980s. Of course,

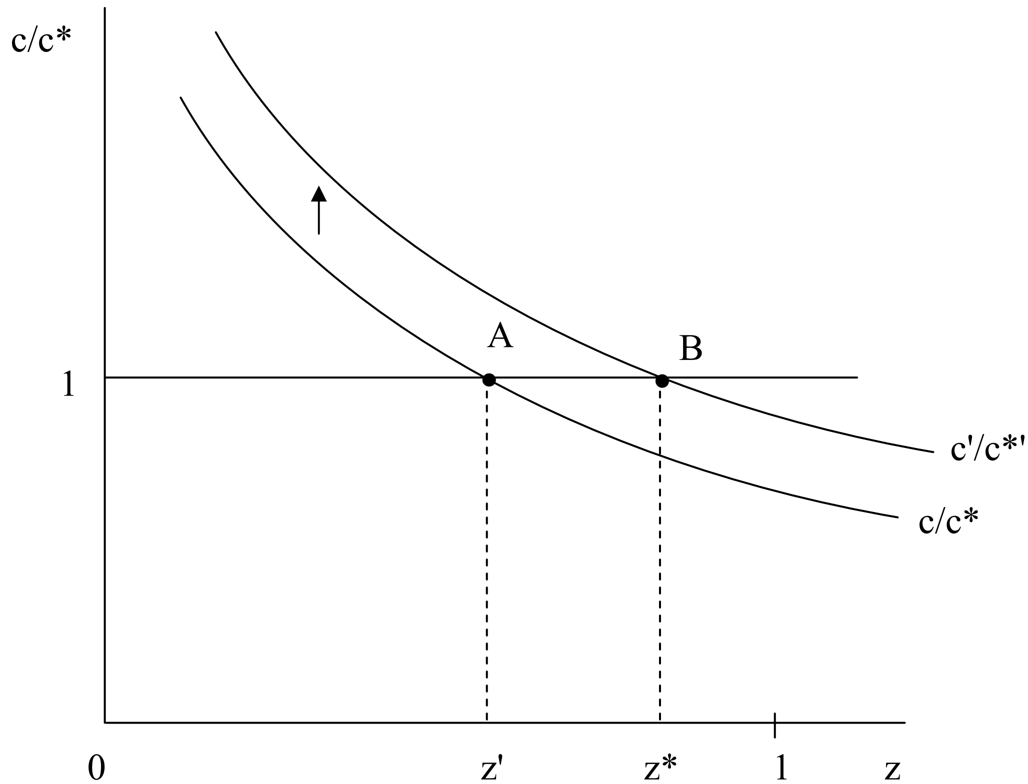

Figure 1.6: Increase in Offshoring

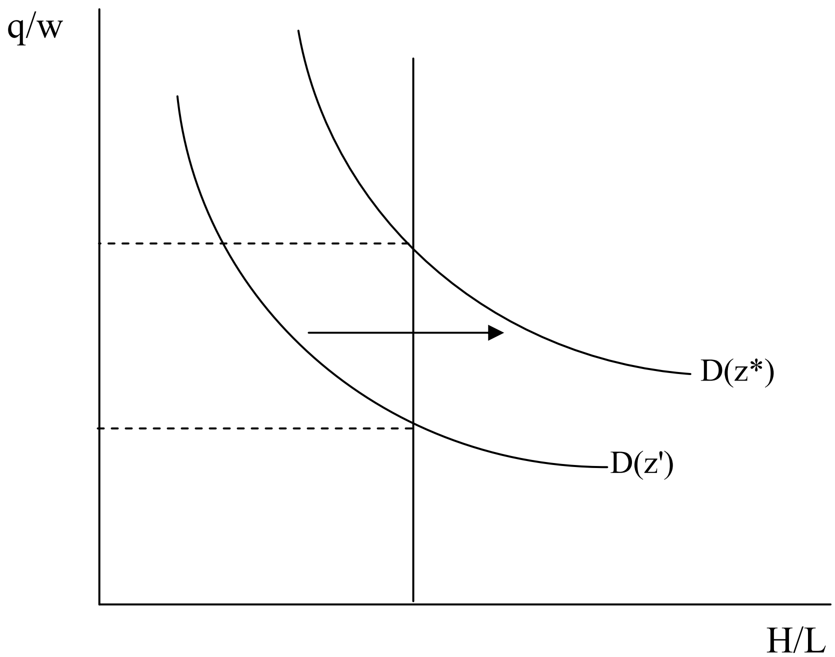

Figure 1.7: Increase in the Relative Demand for Skilled Labor

this explanation does not *prove* that offshoring was the source of the wage changes, since *skill-biased technological change* is equally well an explanation. So determining which of these explanations accounts for the changes observed during the 1980s is an empirical question.

To address that issue, Hanson and I (Feenstra and Hanson, 1999) start again with the mandated wage equation suggested by Leamer, but modify this equation in a fundamental way. We recognize that in any dataset, the wages paid to skilled and unskilled labor differ across industries. We incorporate those inter-industry wage differentials into the model by re-writing the zero-profit conditions as:

$$p_i = \sum_{j=1}^{M} a_{ij} w_{ij} \text{ , } i = 1,\ldots,N.$$

where the wages w_{ij} now differ across industries i and factor j. Differentiating these zero-profit condition we obtain:

$$\hat{p}_i + TFP_i = \sum_{j=1}^{M} \theta_{ij} \hat{w}_{ij} \text{ , } i = 1,\ldots,N.$$

When this regression is run as a mandated wage equation, we are treating the factor price changes as common across industries, thereby ignoring the inter-industry wage differentials. That is, letting $\hat{\bar{w}}_j$ denote the *average* value of the change in factor price j across industries, we are actually running the regression,

$$\hat{p}_i + TFP_i = \sum_{j=1}^{M} \theta_{ij} \hat{\bar{w}}_j + \varepsilon_j, \qquad i = 1,\ldots,N.$$

where the error term is,

$$\varepsilon_j \equiv \sum_{j=1}^{M} \theta_{ij} (\hat{w}_{ij} - \hat{\bar{w}}_j),$$

and reflects the difference between the change in the industry and average factor prices.

When Leamer and other authors have run the mandated wage regression they have ignored the presence of error term ε_j, leading to a potential bias in the estimated coefficients. But in fact, we can construct this error term from data on industry wages as compared to the overall average wage, and incorporate it into our estimation. One way to achieve that is to define a dual measure of *effective* TFP as:

$$ETFP_{it} \equiv \sum_{j=1}^{M} \tfrac{1}{2}(\theta_{ijt} + \theta_{ijt-1})\Delta \ln \overline{w}_{jt} - \Delta \ln p_{jt}, \qquad i = 1,\ldots,N.$$

That is, we are using the economy-wide change in wages rather than the industry wages to define effective TFP. In this case the mandated wage equation clearly holds as an identity:

$$\Delta \ln p_{jt} + ETFP_{it} \equiv \sum_{j=1}^{M} \tfrac{1}{2}(\theta_{ijt} + \theta_{ijt-1})\Delta \ln \overline{w}_{jt}, \qquad i = 1,\ldots,N.$$

Running this regression gives estimated coefficients on the average factor shares that exactly match the economy's average changes in factor prices.

To move beyond this identity and estimate the impact of offshoring or skilled-biased technological change on factor prices, Hanson and I recommend a two-step procedure. First, we regress the change in prices plus effective TFP on various structural variables Z that we think could affect factor prices.

$$\Delta \ln p_i + ETFP_i = \alpha_0 + \alpha_1 \Delta Z_{1i} + \alpha_2 \Delta Z_{2i}, \quad i = 1,\ldots,N.$$

In the second step, we then take the estimated coefficients $\hat{\alpha}_1$ and $\hat{\alpha}_2$, and use these to construct the dependent variables for the following regressions,

$$\hat{\alpha}_1 \Delta Z_{1i} = \sum_{j=1}^{M} \tfrac{1}{2}(\theta_{ijt} + \theta_{ijt-1})\Delta \ln \beta_{1j}, \quad \text{and,}$$

$$\hat{\alpha}_2 Z_{2i} = \sum_{j=1}^{M} \tfrac{1}{2}(\theta_{ijt} + \theta_{ijt-1})\Delta \ln \beta_{2j}, \quad i = 1,\ldots,N.$$

That is, we take the portion of price and productivity changes that are explained by each structural variable, and regress that on the factor shares, to obtain estimates of the change in factor prices explained by that structural variable.

We consider two such variables: offshoring and the use of high-tech equipment such as computers. Offshoring is measured as the intermediate inputs imported by each industry, using either a broad definition where we include all imported inputs, or a narrow definition where we focus on imported inputs within the same overall industry (e.g. the automobile industry importing auto parts). In addition, high-technology equipment can be measured in two ways: either as a fraction of the total capital equipment installed in each industry; or as a fraction of new investment in capital that is devoted to computers and other high-tech devices.

In Table 1.1, I report the results from the broader measure of offshoring, including imported inputs from other industries, for the 1980s. Using the first measure of high-tech equipment (i.e. fraction of the capital stock), the results in the first row show that roughly 25% of the increase in the relative wage of nonproduction workers was explained by offshoring, and about 30% of that increase was explained by the growing use of high-tech capital. So we conclude that both offshoring and the increased use of high-tech capital are important in explaining the actual increase in the relative wage of skilled workers. In the second row we use the other measure of high-tech equipment (i.e. fraction of new investment). In that case, the large spending on high-tech equipment in new investment can explain *nearly all* (99%) of the increased relative wage for nonproduction workers, leaving little room for offshoring to play much of a role (it explains only 12% of the increase in the relative wage). These results are lopsided enough that we might be skeptical of using new investment to measure high-tech equipment and therefore prefer the results using the capital stocks.

Table 1.1: Impact on the Relative Wage of Nonproduction Labor in U.S. Manufacturing, 1979-1990

	Percent of Total Increase Explained by each Factor	
	Offshoring	High-technology Equipment
Measurement of high-tech equipment:		
As a share of the capital stock	21 – 27%	29 – 32%
As a share of capital flow (i.e. new investment)	12%	99%

Source: Robert C. Feenstra and Gordon H. Hanson, "The Impact of Outsourcing and High-Technology Capital on Wages: Estimates for the U.S., 1979-1990," *Quarterly Journal of Economics*, August 1999, 114(3), 907-940.

I mention these final results because labor economists, such as Larry Katz and David Autor (1999), often use high-tech equipment as a fraction of new investment, which explains why they find little scope for international trade to be important in their regressions. Those views might be changing, however. Interviewed for an article in the *New York Times* last year, David Autor said that:[5] "The consensus until recently was that trade was not a major cause of the earnings inequality in this country …That consensus is now being revisited."

Summing up, both offshoring and high-tech equipment are important explanations for the shift in demand towards nonproduction workers in U.S. manufacturing, though the relative contributions of the two measures are sensitive to how we measure high-tech equipment. But the results I have reported so far are only part of the story, since I have focused on explaining the *relative* wage of nonproduction workers. Instead, we could ask about the *real wages* of nonproduction and production workers.

Regardless of how offshoring affects the relative wages, it is entirely possible that the *real wages* of all workers will improve. The reason for this improvement is that offshoring leads to a productivity increase for firms, which will lower the prices for final goods. It is certainly possible that the drop in prices exceeds the fall in the wage of either type of worker, so that real wages improve in theory. The actual data for the real wages of production workers in U.S. manufacturing are shown in Figure 1.8, and tell a mixed story. From the mid-1980s to the mid-1990s, real wages of production workers fell. Fortunately, they recovered in the latter part of the 1990s, so that by 2000 real wages exceeded their level in earlier years. They have continued to rise, but with a slight dip in 2004.

To see the impact of offshoring on real wages, let us return to my earlier study with

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5 Louis Uchitell, "To Mend the Flaws in Trade," *The New York Times*, January 30, 2007, pp. C1-C7.

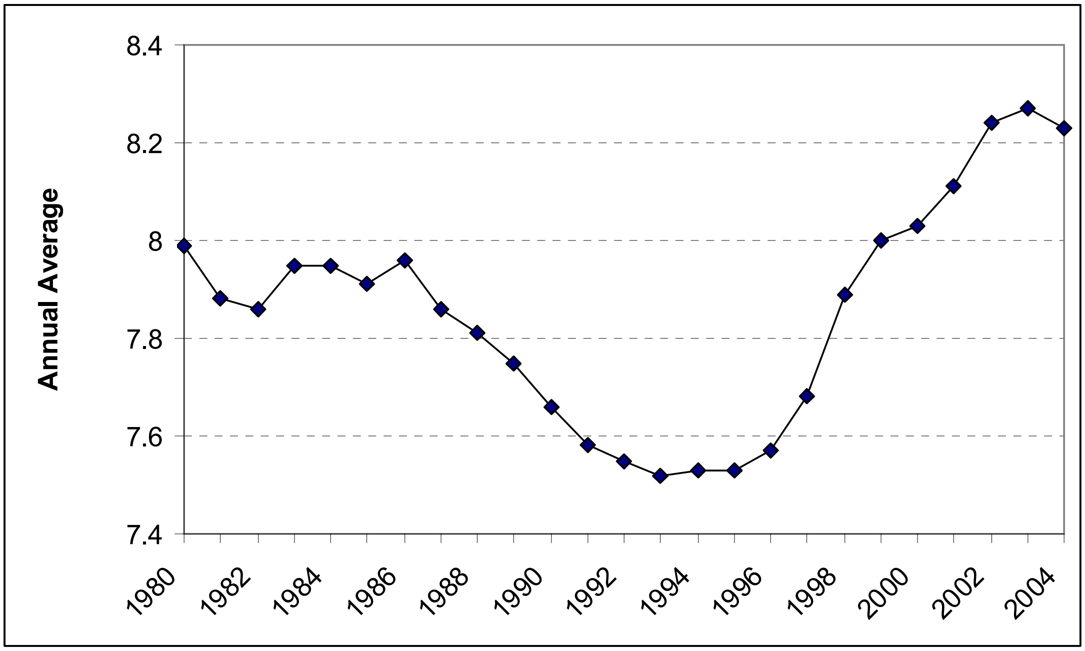

Figure 1.8: Real wages of Production Workers, U.S. manufacturing (1982 dollars)

Source: Bureau of Labor Statistics

Hanson (1999). The two-step procedure allows us to isolate the impact of offshoring and the increased use of high-tech capital on the real wage, directly from the regression coefficients in the second stage. Let me focus on the most reliable case where high-tech capital is measured as a share of the capital stock. In Table 1.2, I record our estimates of the impact of offshoring during the 1980s on real wages of nonproduction and production workers. For nonproduction workers, we find that their real wages rose between 1 and 2% over the entire decade due to offshoring, and closer to 3% over the decade due to the increased use of high-technology capital. For production workers, we cannot identify any significant impact of offshoring on their real wage, and a very slight positive impact of the increased use of high-tech capital. So for both types of labor, there is no evidence at all that real wages are negatively impacted at all due to offshoring in the 1980s. These are the results that Jagdish Bhagwati refers to in his writings, to support the view that offshoring does not harm labor.

Offshoring in the 1990's and Services

Let me turn now to consider the evidence in the United States for the 1990s. The picture for the 1980s is well-known and launched dozens of research studies, but it is surprising that the picture for the 1990s – shown in Figure 1.9 – is not yet familiar. We see that from 1989-2000, there continued to be an increase in the relative wage of nonproduction/production labor in U.S. manufacturing, but in addition, there was a *decrease* in the relative employment of these workers. There are two possible explanations for this shift suggested by the literature. First, some labor economists have argued that the 1990s witnessed a changing pattern of labor demand, benefitting those in the highest and lowest-skilled occupations, at the expense of others in moderately skilled occupations. Autor, Katz and Kearney (2008, p. 301) attribute this once again to technological change: "…we find that these patterns may in part be explained by a richer

Table 1.2: Impact on the Real Wages of Nonproduction and Production Labor in U.S. Manufacturing, 1979-1990

	Percentage Increase Explained by each Factor	
	Offshoring	High-technology Equipment
Type of Labor:		
Real wage of nonproduction workers	1.1 – 1.8%	2.7 – 2.8%
Real wage of production workers	0%	0 – 0.3%

Source: Robert C. Feenstra and Gordon H. Hanson, "The Impact of Outsourcing and High-Technology Capital on Wages: Estimates for the U.S., 1979-1990," *Quarterly Journal of Economics*, August 1999, 114(3), 907-940. Takes the annual percentage changes recorded in Table 1.V and multiplies them by 11 years. High-tech equipment is measured as a share of the capital stock.

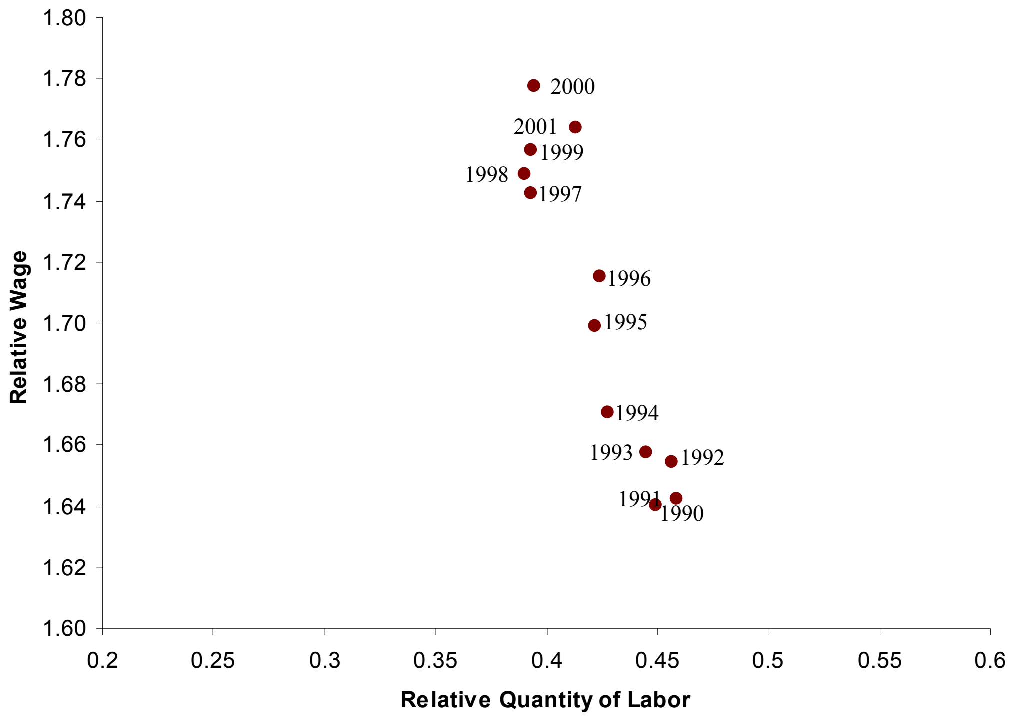

Figure 1.9: Relative Wage and Employment of Nonproduction/Production Workers, 1990-2000

Source: Updated from National Bureau of Economic Research productivity database.

version of the skill-biased technical change (SBTC) hypothesis in which information technology complements highly educated workers engaged in abstract tasks, substitutes for moderately educated workers performing routine tasks, and has less impact on low-skilled workers performing manual tasks."

A second possibility is that Figure 1.9 is a "smoking gun" for service offshoring from U.S. manufacturing. To the extent that the back-office jobs being offshored from manufacturing use the lower-paid nonproduction workers, then the offshoring of those jobs could very well *raise the average* wage among nonproduction workers, while lowering their employment. So like we found for the 1980s, we once again have two different explanations for the change in wages and employment: the first, emphasized by labor economists drawing on technological change, and the second emphasizing offshoring, but of a different type than was found in the 1980s.

It might be admitted that both the labor economists arguing that technical change explains the shifting wages, and the trade economists suggesting that service offshoring is the reason, are both in danger of relying on an *ad hoc* explanation: with the pattern of wage and employment changes differing from the 1980s, we just change the nature of technological change or offshoring, and still present these as the relevant explanations. To avoid this pitfall, we need to back up the case with compelling theoretical or empirical evidence. Let us first ask whether there is any new theory that can guide us.

It turns out that there is, due to Gene Grossman and Esteban Rossi-Hansberg (2008a). These authors prefer to think of "tasks" performed by high-skilled or low-skilled labor, rather than "activities" that combine factors, which is what Hanson and I used. They present a simple two-sector model of the economy, where in each sector and for each factor there are a continuum of tasks. Any of these tasks could be offshored, and if that occurs, then the home firm will use its *own* technology abroad. While Grossman and Rossi-Hansberg do not specify whether the offshoring is done inside or outside of the firm, the fact that the home technology is transferred abroad suggests a multinational relationship between the firms.

Focusing first on low-skilled labor, offshoring one unit of task i means that $\beta t(i)$ units of low-skilled labor must be employed abroad. The tasks are ordered so that the function $t(i)$ is increasing, as shown in Figure 1.10. The amount $\beta t(i)$ indicates the "extra" labor that must be employed abroad to achieve the same outcome as one unit of labor at home. This formulation is similar to Paul Samuelson's iceberg transport costs, in the sense that it is the services of low-skilled labor itself that gets used up in the offshoring process.

We follow Grossman and Rossi-Hansberg in further assuming that the offshoring costs $\beta t(i)$ are identical in the two sectors. Then the equilibrium amount of offshoring is determined where the costs of performing the borderline task abroad, or $w^*\beta t(I)$, equals its cost at home,

$$w^*\beta t(I) = w.$$

This equilibrium condition for offshoring needs to be supplemented with the zero-profit and the full-employment conditions. The zero-profit conditions are that the sum of costs of domestic and offshored labor for each unit of production equal the price, or,

$$p_j = wa_{Lj}(1-I) + w^* a_{Lj}\int_0^I \beta t(i)di + sa_{Hj}, \qquad j = 1,2.$$

Using the equilibrium offshoring condition, zero profits are re-written as:

$$p_j = wa_{Lj}\Omega(I) + sa_{Hj}, \qquad j = 1,2.$$

where,

$$\Omega(I) = (1-I) + \int_0^I t(i)di \,/\, t(I) < 1.$$

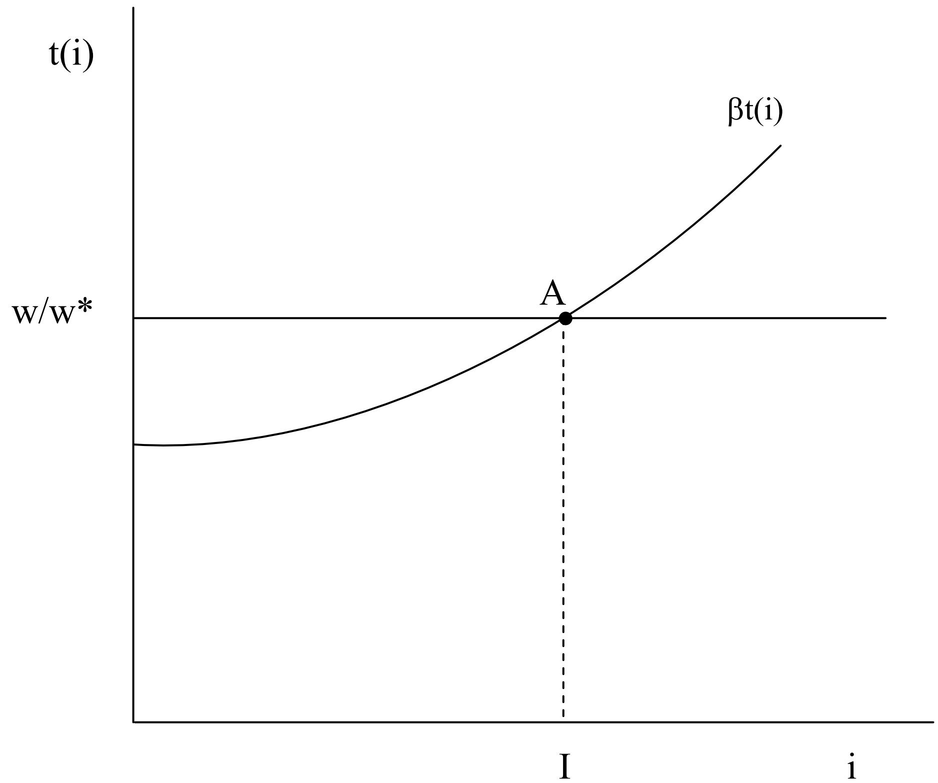

Figure 1.10: Equilibrium with Costs of Offshoring

Notice that in this zero-profit condition, offshoring acts just like a low-skilled labor-saving technological innovation, or another form of skill-biased technological change. We can therefore graph two zero-profit conditions to determine the factor prices, as at point A in Figure 1.11, recognizing that the iso-cost curves depend on the amount of offshoring.

Now suppose there is a reduction in the costs of offshoring, which is a fall in β. In Figure 1.12, there is an increase in the amount of offshoring as I increases to I', holding wages fixed for the moment. That acts like a low-skilled labor-saving innovation, which shifts both the iso-cost curves to the right horizontally in Figure 1.13. The new equilibrium is established where the wage of low-skilled labor has increased, while the wage of high-skilled labor is unchanged. The reason for this increase in the low-skilled wage, as emphasized by Grossman and Rossi-Hansberg, is that offshoring acts like a productivity increase for low-skilled labor. That group that gains the most from offshoring, because their productivity is enhanced: both the real wage and the relative wage of unskilled labor go up.

This result received substantial attention when it was presented at the meeting of the Federal Reserve Bank in Jackson Hole, Wyoming, in 2006 (Grossman and Rossi-Hansberg, 2007), meriting a write-up in the *Economist* magazine at the time and again last year. Let me quote from that article:[6]

> Offshoring makes firms more productive. The tasks that are best kept close to home remain onshore; other tasks can be taken care of in cheaper places abroad. Everyone benefits from this gain in productivity, including workers who have fewer tasks to perform.

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[6] *The Economist,* Economics Focus, "The Great Unbundling: Does Economics Need a New theory of Offshoring?," January 18, 2007.

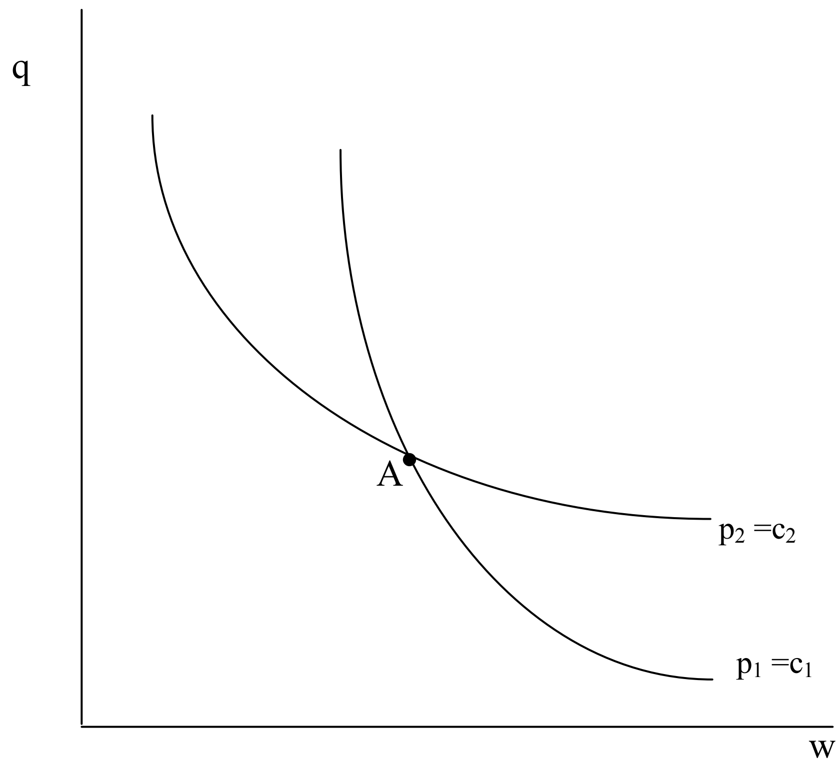

Figure 1.11: Zero-profit Equilibrium

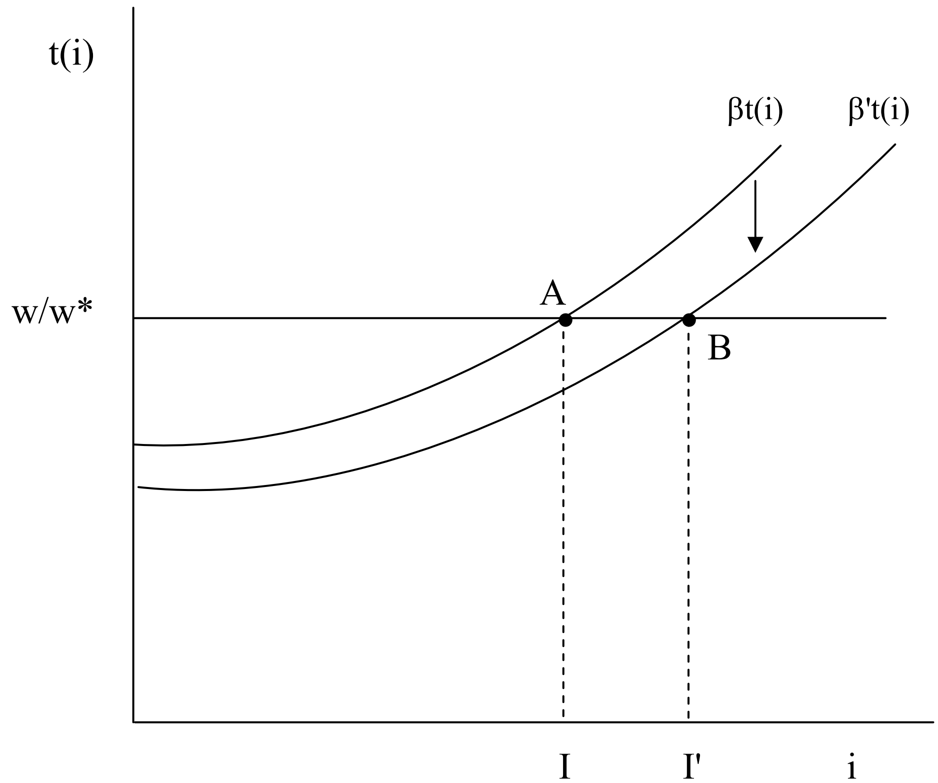

Figure 1.12: Reduction in the Costs of Offshoring

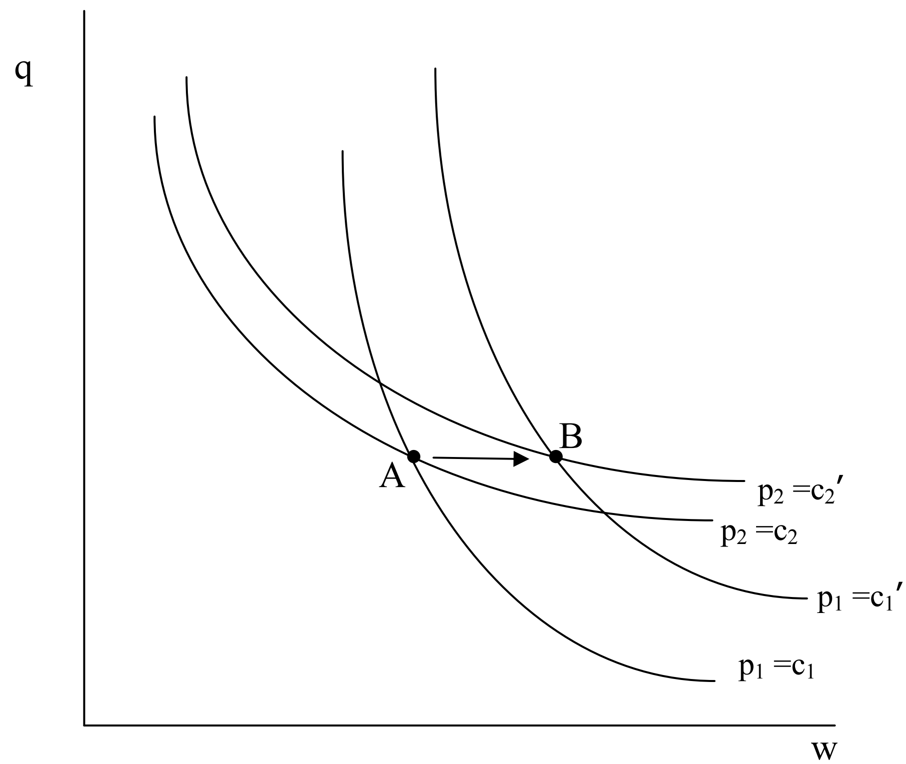

Figure 1.13: Low-Skilled Labor-Saving Technical Progress

I have no problem with the conclusion that the real wages of all workers might rise due to offshoring: that is also a possibility in my model with Hanson. But the prediction that the *relative* wage of low-skilled workers will rise is counterintuitive. That prediction is clearly counterfactual to the experience of the United States and other countries during the 1980s and 1990s. It also contradicts the idea that skill-biased technological change – shifting relative demand towards skilled labor – should increase the relative wage of skilled workers.

To understand where this result is coming from, it is useful to go back to the debate a decade ago between Leamer and Krugman. Leamer considered a small country model, in which case the sector-bias of technical change determines the change in wages. That is exactly what is occurring in this small-country version of the model by Grossman and Rossi-Hansberg. Offshoring acts like low-skilled labor-saving technical progress and has the greatest impact in the sector intensive in low-skilled labor, so the real and relative wage of that factor rises. Indeed, this idea was suggested earlier in the fragmentation literature, by Sven Arndt (1997) and Jones and Kierzkowski (2001). So these results confirm Leamer's thesis.

But Krugman would respond that we should instead focus on a large-country model, as Grossman and Rossi-Hansberg do next. In that case, we need to take into account how outputs change due to offshoring. The only way the unskilled labor can remain fully employed at home in the presence of offshoring is for there to be a magnified increase in the output of the low-skilled-intensive sector. That result follows from the Rybczynski Theorem, which holds in a modified version here. Since both sector are offshoring the activities up to I, the full-employment condition for low-skilled labor is:

$$y_1 a_{L1}(1-I) + y_2 a_{L2}(1-I) = L,$$

which is rewritten as: $y_1 a_{L1} + y_2 a_{L2} = L/(1-I).$

Thus, a rise in offshoring will have the same impact on sector outputs as an effective increase in the endowment of low-skilled labor. Through the usual Rybczynski effect, this will have a magnified impact on the home output of the low-skilled-intensive sector, and thereby also raise that output on world markets and lower its relative price. By the usual Stolper Samuelson results, that will reduce the relative wage of low-skilled labor. So the price effect works against low-skilled labor, whereas the productivity effect of offshoring works in its favor. In general, either of these effects can dominate, so the relative wage can move in either direction.

To sharpen the results, suppose that preferences are Cobb-Douglas, as Krugman assumed. If production is also Cobb-Douglas, then any technological progress looks like Hicks-neutral, so we are almost back in Krugman's case where the price effect just offsets the productivity effect, and relative wages do not change at all. That result does not quite hold in Grossman and Rossi-Hansberg's model, because the productivity effect of offshoring applies only in the home country and not abroad (whereas Krugman assumed that the Hicks-neutral technological change was in both countries). For that reason, we need to add more structure to obtain definite results on whether the price effect dominates the productivity effect or not.

Specifically, we follow Grossman and Rossi-Hansberg in assuming that both industries in the foreign country is uniformly less productive than at home, applying the Hicks-neutral productivity disadvantage A*>1 abroad. In addition, the home country still has the low-skilled labor technological advantage of $\Omega(I) < 1$ due to offshoring, as described above. It is still possible that there is "adjusted factor price equalization", meaning that $w\Omega = w^* A^*$ and $q = q^* A^*$, as we shall assume. The fact that the ratio of effective factor prices $w\Omega / q$ and w^* / q^* are equal across countries means that the factor intensities are also equal, $a_{Li} = a^*_{Li}$ and $a_{Hi} = a^*_{Hi}$, i = 1,2, where $A^* a^*_{Li}$ and $A^* a^*_{Hi}$ are the foreign labor requirements per unit of output. The cost shares are then $\theta_{Li} \equiv w\Omega a_{Li}/p_i = w^* A^* a^*_{Li}/p_i$ for low-skilled labor, and

$\theta_{Hi} \equiv q a_{Hi}/p_i = q^* A^* a^*_{Hi}/p_i$ for high-skilled labor.

With this notation, we can state the conditions under which the price effect dominates the productivity effect, so that the relative wage of high-skilled labor rises with offshoring, or when we obtain the converse result (as proved in the Appendix):

Proposition 1.1

Suppose that demand in both countries is Cobb-Douglas, with expenditure shares on the two goods of α_i, i = 1,2. Then if the elasticities of substitution in production σ_i are sufficiently less than unity and the home country is sufficiently large, so that the following inequality holds:

$$\sigma_i < \frac{L/\Omega}{(\frac{L}{\Omega}+\frac{L^*}{A^*})} - \left\{ \frac{L^*/A^*}{(\frac{L}{\Omega}+\frac{L^*}{A^*})} \left[\frac{\alpha_1\alpha_2(\theta_{H1}-\theta_{H2})^2}{\alpha_1\theta_{H1}\theta_{L1}+\alpha_2\theta_{H2}\theta_{L2}} \right] \right\}, \quad \text{for } i = 1,2,$$

then the price effect dominates the productivity effect, so that the relative wage of high-skilled labor rises with increased offshoring. If this inequality is reversed for i = 1,2, then the relative wage of high-skilled labor falls instead.

We see that a necessary condition to obtain a rise in the relative wage of high-skilled labor is that the elasticities of substitution in production are less than unity (as obtained from the above inequality when $L \to \infty$). The intuition for this result is clear from Krugman's arguments: if offshoring acts like low-skilled labor-saving technical progress, it therefore shifts demand *away* from that factor, and in a large country setting reduces its relative wage. But because only the home country is experiencing the technical progress, we need the added condition that home is large enough as compared to the foreign country, so that the inequality in Proposition 1.1 is satisfied. These results confirm Krugman's thesis, that skill-biased technological changed will raise the relative wage of high-skilled labor, as well as being closest to my model with Hanson (where it was assumed that the elasticities of substitution in production were zero). Conversely, if the inequality in Proposition 1.1 is reversed, then the productivity effect necessarily dominates the price effect, and the relative wage of high-skilled labor will fall due to offshoring. That is the result in the small-country version of the model, for example.

Even without Cobb-Douglas preferences, results similar to the large-country case (with elasticities of substitution less than unity) occur if there are more factors than goods. For example, suppose there is only a single sector in both countries. That good will still be traded to compensate for the labor earnings from offshoring. In this case, Grossman and Rossi-Hansberg argue that there is a third effect at work, which they call the labor-supply effect. The effective increase in low-skilled labor due to the productivity effect cannot be absorbed by Rybczynski-like reallocation across sectors, and instead will lead to a fall in the relative wage of low-skilled labor. In this case, it turns out that if the initial amount of offshoring is small, then the labor-supply effect will definitely dominate the productivity effect, so that the relative wage of low-skilled labor falls. Once again, its real wage can move in either direction, while the real wage of high-skilled labor rises.

So we see that the microeconomic structure of the model – small country versus large country, and the number of sectors as compared with factors – is crucial to the results.[7] The large-country version has predictions that fit the facts for the United States in the 1980s. But the 1990s were different, and combined an increase in the relative wage of nonproduction workers with a *fall* in their relative demand. I have already suggested that the evidence is consistent with the offshoring of service activities from the United States, or the lower-paid of the nonproduction

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[7] Kohler (2001) has shown that the fragmentation results of Arndt (1997) no longer hold when capital is sector-specific, so there are more factors than goods. See also Kohler (2004).

tasks. That outcome can also arise in the model of Grossman and Rossi-Hansberg, provided that we focus on the offshoring of *high-skilled* labor tasks rather than *low-skilled* tasks.

With offshoring of high-skilled labor, the equilibrium condition becomes,

$$q^*\beta t(I) = q.$$

The zero-profit conditions are that the sum of the costs of domestic and offshored labor for each unit of production equal the price, or,

$$p_j = wa_{Lj} + qa_{Hj}(1 - I) + q^* a_{Hj}\int_0^I \beta t(i)di, \qquad j = 1,2.$$

Using the equilibrium offshoring condition, zero profits are re-written as:

$$p_j = wa_{Lj} + qa_{Hj}\Omega(I), \qquad j = 1,2.$$

where $\Omega(I) < 1$ is defined as before.

Now offshoring acts just like a high-skilled labor-saving technological innovation. An increase in the amount of offshoring shifts the iso-cost curves vertically upwards, as shown in Figure 1.14. The offshoring of the skilled-labor tasks, which we are thinking of as service activities, leads to an increase in the relative wage of skilled labor and no change in the relative wage of unskilled labor. Furthermore, such offshoring will reduce demand for skilled labor, at given industry outputs, as we have seen occurred in the United States during the 1990s. So the real contribution Grossman and Rossi-Hansberg's model, in my opinion, is that it gives us a robust way to model this service offshoring in addition to the low-skilled offshoring of the 1980s. The rich specification of offshoring costs that are built into the model allow for a wide array of outcomes, and go beyond the Heckscher-Ohlin structure.

The idea the United States is now offshoring jobs that require skilled labor is not really that surprising, and probably this phenomenon has occurred from the start. Indeed, the New York Times columnist William Safire traces the earliest published use of the word "outsourcing" to an

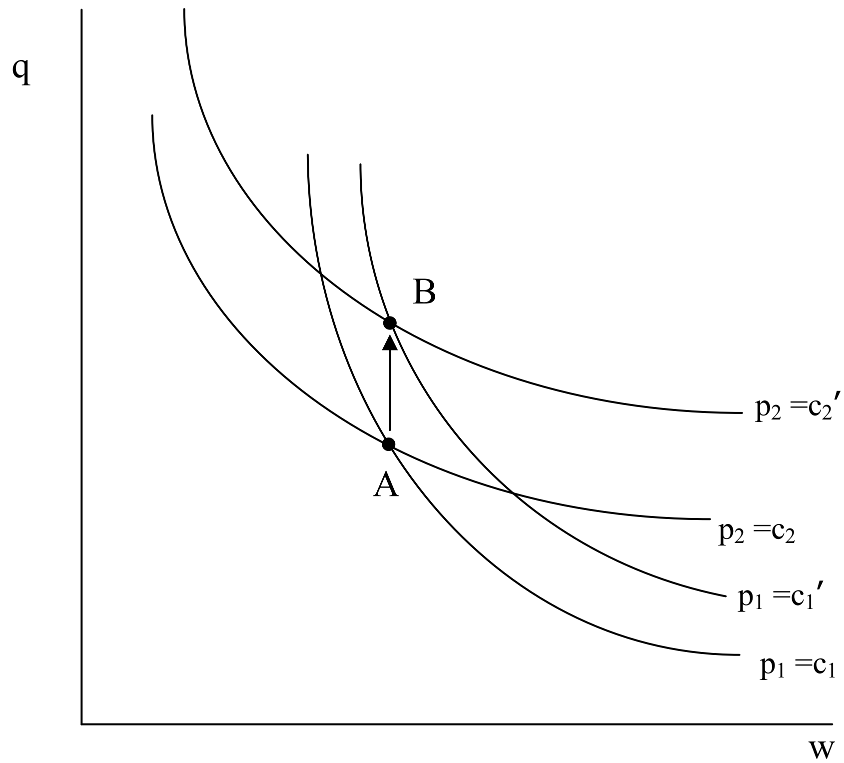

Figure 1.14: High-Skilled Labor-Saving Technical Progress

American auto executive writing in the *Journal of the Royal Society of Arts*, 1979, who said: "We are so short of professional engineers in the motor industry that we are having to outsource design work to Germany."[8] The same phenomenon appears to have occurred in Europe for some time. An early study by Magnus Blomstrom and Robert Lipsey (Blomstrom, Fors and Lipsey, 1997) has shown that Swedish multinationals establish affiliates primarily in developed countries, most likely performing skill-intensive tasks, which supports blue-collar employment at home. The smaller number of affiliates located in developing countries supports white-collar employment at home. A later study (Becker, *et al,* 2005) is less optimistic on the employment-creation at home, but finds that the jobs created by German and Swedish multinationals in Central and Eastern Europe more than compensates for those lost at home. Furthermore, Dalia Marin (Lorentowicz, *et al,* 2005; Marin, 2005) has shown that the jobs being offshored from Germany and Austria to locations in Eastern Europe are in fact high-skilled jobs.

For the United States, there are several studies that document the growing importance of service offshoring. Mary Amiti and Shang-Jin Wei (2005a) find that for U.S. manufacturing, imported services grew from two-tenths of one percent of total inputs used in 1992, to three-tenths by 2000. The fact that imported services are so small, however, does not prevent them from being important for productivity. In Table 1.3, I show the impact of service offshoring and high-technology equipment on labor productivity in manufacturing. Over these eight years, service offshoring can explain 12 to 17% of the total increase in productivity. The contribution of service imports can be compared to the contribution of high-tech equipment in manufacturing, which explains a further 4 to 7% of the total increase in productivity. Adding together these contributions, we see that these two factors explain as much as one-quarter of productivity

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[8] William Safire, 2004, "On Language," *New York Times Magazine*, March 21, p. 30

Table 1.3: Impact on Productivity in U.S. Manufacturing, 1992-2000

	Percent of Total Explained by each Factor: Service Offshoring	High-technology Equipment
Productivity growth in manufacturing	12 – 17%	4 – 7%

Source: Mary Amiti and Shang-Jin Wei, "Service Offshoring, Productivity, and Employment: Evidence from the United States," IMF Working Paper 05/238, International Monetary Fund, Washington, D.C.

growth. Since labor productivity rose by about 4% per year in manufacturing, we conclude that service offshoring together with the increased use of high-tech equipment can explain as much as one percentage point of productivity growth per year, which is economically important.

Amiti and Wei (2005a,b) do not identify a significant impact of service offshoring on employment, possibly because they work with a single aggregate of labor. But another study separates the impact of offshoring on production and nonproduction workers in U.S. manufacturing, for the 1990s (Sitchinava, 2008). It applies the two-step procedure of Feenstra and Hanson, using materials offshoring, service offshoring, as well as computer capital as potential explanations. These results are summarized in Table 1.4, for 1989 through 1996. While the relative wage of nonproduction workers continued to rise during this period, materials offshoring explains only 7% of that increase. Service offshoring is twice as important, explaining some 15% of the increase in the relative wage. But the increased use of computers (as a share of the capital stock) can account for nearly all of the rise in the relative wage.

What about employment? We have seen the relative employment of nonproduction workers fell during the 1990s, in marked contrast to the 1980s. Can we attribute that fall to tasks that require skills but are more routine, allowing them to be offshored? A careful study of white-collar employment in the U.S. (Crino, 2007), for both manufacturing and services, suggests that is the case.[9] The author finds that service offshoring raises high-skilled employment and lowers medium and low-skilled employment. But within each skill group, there is a differential response depending on whether the tasks being performed are classified as routine and transporTable 1.– hence tradable – or not. Service offshoring is found to penalize the tradable occupations and benefit the non-tradeable occupations, consistent with the theory.

[9] Jensen and Kletzer (2006) provide additional evidence on potential services trade outside of manufacturing.

Table 1.4: Impact on the Relative Wage of Nonproduction Labor in U.S. Manufacturing, 1989-1996

	Percent of Total Increase Explained by each Factor		
	Materials Offshoring	Service Offshoring	High-technology Equipment
Relative wage of non-production labor	7%	15%	95%

Source: Nino Sitchinava, 2008, "Trade, Technology, and Wage Inequality: Evidence from U.S. Manufacturing, 1989-2004," University of Oregon, Ph.D. dissertation. Computed from the first-difference results in Table 1.8.

Supermodular Production

Let me turn now from the evidence to consider the most recent theory on offshoring. To motivate this, let me begin with an unpublished 1996 paper by Michael Kremer and Eric Maskin (1996). They begin their paper with the same observations as many others at that time: wage inequality in the United States was increasing. But they propose a new feature of this shift, and that is the segregation of workers across firms. They use the example of shifting from General Motors, which uses both skilled and unskilled workers, to an economy based on Microsoft and McDonalds, which segregates skilled and unskilled workers across companies. While the segregation of workers across firms is endogenous, they suggest that it can help us to understand increasing wage inequality.

To develop a model with these features, Kremer and Maskin (1996, p. 4) argue that the production function of a firm should satisfy three conditions, which they describe as:

(i) workers of different skills are imperfect substitutes for one another;

(ii) different tasks within a firm are complementary; and

(iii) different tasks within a firm are differentially sensitive to skill.

The second of these features – complementarity – is also called supermodularity of the production function.[10]

While Kremer and Maskin's analysis was for a closed economy, it seemed to have a clear application to trade, and to offshoring in particular. I commented on that application in a summary of research that I prepared for the *NBER Reporter* in 2000. Writing on the topic of "Globalization and Wage," I described their results as follows:[11]

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[10] A function $f(x,y)$ is said to be supermodular if for all $x' > x$ and $y' > y$, then $f(x,y) + f(x',y') > f(x,y') + f(x',y)$. This condition is equivalent to $\partial^2 f/\partial x \partial y > 0$ for all (x,y), so that x and y are complementary in production.

[11] Robert Feenstra, "Program report of the International Trade and Investment program," *NBER Reporter,* Winter 2000/2001.

> One intriguing channel [for trade to affect wages], described by Michael Kremer and Eric Maskin (1996), involves the hiring of low-skilled and high-skilled workers in a single firm. Under certain assumptions on the technology, this will prop up the wages of the less-skilled workers. But if the overall distribution of workers by skill *widens*, then firms can instead segregate high-skilled and low-skilled workers in different plants, which lowers the latter wages and increases wage *inequality*. While Kremer and Maskin apply their model to a closed economy, the analysis is highly suggestive of foreign outsourcing, whereby firms in one country are able to send abroad the less-skill intensive activities in the production process. Extending the Kremer-Maskin analysis to an open economy is an important research priority.

Perhaps no one read these remarks that I made, but at least I made a good guess on the course of future research. Soon afterwards, there have been a number of papers published that address aspects of the problem that Kremer and Maskin proposed. For example, one class of models has managers solving problems for employees (Garicano, 2000), which leads to complementarities between these two types of workers, or supermodularity. That type of model has been applied to offshoring, with the managers and employees located in different countries.[12] Another set of papers analyzes trade between economies with supermodular production and more general distributions of worker skills, but without offshoring.[13] Kremer and Maskin (2006) themselves have a new paper which allows for offshoring in a two country model, with only two types of workers in each country. While this illustrates some of the results from their earlier one country model, the analysis remains rather special.

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12 See Antràs, Garicano and Rossi-Hansenberg (2006a,b), and Garicano and Rossi-Hansenberg (2006).

13 See Grossman and Maggi (2000), Grossman (2004), and Manasse and Turrini (2001).

The latest paper in this line of research, by Arnaud Costinot and Jonathan Vogel (2008), allows for both trade and offshoring, in very general framework with a continuum of goods and continuum of factors. We might think of this as this framework as a substantial generalization of the HO model, but one that is possible only by using some strong simplifying assumptions. Their results can be summarized as follows.

Costinot and Vogel work with a continuum of skill-types, denoted by $s \in [\underline{s}, \overline{s}]$, and a continuum of sectors, denoted by $z \in [0,1]$. Let A(s,z) denote the output in sector z from using one unit of labor with skill s, which is strictly increasing in s, and let L(s,z) denote the units of labor with skill s that are allocated to sector z. To simplify the problem, they make the strong assumption that workers are perfect substitutes in production, so that output in sector z is:

$$Y(z) = \int_{\underline{s}}^{\overline{s}} A(s,z)L(s,z)ds .$$

Notice that this assumption violates the first condition proposed by Kremer and Maskin, that workers of different skills are imperfect substitutes.

The second condition – of complementarity – is maintained by assuming that the production function A(s,z) is log-supermodular between the skills of workers and their sectors. That is, choosing two skills with $s > s'$, and two sectors with $z > z'$, we assume that:

$$\ln A(s',z') + \ln A(s,z) > \ln A(s,z') + \ln A(s',z) .$$

Rewriting this condition slightly we get:

$$\frac{A(s,z)}{A(s',z)} > \frac{A(s,z')}{A(s',z')} \ , \text{ for } s > s', \text{ and } z > z'.$$

Thus, workers with higher skills are relatively more productive in sector with higher index z, so we have arranged sectors in increasing order of their skill-intensity. The exogenous distribution of workers is denoted by V(s) > 0, so we close the model by using full employment of factors:

$$\int_0^1 L(s,z)dz = V(s)\text{, for all s,}$$

as well as demand equal to supply in each sector.

When workers are perfect substitutes, the firm can easily be indifferent as to whom it hires. But that ambiguity is resolved in general equilibrium, because Costinot and Vogel show that there is a monotonically increasing matching function M(s), mapping the interval of skills $[\underline{s}, \bar{s}]$ onto the interval of sectors [0, 1]. Each sector z employs only one skill-type of worker s, with z = M(s). I illustrate such a function in Figure 1.15, which maps the skills of workers to their sectors.

That result that each sector employs only one type of worker, due to the assumption of perfect substitution, gives us an easy way to determine the wage profile w(s). Denoting the equilibrium prices across sectors by p(z) = p[M(s)], profit maximization by competitive firms means that they will choose the skill level of workers to solve the problem:

$$p[M(s)]A[s, M(s)] - w(s) = \max_{s'} \{ p[M(s)]A[s', M(s)] - w(s') \}.$$

Differentiating this expression with respect to s and using the envelope theorem, we find that the slope of the wage schedule reflects the slope of the technology:

$$w_s(s) = p[M(s)]A_s[s, M(s)].$$

Furthermore, since wages in equilibrium equal the value of the marginal product of labor, $w(s) = p[M(s)]A[s, M(s)]$, we obtain a differential equation to determine the wage profile:

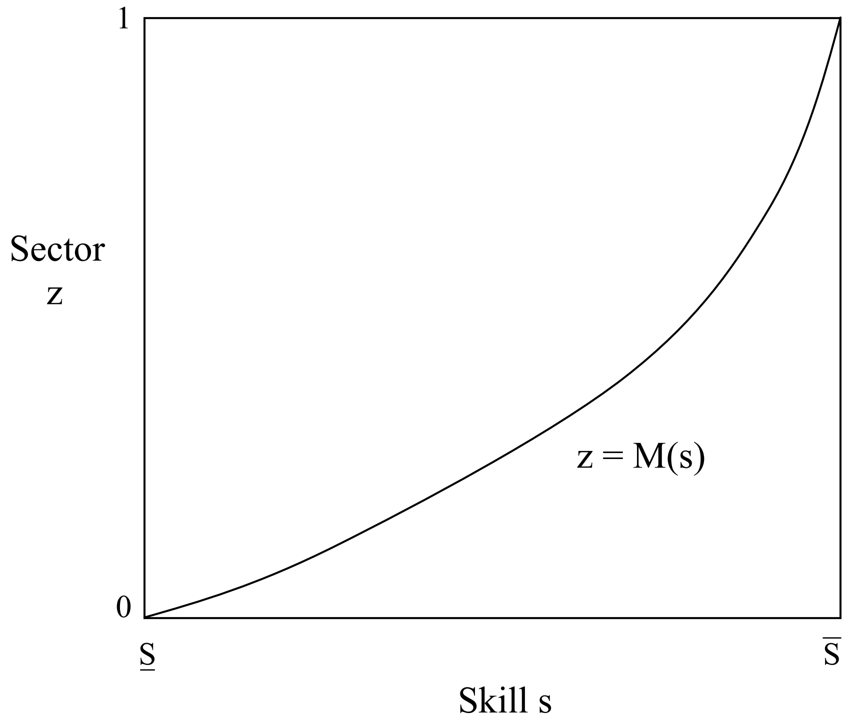

Figure 1.15: Matching of Skills to Sectors

$$\frac{w_s(s)}{w(s)} = \frac{A_s[s, M(s)]}{A[s, M(s)]}.$$

Of course, solving this differential equation requires knowledge of the matching function, which can be obtained from the equality of demand and supply in each sector. Costinot and Vogel now make a second simplifying assumption, and that is that demand is obtained from Leontief preferences, so demand in each sector is proportional to the exogenous taste parameter $B(z) > 0$. To equate demand and supply, let us first compute the integral of output over workers between the skill levels s_1 and s_2. That output is as follows:

$$\int_{s_1}^{s_2} A[s, M(s)]L[s, M(s)]ds.$$

To focus on sectors rather than skills, let us make a change of variables within this integral, from s to z. The range of integration is from $z_1 = M(s_1)$ to $z_2 = M(s_2)$, and making the change of variables with $dz = M_s(s)ds$, the integral becomes:

$$\int_{z_1}^{z_2} A[M^{-1}(z), z]L[M^{-1}(z), z]M_s[M^{-1}(z)]dz.$$

This expression gives us the value of output over a range of sectors. Output in a single sector, say z_2, can be obtained by differentiating with respect to z_2, to obtain:

$$Y(z) = A[M^{-1}(z), z]L[M^{-1}(z), z]M_s[M^{-1}(z)], \text{ for } z = z_2.$$

This expression for output is rewritten for a given skill level as:

$$Y[M(s)] = A[s, M(s)]L(s, z)M_s(s).$$

So while we would normally think of output as just $A(s,z)L(s,z)$ in a model with discrete goods, we now obtain the expression $A(s,z)L(s,z)M_s(s)$, which incorporates the rate at which workers are matched to sectors.

From the assumption that preferences are Leontief with the taste parameters B(s), and using $L(s,z) = V(s)$, the equality of demand and supply means that:

$$A[s, M(s)]V(s)M_s(s) = kB(s),$$

where k > 0 is a constant. This gives us a differential equation that we can use to solve for the matching function, which has the implicit solution:

$$M(s) = \int_{\underline{s}}^{s} \frac{kB(s)}{A[s, M(s)]V(s)} \, ds .$$

The constant k can be determined by the condition that the matching function maps the interval of skills $[\underline{s}, \bar{s}]$ onto the interval of sectors [0, 1], so that $M(\bar{s}) = 1$ which implies:

$$k = \left[\int_{\underline{s}}^{\bar{s}} \frac{B(s)}{A[s, M(s)]V(s)} \, ds \right]^{-1} .$$

This completes the solution of the model.

Now consider the effect of changing the distribution of skills, from V(s) to V'(s). First, suppose that the distribution shifts to the left, in the sense that:

$$\frac{V(s)}{V(s')} > \frac{V'(s)}{V'(s')} \ , \ \text{for } s > s'.$$

This condition means that there are relatively more workers of lower-skills in the distribution V'(s). For concreteness, we can think of the original distribution as applying to the North and the new distribution to the South. Heuristically, we can see how this shift will impact the matching function from examining the differential equation:

$$\underset{\uparrow}{M(s)} = \int_{\underline{s}}^{s} \frac{kB(s)}{A[s, M(s)]\underset{\downarrow}{V(s)}} \, ds$$

It appears that the fall in V should increase the matching function M'. This intuition is very rough, because M also enters into the right-hand side of the equation (both directly in A and through the term k). But it proves to be correct, and Costinot and Vogel show that the shift in the skill-distribution to the left leads to a rise in the matching function for all skills except at the end points, $\underline{s} < s < \overline{s}$.

This rise is illustrated in Figure 1.16, with the old matching function M applying to the North and the new function M' to the South. In the South, workers of lower skill are matched to sectors with higher z, as compared to the North. From the differential equation for wages, we use the rise in the matching function to infer that the slope of the wage schedule must increase:

$$\frac{\overset{\uparrow}{\partial \ln w(s)}}{\partial s} = \frac{\partial \ln A[s, \overset{\uparrow}{M(s)}]}{\partial s}$$

The rise in the matching function implies a steeper slope for the wage profile, as follows from the assumed log-supermodularity of the technology.[14] The Southern economy, with a greater number of less-skilled workers, will therefore have a more unequal wage distribution than in the North.

This type of exercise is not restricted to shifts in the mean of the distribution of skill, and Costinot and Vogel also examine the impact of changes in the spread of the skill distribution, or the diversity of skills, as might apply between two Northern countries. But rather than describing those results, let me turn to the impact of international trade. A quick type of Heckscher-Ohlin result is available from the case we just examined. Suppose that the North and South engage in

[14] As in note 10, supermodularity of lnA(s,z) means that $\partial^2 \ln A/\partial s \partial z > 0$, so that $\partial \ln A/\partial s$ rises as M rises.

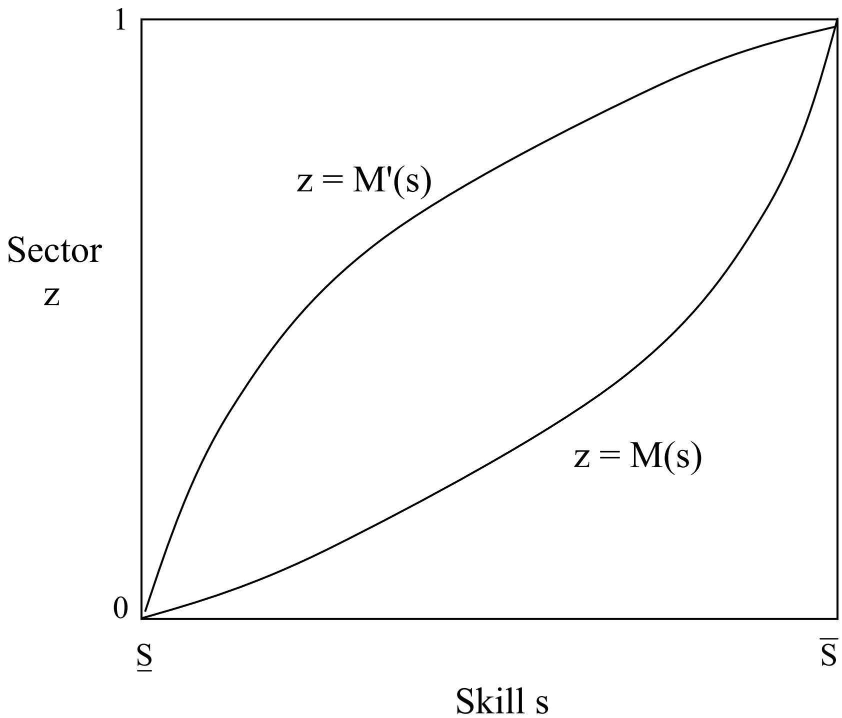

Figure 1.16: Changing Distribution of Skills

trade, with factor price equalization. Then the integrated world economy will have a distribution of skills that lies *in-between* the distributions in the two countries. From the Northern point of view, wages are now determined by a distribution of skills that is shifted to the left, so that wages become more unequal. From the Southern point of view, however, the world distribution of skills lies to the right of its own distribution, so that wages become more equal. Therefore, in a standard Heckscher-Ohlin fashion, opening trade leads to changes in the wage distributions that are in opposite directions in the two countries.

Of course, a starting point for my lecture today was the observation that relative wages did not move in opposite direction across countries during the 1980s, but in the same direction: towards greater inequality. A result of that type can be generated by considering a simple form of offshoring in this model. Specifically, suppose that the Southern technology is uniformly less productive to that in the North. That is equivalent to saying that all factors of production are uniformly less productive in the South. Then in an equilibrium with free trade we can still observe effective factor price equalization, defined by efficiency-adjusted wages. To this equilibrium we now add the option of offshoring, which means that Northern firms can use their technology when they employ Southern workers. As a result, Northern technologies will be employed worldwide, which eliminates the productivity disadvantage in the South, and is equivalent to a uniform rise in the Southern endowments. That rise will shift the world distribution of skills to the left, since there are now more effective Southern workers. It follows that the wage distributions in *both* countries now become more unequal, due to offshoring.

While that simple prediction is consistent with the facts, at least for the 1980s, this framework leaves out a number of elements that we would want to incorporate into a model of offshoring: there is no difference in the range of products produced in the North and South, since effective factor-price equalization is assumed; likewise, there is no difference in the skills of workers employed at a given industry in the North or South; and also, there is no difference in the skills of workers employed within each industry, due to the perfect substitutes assumption. Clearly, we could want to modify some of these strong assumptions in future work. But there is one intriguing feature of the model that deserves to be highlighted: because it is a many-good, many-factor generalization of the Heckscher-Ohlin model, we expect that it will have factor-content predictions. In the case we just discussed, a rise in the effective factor endowment of the South would increase its embodied exports of less-skilled factors, which is what leads to a fall in those wages in the North, or a rise in wage inequality. In other words, the Heckscher-Ohlin link between the factor embodied in trade and factor prices should continue to hold.

Factor Content of Trade Once Again

To conclude my talk today, I would like to go back to the question raised by Krugman (2008) in his recent Brookings paper: why doesn't the factor content of trade help to explain the change in wage patterns that have occurred in the United States? Some, such as Leamer (2000), would answer that factor contents are inadequate to predict wage changes. On the other hand, writers such as Alan Deardorff (2000) and Arvind Panagariya (2000), building on the results of Deardorff and Staiger (1988), show that factor-content calculations can be used to predict the wage changes as compared to autarky. That result is shown to generalize beyond the Cobb-Douglas case to allow for CES technologies with common elasticities of substitution, or with infinitesimal changes, to more general technologies. And I believe that a generalization to the many-good, many-factor model of Costinot and Vogel (2008) should also apply.

So I am inclined to agree with Krugman: there should be some factor content calculation for the United States that would show the impact of increased trade on factor prices. The problem that he points to is one of aggregation. We know from the detailed work on trade data by Peter Schott (2003, 2004) that a great deal of the heterogeneity occurs at a very disaggregate level, such as the 10-digit Harmonized System level, and even *within* that level countries supply product varieties of differing quality. If these product varieties were made in the United States they could require quite diverse technologies, some potentially quite labor-intensive. The problem is that we observe factor requirements at a much more aggregate level, often with less than 500 industries, whose factor requirements are necessarily averages of those in the underlying activities. Working with such average factor requirements, we cannot expect to observe the underlying heterogeneity in technologies and factor use.

I would like to propose a solution to the aggregation problem that allows us to make a new factor content calculation. My solution will rely on an older technique used to analyze the HO model, due to Robert Baldwin (1971). His approach was to regress net exports across industries on their factor requirements. So, for example, he finds that skilled labor has a positive coefficient in predicting net exports, while unskilled labor has a negative coefficient. I will show that univariate regressions of that type arise very naturally in the aggregation problem. The difference between the true factor contents, and those computed at an aggregate level, will depend on these Baldwin-style regressions: if there is no correlation between net exports and factor contents, then there is no aggregation problem either.

To compute the bias due to aggregation, in principle we need to run the Baldwin regression at a disaggregate level, but again we run into a problem of missing data: the net exports used at the *dependent* variable are observed at a very disaggregate level, but not the factor requirements, used as independent variables. So my solution will be to run the Baldwin regressions at a *more aggregate* level, and then apply the coefficients we obtain to the disaggregate level, too. In that way, we can essentially "invert" the regression and infer what U.S. factor requirements would have to be to produce highly disaggregate traded products in the U.S. It will turn out that in this procedure I use will also be keeping track of the fit of the regressions, so for aggregate industries where the fit is poor, I will be inferring correspondingly less aggregation bias in the factor content calculation.

Let me now describe the details of this new approach. Suppose that there are i = 1,…,N goods and j = 1,…,M factors. The (MxN) matrix $A=[a_{ij}]'$ denotes the quantity of primary factor j used per unit output in industry i. This can be interpreted as the "direct plus indirect" factor requirements. A standard calculation of the factor content of trade for the United States is then:

$$\text{Factor content of trade} = AT \quad ,$$

where the output vector for the U.S. is denoted by Y, and the consumption vector by C, so that the net export (or "trade") vector is given by $T = Y - C$.

We now consider how the measurement of the factor content of trade is affected by aggregation across industries. Suppose that the i=1,…,N industries are divided into G groups, denoted by the disjoint sets I_g, each of which have N_g industries, g=1,…,G. The values of output, consumption and trade are then summed across industries within these groups,

$$\overline{Y} = \begin{bmatrix} \sum_{i \in I_1} Y_i \\ \sum_{i \in I_2} Y_i \\ \vdots \\ \sum_{i \in I_G} Y_i \end{bmatrix}, \qquad \overline{C} = \begin{bmatrix} \sum_{i \in I_1} C_i \\ \sum_{i \in I_2} C_i \\ \vdots \\ \sum_{i \in I_G} C_i \end{bmatrix}, \qquad \text{and} \quad \overline{T} = \begin{bmatrix} \sum_{i \in I_1} T_i \\ \sum_{i \in I_2} T_i \\ \vdots \\ \sum_{i \in I_G} T_i \end{bmatrix}.$$

We also need to aggregate the primary factor-requirements matrix A, to obtain $\overline{A}$. We assume that this aggregation is performed in such as way that the full-employment condition $\overline{A}\,\overline{Y} = V$ is *preserved,* where V is the vector of factor endowments for the U.S. This is a reasonable description of how any statistical agency would aggregate the data. In order to preserve this condition, the factor-requirements data would need to be aggregated using the outputs of each industry as weights,

$$\overline{A} = \begin{bmatrix} \sum_{i\in I_1} \lambda_{i1} a_{i1} & \cdots & \sum_{i\in I_G} \lambda_{iG} a_{i1} \\ \sum_{i\in I_1} \lambda_{i1} a_{i2} & \cdots & \sum_{i\in I_G} \lambda_{iG} a_{i2} \\ & \vdots & \\ \sum_{i\in I_1} \lambda_{i1} a_{iM} & \cdots & \sum_{i\in I_G} \lambda_{iG} a_{iM} \end{bmatrix}, \text{ where } \lambda_{ig} \equiv \frac{Y_i}{\sum_{i\in I_g} Y_i}, \, g = 1,\ldots,G.$$

The weights λ_{ig} denote the share of output of industry i within the overall output of group g.

With this aggregation, we clearly preserve the full-employment condition (since $\overline{A}\ \overline{Y} = AY$, which then equals endowments V). But we now *change* the calculation of the factor-content of trade, which now becomes:

$$\text{Computed factor content of trade} = \overline{A}\ \overline{T}\ .$$

We can directly calculate the "aggregation bias" as follows (as proved in the Appendix):

Proposition 1.2

The difference between the true factor content of trade and that obtained with aggregated data is:

$$AT - \overline{A}\,\overline{T} = \begin{bmatrix} \sum_{g=1}^{G} N_g \mathrm{cov}_g(T_i, a_{i1}) \\ \sum_{g=1}^{G} N_g \mathrm{cov}_g(T_i, a_{i2}) \\ \vdots \\ \sum_{g=1}^{G} N_g \mathrm{cov}_g(T_i, a_{iM}) \end{bmatrix} + \begin{bmatrix} \sum_{g=1}^{G} \overline{T}_g \sum_{i\in I_g} (\frac{1}{N_g} - \lambda_{ig}) a_{i1} \\ \sum_{g=1}^{G} \overline{T}_g \sum_{i\in I_g} (\frac{1}{N_g} - \lambda_{ig}) a_{i2} \\ \vdots \\ \sum_{g=1}^{G} \overline{T}_g \sum_{i\in I_g} (\frac{1}{N_g} - \lambda_{ig}) a_{iM} \end{bmatrix}.$$

We see that the aggregation bias consists of two terms. The first depends on the covariances between the net exports in industry i and the factor requirements for industry i and factor j:

$$\operatorname{cov}_g(T_i, a_{ij}) = \frac{1}{N_g}\sum_{i\in I_g}\left(T_i - \sum_{i\in I_g}\frac{T_i}{N_g}\right)\left(a_{ij} - \sum_{i\in I_g}\frac{a_{ij}}{N_g}\right),$$

It is immediate that this portion of the aggregation bias is *zero* when the disaggregate industries *within* each group have input requirements that are *uncorrelated* with net exports. In other words, if there is zero correlation between net exports and factor input requirements within each aggregate group, then there is no aggregation bias in computing the factor content of trade.

That zero correlation condition is unlikely to hold however, and violates the spirit of the Heckscher-Ohlin theorem, that trade is related to industry factor requirements. We certainly expect to observe some correlation between net exports and factor requirements within each industry aggregate. Furthermore, such a correlation will affect the second term in the aggregation bias, which is the difference between a simple and weighted average of factor requirements within each industry aggregate, multiplied by total net exports. Since the weights appearing in that formula reflect industry outputs, that second term will be non-zero when input requirements within each group are correlated with outputs, which we expect to hold.

The challenge with implementing this formula for the aggregation bias is that the data we need, especially the factor contents, may not be observed at the same disaggregate level as the trade data. So instead, I will start with the regression equation suggested by Baldwin, run at whatever level allowed by the data: say, regressing net exports on factor requirements at the 4-digit industry level within each 2-digit group g . I will then assume that the coefficient estimates of this regression at the 4-digit level *also hold* at a more disaggregate 10-digit level. At that more disaggregate level, we have the trade information, which is the dependent variable in the regression. Then we can use the estimated coefficients (from the 4-digit regression), together with the 10-digit trade data, to *infer* what the underlying factor requirements must be. That is, we essentially "invert" the regression to uncover the detailed factor requirements that are consistent with a Heckscher-Ohlin pattern of trade.

To outline this procedure more carefully, start with the regression of net exports on the factor requirements for each input j, for each industry group g:

$$T_i = \alpha_{jg} + \beta_{jg} a_{ij} , \qquad i \in I_g .$$

The estimates $\hat{\beta}_{jg}$ obtained for each factor j are given by the usual OLS formula:

$$\hat{\beta}_{jg} = \frac{\text{cov}_g(T_i , a_{ij})}{\text{var}_g(a_{ij})} ,$$

where the variance of the factor requirements are:

$$\text{var}_g(a_{ij}) = \frac{1}{N_g} \sum_{i \in I_g} \left(a_{ij} - \sum\nolimits_{i \in I_g} \frac{a_{ij}}{N_g} \right)^2 ,$$

We can also write the R^2 of the regression for factor j as:

$$R_g^2 = \frac{\hat{\beta}_{jg}^2 \text{var}_g(a_{ij})}{\text{var}_g(T_i)} .$$

Combining these various terms, we can write the covariance between trade and factor requirements as,

$$\text{cov}_g(T_i , a_{ji}) = \left(\frac{R_g^2}{\hat{\beta}_{jg}} \right) \text{var}_g(T_i) .$$

In this formula for the covariance, we will use the variance of trade obtained from disaggregate, 10-digit trade data. But the R^2 and $\hat{\beta}_{jg}$ coefficients are obtained from a regression at a *more aggregate level* (i.e. the 4-digit SIC industries i within each 2-digit group g). We will be assuming that those coefficients, or more precisely their ratio, apply equally well at the disaggregate level. Then we can use this formula can be used to infer what the covariance is at the disaggregate level. This is the idea of "inverting" the Baldwin regression. Let me now turn to the results.

Empirical Implementation

I make use of an input-output table for the United States for 1982, which includes 371 manufacturing industries, which I refer to as 4-digit SIC.[15] I will compare the factor content of trade measured using the 4-digit data with that obtained from a calculation using 7-digit Tariff Schedule (TSUSA) level for the U.S. before 1989, and the 10-digit HS level after 1989, which number more than 10,000 goods.

In Table 1.5, I report the results for U.S. manufacturing in various years between 1982 and 2000. In the first row for each year, I simply report the total usage of capital, production labor, and nonproduction labor. For example, in 1982 there were some 12 million production workers and 5 million nonproduction workers employed in manufacturing, with a ratio of 2.29 production workers for each nonproduction worker. In the second row I report the content of each factor in net exports, computed using the 4-digit data. In 1982, there were 229 thousand production workers imported, and 95 thousand exported. If we add and subtract these from the U.S. endowments, we obtain an effective ratio of 2.37 production workers for each nonproduction worker. If instead we do the factor content calculation using the 10-digit trade data, and imputing the U.S. factor intensities as I have discussed, then for 1982 the production

[15] Following Trefler and Zhu (2000), we subtract *imported* intermediate inputs from this matrix before using it as B. The trade and direct factor requirements are concorded to the same 371 industries, which we still refer to as 4-digit SIC. Having obtained the director factor requirements D (3x371), and the input-output matrix B (371x371), we compute the total factor requirements (direct plus indirect) as $A = D(I - B)^{-1}$. See Feenstra and Hanson (2000).

Table 1.5: Factor Content of Net Exports for U.S. Manufacturing

Year		Capital Stock ($ billion)	Production Labor (thousands)	Nonprod. Labor (thousands)	Implied Prod/Nonprod. Ratio[a]
1982	Total manufacturing use	1,113	12,403	5,426	2.29
	Factor content, 4-digit data	-12	-229	95	2.37
	Factor content, 10-digit data	134	-351	79	2.39
	Assuming 1982 input-output matrix:				
1985	Total manufacturing use	1,151	12,171	5,332	2.28
	Factor content, 4-digit data	-104	-1,324	-322	2.39
	Factor content, 10-digit data	-26	-776	-306	2.30
1988	Total manufacturing use	1,116	12,404	5,514	2.25
	Factor content, 4-digit data	-92	-1,420	-349	2.36
	Factor content, 10-digit data	-288	-1,385	-136	2.44
1991	Total manufacturing use	1,204	11,514	5,279	2.18
	Factor content, 4-digit data	-34	-844	-130	2.28
	Factor content, 10-digit data	-123	-861	-104	2.30
1994	Total manufacturing use	1,285	11,946	5,139	2.32
	Factor content, 4-digit data	-73	-1,252	-304	2.42
	Factor content, 10-digit data	-77	-9,447	-277	3.95
1997[b]	Total manufacturing use	na	12,065	4,740	2.55
	Factor content, 4-digit data	-56	-1,133	-201	2.67
	Factor content, 10-digit data	-310	-1,840	-240	2.79
2000[b]	Total manufacturing use	na	11,944	4,708	2.54
	Factor content, 4-digit data	-133	-2,002	-515	2.67
	Factor content, 10-digit data	94	-13,883	-468	4.99

Notes:

na = not available
a. For total direct & indirect usage, this is the ratio of production/nonproduction labor. For the factor content calculations, we reverse the sign (i.e. take the factor content of imports), add the imported production and nonproduction labor to the total usage, and then take the ratio.
b. Calculations for 1997 and 2000 use the same factor requirements as in 1994, but update the trade data.

workers imported increases by about 50% and the nonproduction workers exported falls somewhat. The implied effective ratio of production to nonproduction workers is then 2.39.

The increase in the effective ratio of production to nonproduction workers due to trade in 1982 is therefore quite small: slightly less than 4% with the 4-digit calculation, and slightly more that 4% with the 10-digit calculation. But manufacturing employment accounted for only about 20% of total U.S. employment in the early 1980s, and less than 10% today. So a 4% effective increase in the ratio of production to nonproduction workers will not translate into a significant impact of trade on wages. Looking down the final column of Table 1.5, the impact of trade on this ratio remains less than 10% until 1994. In that year, we find for the first time a large impact of trade, once we focus on the 10-digit calculation with imputed factor intensities. The 10-digit factor content calculation gives us a net import of nearly 10 million production workers, so the ratio to nonproduction workers increases from about 2.3 to 4. In 2000 the calculation is even more dramatic, with the implied import of production workers *exceeds their employment* in U.S. manufacturing. In this case, the effective ratio of production to nonproduction workers doubles from 2.5 to 5. Even with manufacturing accounting for only 10% of total employment, that change in the effective ratio will have a significant impact on factor prices. I conclude that once we impute the factor intensities corresponding to disaggregate trade flows, then a factor content calculation can indeed give us a large impact of trade on factor prices.

Conclusions

I began my lecture today with the question of whether offshoring represents a new paradigm for trade, or whether the HO framework can be extended to incorporate this new type of trade. While this is in part just a rhetorical question, it provides a useful organizing principle. Let me conclude by reviewing some of the main insights from this perspective.

Starting with my work with Gordon Hanson (1996, 1997, 1999), I suggested that it can be viewed as a straightforward extension of the HO model with a continuum of goods, treating the factors as skilled and unskilled labor, along with capital. Hanson and I relabeled the goods as activities, and thought of these activities as occurring along the value-chain of an industry. The activities being offshored are those predicted by comparative advantage, with lower relative wages abroad. This model allows us to predict within-industry shifts in labor demand due to offshoring, just as occurred in the U.S. and other countries in the 1980s, or what we can call materials offshoring

But the evidence for the 1990s in the United States, and for Europe over a longer period, is that it is not just the less-skilled activities that are sent abroad; instead it may be high-skilled activities. That fact does not sit well with the comparative advantage-based rationale for offshoring, and requires, I believe, a specification of the extra costs involved with offshoring. That is where the recent work of Grossman and Rossi-Hansberg (2008a) comes in so useful. By allowing for a rich structure of offshoring costs, we can predict that either the less-skilled activities are offshored, as in the 1980s, or that the more-skilled activities are sent abroad, as in the 1990s. The motivating force for the offshoring is still factor price differences across countries, but the way that these differences are reflected in the tasks that are sent abroad depends crucially on those extra costs. This is clearly a new aspect of trade, or of the costs of doing trade, which is the first step beyond the Heckscher-Ohlin model.

A further step beyond the Heckscher-Ohlin structure is to allow for workers of many different skills, with supermodular production functions. The recent work of Costinot and Vogel (2008) allows the second-moments of the skill distribution to influence trade and therefore factor earnings. While I have suggested that a factor content calculation will continue to hold in this framework, and have provided a new method for making this calculation, my treatment today oversimplifies the issue. It is not just the average amount of factors found in an economy – such as high-skilled and low-skilled individuals, or nonproduction and production workers – but the entire distribution of skills that determines trade. Countries with more diverse endowments of skills can be expected to export goods at the extreme ends of the skill requirements (Grossman and Maggi, 2000, Grossman, 2004, Costinot and Vogel, 2008). This type of model therefore gives us a rationale for North-North trade, even when average endowments are the same, in addition to North-South trade. And offshoring needs to be incorporated into a North-North model, too, as in the most recent work of Grossman and Rossi-Hansberg (2008b). These issues all point towards exciting research on the microeconomic structure of these models in the years ahead.

Offshoring in the Global Economy
Lecture 2. Macroeconomic Implications

Introduction

In yesterday's lecture I discussed in depth the microeconomic structure of trade models with offshoring. Today, I want to shift attention to macroeconomic implications, of which three come to mind immediately: business cycle volatility, price determination, and productivity. I will begin with business cycle volatility. The model I discussed yesterday, whereby firms choose the least-cost country for each stage of the production process, allows for the rapid movement of activities across countries in response to wage movements. This is an example of what Jagdish Bhagwati (1997) calls "kaleidoscopic comparative advantage." Writing in the *Financial Times* just one month ago, he explains that this phenomena "leads to volatility of jobs, as you have an advantage today and can lose it tomorrow"[16] I will argue that such rapid movement has been seen in the experience of the Mexican economy, and especially the *maquiladora* sector, which are the Mexican firms located just south of the U.S. border. That sector of the economy displays more volatility than overall for Mexican manufacturing, and also more volatility than those industries in the United States. This amplified volatility is not a coincidence, and in fact, follows from the structure of the models that I discussed yesterday. Demonstrating this amplified volatility, both in theory and in the data for Mexico and the U.S., is the first goal for today's lecture.

Second, I will turn attention to the nominal side of the economy, to prices and exchange rates. This is a topic that was touched on in last year's Ohlin lecture, by Ken Rogoff. The impact

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[16] Bhagwati, Jagdish, 2008, "The Selfish Hegemon Must Offer a New Deal on Trade," *The Financial Times,* August 20, p. 11.

of offshoring, or globalization more generally, on nominal variables is inherently controversial. As Milton Friedman (1974) famously said: "Inflation is always and everywhere a monetary phenomena …," which does not seem to leave much room for international trade to enter the equation. But researchers are now asking whether increased globalization is responsible for at least some of the features of prices and exchange rates that have been observed in recent years.

Of particular interest is the question of whether the pass-through of nominal exchange rate to import prices, and ultimately to domestic prices, differs today than in past decades. I will show how the pass-through of the dollar exchange rate to U.S. import prices depends on the share of imports coming from China, a leading location for offshoring. Demonstrating that result will require changing one assumption normally used in the monopolistic competition model, and that is the assumption of CES preferences. Instead, I will introduce a new class of preferences that allow the markups of firms to vary due to market pressures, and these changing markups will end up having macroeconomic effects on prices.

Besides exchange rates, aggregate prices can be affected by offshoring through its impact on productivity. I have touched on that topic yesterday, and today will look more thoroughly at how offshoring affects productivity growth in the United States. This is an issue that has received much attention recently in Washington, D.C., with various statistical agencies trying to update their procedures to deal with this new form of international trade. After discussing the empirical issues raised in the U.S., I will conclude my talk by returning to the theory linking international trade to productivity. To the most recent class of models I will add one new element, and that is the endogenous choice of effort by workers, which then determines productivity. That will allow me to consider the impact of trade on the biggest macroeconomic shock of all, the industrial revolution.

Business Cycle Volatility

Let me begin with the connection between offshoring and volatility. The idea that openness to trade might amplify the volatility of an economy is hardly new, and has been studied empirically for some time. Initial work by William Easterly and Joseph Stiglitz (Easterly, Islam, and Stiglitz ,2000) established that increased openness contributed to aggregate volatility across a wide range of countries. That conclusion has now been re-examined at a sectoral level (Giovanni and Levchenko, 2008a), in which case there are offsetting effects: sectors that are more open to international trade are more volatile, but they are also less correlated with the rest of the economy. On net, the evidence still suggests that sectoral openness leads to increased aggregate volatility, but this effect is stronger for developing economies. If we add the firm dimension, as done by Claudia Buch for Germany (Buch, Döpke and Strotmann, 2007), then we find instead that exporting leads to less firm-level volatility.

With this range of empirical results, we cannot help but ask: what is the model? My own contribution in this area, with Paul Bergin and Gordon Hanson, is to construct a model that is very closely related to the offshoring literature, but introduces demand and supply shocks (Bergin, Feenstra and Hanson, 2007, 2008a,b). It turns out that only demand shocks are important, for reasons I will explain. Furthermore, it turns out the demand shocks have differential impacts on the home country where offshoring originates and the foreign country where the offshoring takes place. Essentially, offshoring allows the home country to export its business cycle fluctuations, so that volatility is amplified abroad. The idea that the co-movement of business cycles across countries will depend on whether we are looking at North-North versus North-South trade, and also depend on the vertical linkages between countries, has been confirmed in recent empirical work (Burstein, Kurz and Tesar, 2005; Giovanni and Levchenko, 2008b). Linda Tesar has recently extended that work to study the synchronization of business cycles across East and West Europe (Tesar, 2008), as I will come back to later.

Model of Offshoring

Let me briefly outline the theoretical model that I have in mind. To simplify the offshoring model from yesterday, suppose that there is a single factor of production – labor. There is again a continuum of activities, which we arrange in increasing order of U.S. or home comparative advantage. Then just like the Ricardian model with a continuum of goods, we obtain a downward sloping schedule between relative labor requirements at home and abroad,

$$A(z) \equiv \frac{a(z)}{a^*(z)} = \exp(bz + c), \quad b < 0.$$

The intersection between the relative labor requirements A(z) and the relative wage determines the borderline activity that can be done in either country, shown in Figure 2.1. The home country will perform those activities above z', while the foreign country will perform those activities below z'. These activities are treated like intermediate inputs, which are produced in multiple varieties under monopolistic competition, with N firms producing each good z. These inputs are then combined into a final, multinational good using a symmetric Cobb-Douglas function.

We close the model by adding country-specific homogeneous goods produced in each country, which are also traded. The key results can be seen by focusing on labor demand for the multinational good. I denote world demand by $\overline{D}_M \equiv [D_M + D_M^*(1-n)/n]$, where n is a parameter reflecting the size of the home country relative to the foreign country. The labor earnings at home from production of the activities above z' are just:

$$wL_M = \overline{D}_M (1 - z')\left(\frac{\sigma - 1}{\sigma}\right),$$

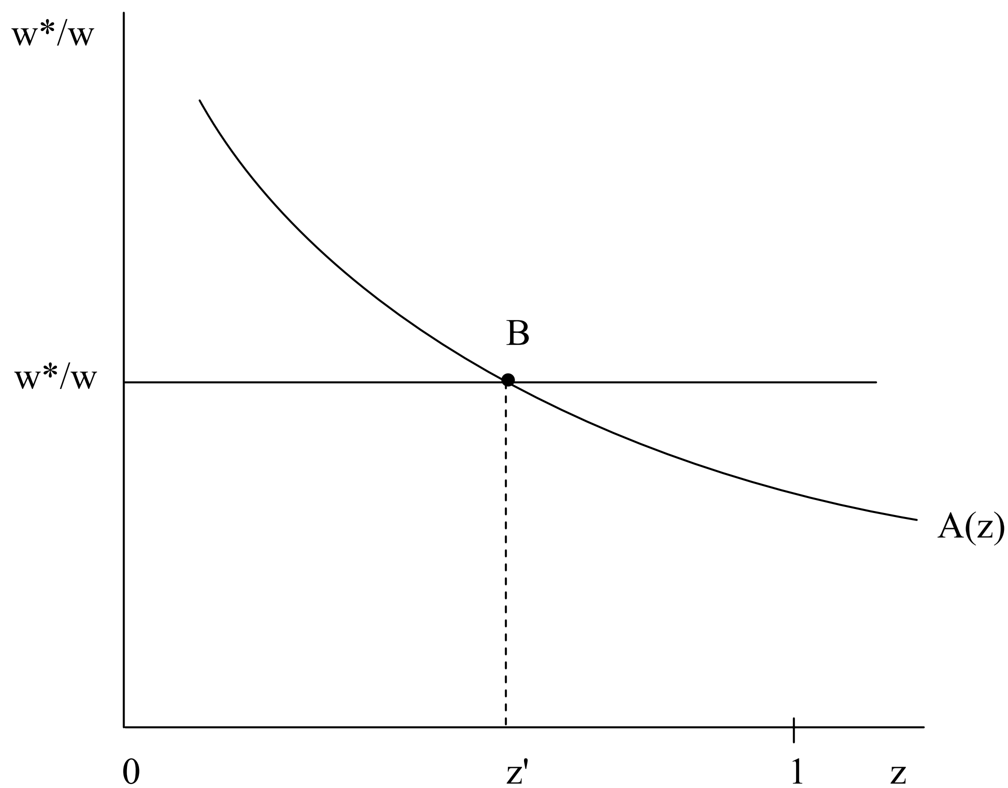


Figure 2.1: Equilibrium with Offshoring

where σ is the elasticity of substitution between varieties of good z. These labor earnings include both the fixed costs and variables costs used in production. It will be convenient to make use of the equilibrium condition to rewrite the employment in the offshored good at home as:

$$\frac{w^*}{w} = A(z') \quad \Rightarrow \quad L_M = \left(\frac{\overline{D}_M}{w^*}\right)(1-z')A(z')\left(\frac{\sigma-1}{\sigma}\right).$$

Likewise, employment in the offshored good in the foreign country is simply:

$$L_M^* = \left(\frac{\overline{D}_M}{w^*}\right)(z')\left(\frac{n}{n-1}\right)\left(\frac{\sigma-1}{\sigma}\right).$$

Taking the logs and variance of these two employment equations, we obtain the following:

$$\mathrm{var}(\ln L_M) = \mathrm{var}\left[\ln\left(\frac{\overline{D}_M}{w^*}\right)\right] + \left[\frac{1}{(1-\overline{z}')} - b\right]^2 \mathrm{var}(z') - 2\left[\frac{1}{(1-\overline{z}')} - b\right]\mathrm{cov}\left[z', \ln\left(\frac{\overline{D}_M}{w^*}\right)\right],$$

and,

$$\mathrm{var}(\ln L_{Mt}^*) = \mathrm{var}\left[\ln\left(\frac{\overline{D}_M}{w^*}\right)\right] + \frac{\mathrm{var}(z')}{(\overline{z}')^2} + \frac{2}{(\overline{z}')}\mathrm{cov}\left[z', \ln\left(\frac{\overline{D}_M}{w^*}\right)\right].$$

where $\overline{z}'$ denotes the mean level of production activities in Mexico.

From these expressions, we can see that the variance of employment in each country depends on three factors: first, on the variance of world demand relative to the foreign wage; second, on the variance of the offshoring margin z', which is measured *relative to* an 'adjusted' size of the offshoring sector, $\{[1/(1-\overline{z}')] - b\}$ at home and $(1/\overline{z}')$ abroad; and third, on the covariance between z' and world demand. The first term, which is the variance of world demand relative to the foreign wage, enters identically in both expressions, so it does not lead to any asymmetric effect across countries. The second term, which is the variance of the offshoring margin z', has a bigger impact in the foreign country when the range of activities done there is small. This just reflects the idea that the percentage impact of any given demand fluctuations on employment will be greater if the economy is smaller. Finally, the covariance between the offshoring margin z' and world demand enters with opposite signs in the two countries. Provided this covariance is positive, it lowers the variance of employment at home, but amplifies it abroad.

In fact, we expect that this covariance is positive from the structure of the model. World demand for the offshored good will be most highly correlated with home, or U.S. demand, since it is the larger economy. An increase in U.S. demand will raise U.S. relative wages, resulting in a shift in the offshoring margin from z' to z* in Figure 2.2. So offshoring activities get shifted to Mexico at the same time as demand is booming, thereby amplifying the volatility of employment there. On the other hand, the impact of the demand shock in the U.S. is offset by shifting production abroad. So there is an asymmetric impact of demand shocks on the two countries.

My focus on demand shocks goes against the conventional practice in real business cycle models of focusing on productivity shocks. The reason I have ignored such supply-side shocks so far is that they have only limited effects in the model. This result follows from my discussion yesterday of Paul Krugman’s (2000) paper. Krugman showed that in a two-country, two-good model with complete specialization and Cobb-Douglas preferences, Hicks-neutral productivity shocks would have no impact at all on employment: the fall in price and increase in demand following a rise in productivity will just offset the potential decline in employment.

The framework I have presented is actually a three-good model, with a homogeneous good exported by each country and also the offshored good. But essentially the same result as in Krugman will hold provided that productivity shocks in the offshoring sector are transmitted instantaneously between countries, so there is no shift in the A(z) schedule. The rapid international transmission of productivity shocks is supported by the empirical work of Berman, Bound and Machin (1998), which I referred to yesterday. So we can draw on that literature to conclude that demand shocks, and not productivity shocks, are the chief source of international

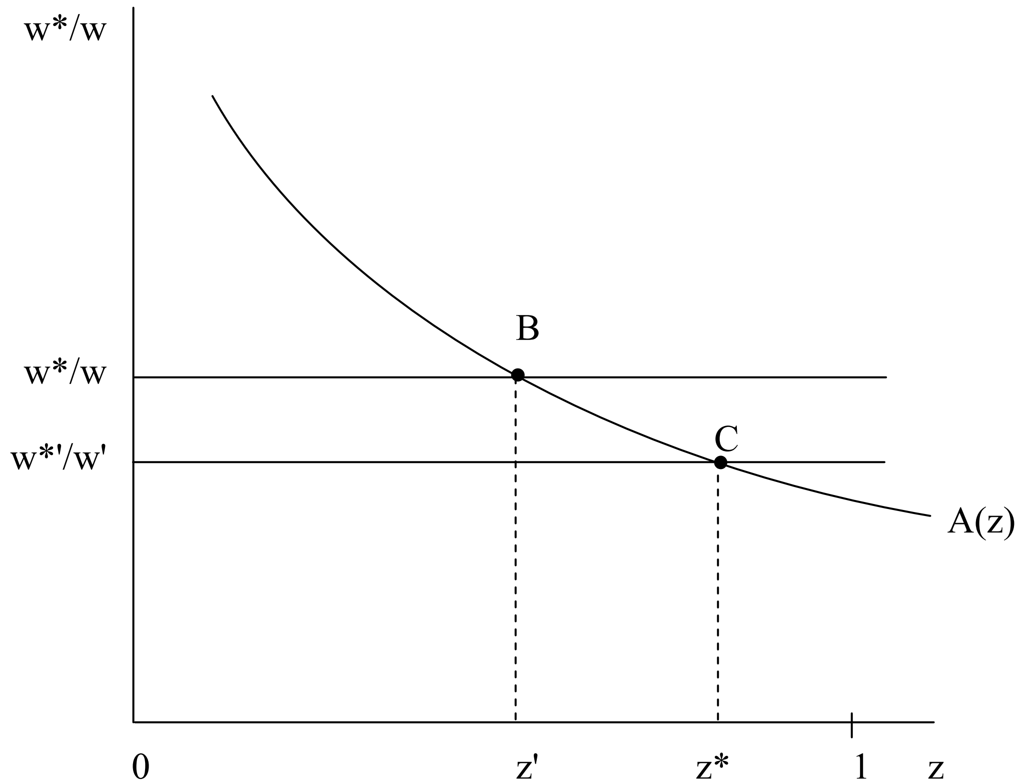


Figure 2.2: Increase in Offshoring Due to rise in Home Wage

transmission of business cycles, in this offshoring model.

Empirical Evidence

Let me turn now to the evidence for the U.S. and Mexico. To avoid the period of the peso crisis in 1994-1995, I focus the analysis on the period 1996-2005. Figure 2.3 plots the production-worker employment for the four main offshoring industries, which are apparel, electronic materials and machinery, and transport equipment. In each industry, employment in Mexico (shown by the dashed line) is substantially more volatile than in the United States. That perception is reinforced by looking at the standard deviations of log employment in U.S. manufacturing industries and the corresponding maquiladora plants in Mexico. Table 2.1 shows the standard deviations for the production worker employment in Mexican and U.S. industries, and in the bottom rows, the ratio of Mexico to the U.S. On average, the standard deviation of Mexican employment is about twice as high as that in the United States in each industry, but smaller than in the U.S. for overall manufacturing.

One simple reason for volatility to be higher in the Mexican offshoring industries is that they are smaller than the U.S. industries, so with idiosyncratic shocks across plants, U.S. employment may be smoothing out shocks. To investigate the size differences between the Mexican and U.S. industries, Table 2.2 lists employment in each industry, showing that in two of the four industries the U.S. is indeed much larger. We can deal with these size disparities by focusing on particular U.S. states. The vast majority of maquiladoras in Mexico are located in Mexican border cities and many are linked to production operations on the U.S. side of the border (Feenstra, Hanson, and Swenson, 2000), in either California or Texas.

Figure 2.3: Employment for Production Workers in Mexico and U.S. Offshoring Industries
(log values, seasonally adjusted and HP filtered)

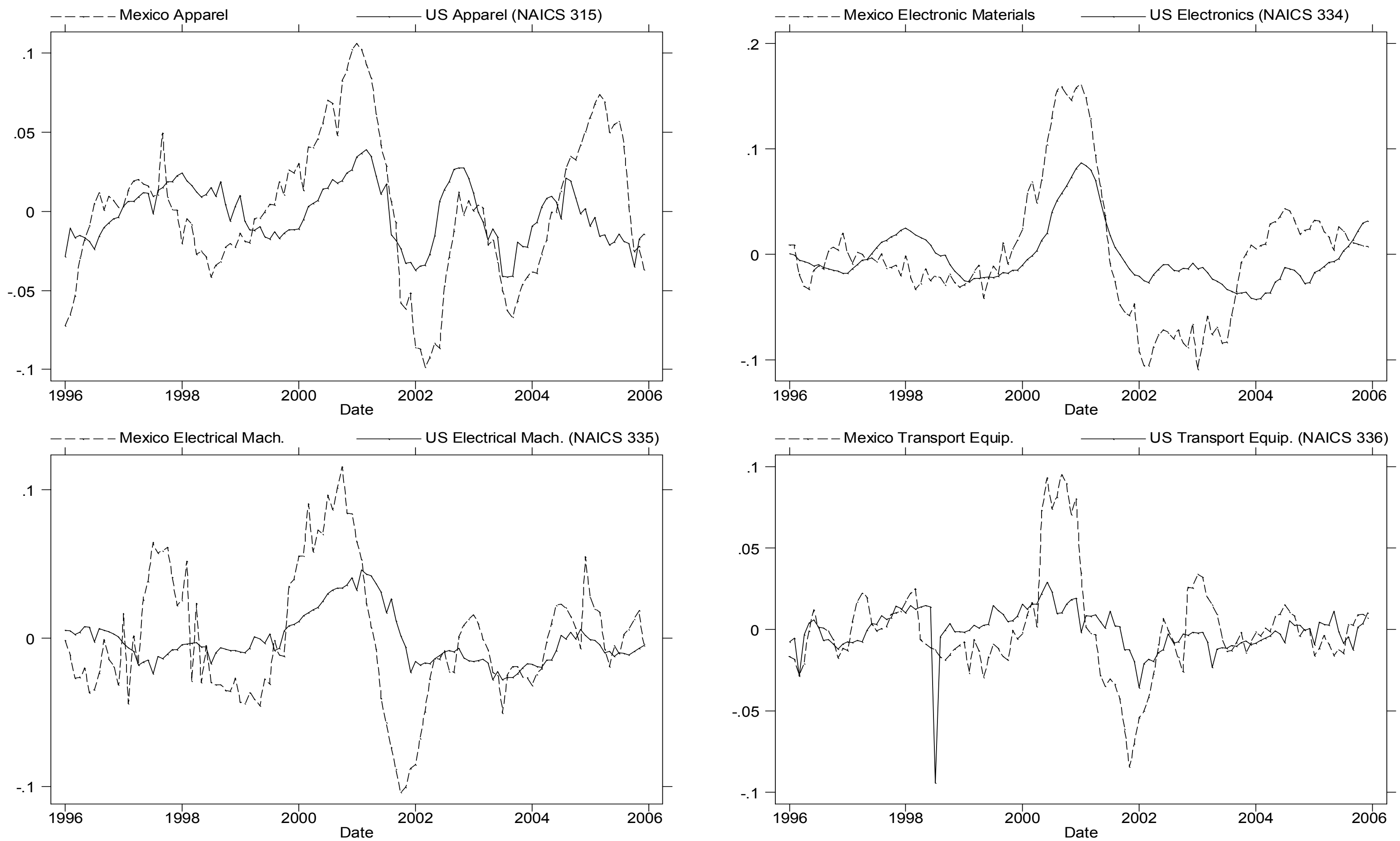


Table 2.1. Relative Volatility in Mexico and U.S. Offshoring Industries: Production Worker Employment

	Apparel	Electrical Machinery	Computer & Electronics	Transport Equipment	Average
Standard Deviations, Employment					
$\sigma(L_i^*)$ **(Mex. Offshoring Industry)**	4.52	4.34	5.95	2.96	4.44
$\sigma(L_i)$ **(U.S. Offshoring Industry)**	1.89	1.79	3.06	1.42	2.04
$\sigma(L^*)$ **(Mex. Aggregate Manufacturing)**	0.89	0.89	0.89	0.89	0.89
$\sigma(L)$ **(U.S. Aggregate Manufacturing)**	1.15	1.15	1.15	1.15	1.15
$\sigma(L_i^*)/\sigma(L_i)$	2.39	2.42	1.94	2.08	2.21
$\sigma(L^*)/\sigma(L)$	0.77	0.77	0.77	0.77	0.77

Notes:
The top potion of the table shows standard deviations (in percent) for the production-worker employment in specific Mexico and U.S. Offshoring industries, and in Mexico and U.S. aggregate manufacturing, and the ratios of these standard deviations. Each series is in log values, seasonally adjusted, and HP filtered. Data are monthly from 1996 through 2005.

So I next compare Mexican industries to their counterparts in California and Texas. Table 2.2 shows that employment in offshoring industries in California and Texas is similar in scale to Mexican industries. Table 2.3 shows that standard deviations and their ratios based on state employment data are broadly similar to those obtained for national data: the four offshoring industries are somewhat less than twice as volatile in Mexico as compared to California or Texas, whereas overall Mexican manufacturing employment is less volatile than in either state. So even after correcting for size differences, we still obtain more volatility in the Mexican maquiladora industries.

The theoretical model I have described implies that changes in employment by offshoring industries are driven in part by adjustment at the extensive margin. If such a mechanism is at work, we should see considerable entry and exit among the assembly plants in Mexico that produce intermediate goods and services for U.S. industry. There is abundant anecdotal evidence of such plant turnover from firms such as Delphi, a large U.S. manufacturer of auto parts. It has opened and closed assembly plants in Mexico during period of expansion and contraction. To see whether there is more formal evidence of adjustment at the extensive margin, we can look at employment data. Let us start with an identity linking industry employment to the employment per plant and the number of plants:

$$E_{it} \equiv N_{it} \times \frac{E_{it}}{N_{it}} \equiv \frac{E_{it}}{E_t} \times E_t ,$$

where E_{it} is employment in industry i at time t, N_{it} is the number of plants in industry i at t, and E_t is aggregate employment in Mexico at t. From this identity we specify two regressions:

$$\ln N_{it} = \alpha_0 + \alpha_1 \ln \frac{E_{it}}{E_t} + \alpha_2 E_t + \varepsilon_{it}$$

and,

$$\ln \frac{E_{it}}{N_{it}} = \beta_0 + \beta_1 \ln \frac{E_{it}}{E_t} + \beta_2 E_t - \varepsilon_{it} .$$

Table 2.2. Size of Offshoring Industries in Mexico and the U.S.

		Thousands of employees (mean 2000-2005)			
NAICS	Industry	Mexico	U.S.	Texas	California
	All maquiladoras (Mexico)	1,151.00	--	--	--
	All manufacturing (United States)	--	15,336.70	955.5	1,649.00
315	Apparel	230.8	356.9	--	97.4
334	Computer & Electronics	265.6	1,512.30	132.9	366.6
335	Electrical machinery	100.2	497.5	20.0	38.5
336	Transport equipment	240.7	1,855.80	85.2	137.5

Source: U.S. Bureau of Economic Analysis, Regional Economic Information System, http://www.bea.gov/bea/regional/reis/; Mexico's National Institute for Statistics, Geography, and Informatics (INEGI), http://www.bea.gov/bea/regional/reis/.

Table 2.3. Relative Volatility in Mexico and U.S. Offshoring Industries: Total Employment at the U.S. State Level

	Apparel	Electrical Machinery	Computer & Electronics	Transport Equipment	Average
			California		
$\sigma(L_i^*)$ **(Mex. Offshoring Industry)**	4.48	4.11	5.50	2.73	4.21
$\sigma(L_i)$ **(U.S. Offshoring Industry)**	2.25	2.35	2.62	1.31	2.13
$\sigma(L^*)$ **(Mex. Aggregate Manufacturing)**	0.77	0.77	0.77	0.77	0.77
$\sigma(L)$ **(U.S. Aggregate Manufacturing)**	1.40	1.40	1.40	1.40	1.40
$\sigma(L_i^*)/\sigma(L_i)$	1.99	1.75	2.10	2.08	1.98
$\sigma(L^*)/\sigma(L)$	0.55	0.55	0.55	0.55	0.55
			Texas		
$\sigma(L_i^*)$ **(Mex. Offshoring Industry)**	4.48	4.11	5.50	2.73	3.09
$\sigma(L_i)$ **(U.S. Offshoring Industry)**	n.a.	2.48	3.12	1.66	2.42
$\sigma(L^*)$ **(Mex. Aggregate Manufacturing)**	0.77	0.77	0.77	0.77	0.77
$\sigma(L)$ **(U.S. Aggregate Manufacturing)**	1.16	1.16	1.16	1.16	1.16
$\sigma(L_i^*)/\sigma(L_i)$	n.a.	1.66	1.76	1.64	1.69
$\sigma(L^*)/\sigma(L)$	n.a.	0.66	0.66	0.66	0.66

Notes:

The table follows the same format as the top portion of Table 2.1, but uses total employment rather than production-worker employment.

n.a. indicates this industry is not available for that state.

Because we started with an identity, the coefficients will sum to zero or unity across these regressions, $\alpha_0 + \beta_0 = 0$, and $\alpha_1 + \beta_1 = 1$ and $\alpha_2 + \beta_2 = 1$.

In Table 2.4, I report the result from these regressions using data for the employment and number of firms in the maquiladora industries. In the first column, the estimates show that in response to an increase in the share of aggregate employment in an offshoring industry, over one-third of adjustment in industry employment occurs at the extensive margin, in the number of plants. Further, in response to an increase in aggregate employment nearly one-half of adjustment in industry employment occurs at the extensive margin. So it appears that plant entry and exit is an important channel by which the maquiladora industry adjusts to aggregate shocks.

A second way to measure the extensive margin is by the number of products that Mexico exports to the U.S. I use the Harmonized System (HS) import data for the U.S., at a monthly frequency, and focus on the three largest land border crossings: Laredo, El Paso and San Diego. In Table 2.5, I summarize the average number of HS 10-digit products crossing at Laredo, in each of the four industries. In the first row, there are between 100 and 400 distinct types of products crossing the border each month. On average, a given product is exported between 6 and 9 months of the years, as shown in the second row. The standard deviation of the log number of products is 2 or 3%, which is quite high for monthly data. There is also a positive correlation between the number of distinct products crossing the border and U.S. manufacturing employment.

These summary statistics show that there are many "zeros" in the data, that is, many instances where a product is not exported some month. That fact is also illustrated by Figure 2.4, where I graph the log number of HS products per month. Some of the fluctuation in the number of HS products reflect products that are exported at irregular intervals during the year. But we

Table 2.4: Adjustment in the Maquiladora Industry: Extensive Margins

	Number of plants	Employment per plant
	(1)	(2)
Industry share of aggregate employment	0.38	0.62
	(0.16)	(0.16)
Aggregate employment	0.49	0.51
	(0.05)	(0.05)
R^2	0.30	0.51
N	480	480

Notes:

Columns (1) and (2) show regressions of either the number of plants or employment per plant on total Mexican manufacturing employment and the industry share of manufacturing employment. The sample is the four Offshoring industries in Mexico, with data at a monthly frequency from 1996:1 to 2005:12. All variables are in logs, expressed in real terms, deseasonalized, and HP filtered. All regressions include controls for industry fixed effects, which are not shown. Standard errors (clustered by industry) are in parentheses.

Table 2.5: U.S. Harmonized System Imports from Laredo, 1996–2006

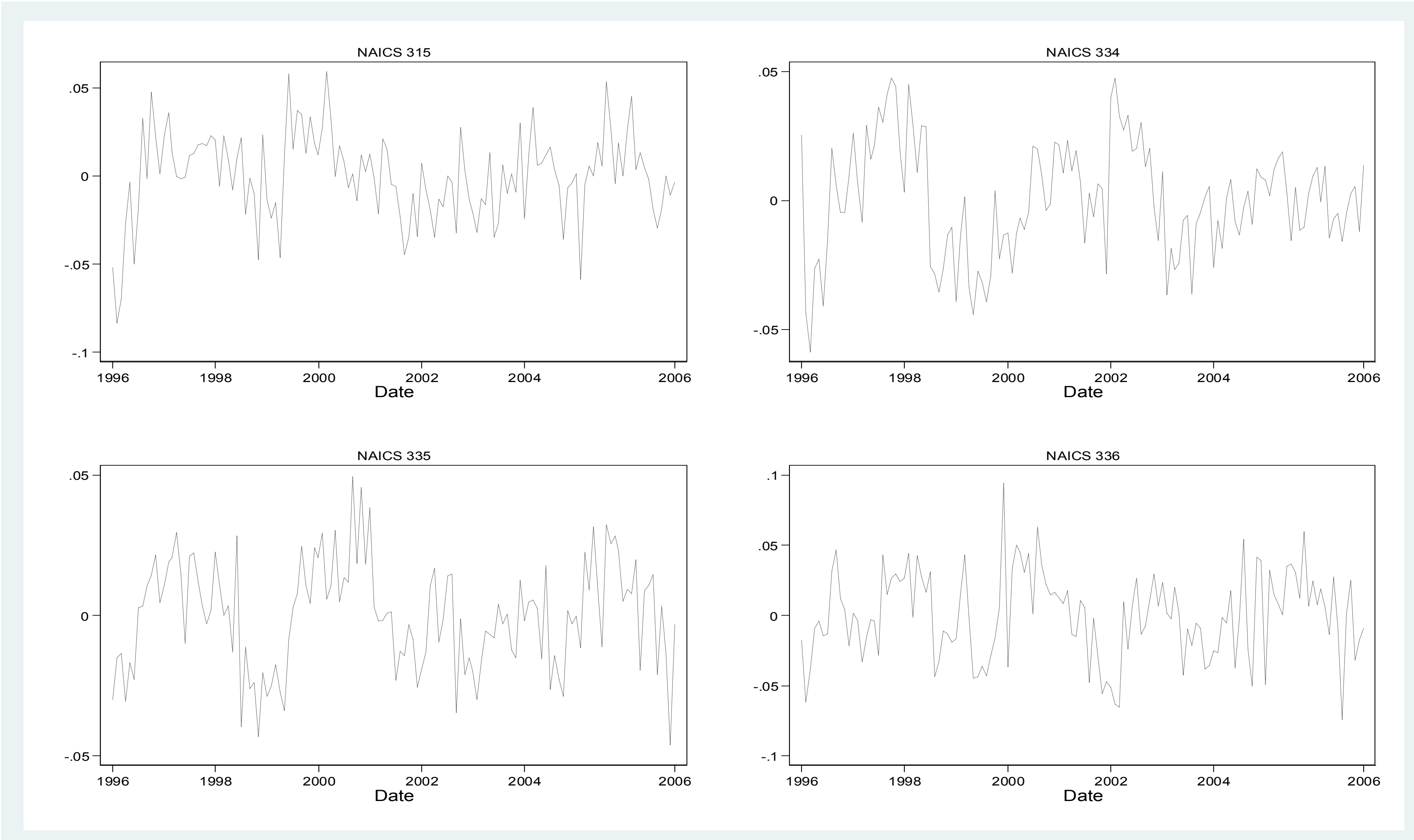
	Apparel	Electrical Machinery	Computer & Electronics	Transport Equipment
Laredo, TX				
Mean Number of HS Products	384.0	219.2	258.6	140.5
Mean Number of Months a HS Product is Imported Per Year[a]	6.9	8.9	7.5	9.0
Std. Dev. Log Number of HS Products [b]	2.64	2.14	3.10	2.94
Correlation of Number of HS Products and U.S. Manufacturing Employment [c]	0.28	0.32	0.07	0.31

Notes:
a. Averaged over HS products and over the years 1996–2006.
b. The log number of HS products has been deseasonalized and HP filtered, and the standard deviation is multiplied by 100.
c. The number of HS products and U.S, manufacturing employment are in logs, and are deseasonalized and HP filtered.

Source:
Bureau of the Census, 1996-2006, *U.S. Exports and Imports of Merchandise on CD-ROM* [machine-readable data file], Washington, D.C.

Figure 2.4: The Number of HS Products Over Years

(Ave. over 3 ports; Log values, seasonally adjusted, HP filtered)



also expect that some fluctuation is systematic: for example, there appears to be a fall in the number of HS products in 2002, when employment in both Mexico and the U.S. was low.

To see whether there is really a systematic fluctuation in the number of products exported from Mexico, we can specify the same regressions as before:

$$\ln N_{it} = \alpha_0 + \alpha_1 \ln \frac{E_{it}}{E_t} + \alpha_2 E_t + \varepsilon_{it}$$

and

$$\ln \frac{E_{it}}{N_{it}} = \beta_0 + \beta_1 \ln \frac{E_{it}}{E_t} + \beta_2 E_t - \varepsilon_{it}.$$

Now N_{it} denotes the number of HS products exported from Mexico in industry i, month t, and a particular border crossing, E_{it} is the value of exports for that industry i and border crossing in month t, and E_t is total exports at that border crossing in month t. The results from these regressions are shown in Table 2.6. In the first column, the coefficient of 0.07 shows that the number of products exported in each industry responds by a small but significant amount to a shift in the value of Mexican exports towards that industry. For an increase in overall exports, with a coefficient of 0.1, the number of HS products in the industry also responds by a modest amount. While these coefficients are small, it is remarkable that there is any systematic pattern at all in the extensive margin of monthly trade data, let alone a pattern whereby the range of exports appears to respond to the overall value of exports.[17]

Simulation Results

Let me now assess how well the theoretical framework is able to match these empirical observations, which we can do by simulating the model. I use monthly data on government

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[17] Similar regression results are found when instead of measuring the number of HS products crossing the border each month, we instead use the extensive margin of exports (which is a weighted count of the number of products); see Bergin, Feenstra and Hanson (2008b).

Table 2.6: Adjustment in the Maquiladora Industry: Extensive Margins

	No. of HS Products	Sales per HS Product
	(1)	(2)
Industry share of exports at border crossing	0.07	0.93
	(0.02)	(0.02)
Total exports at border crossing	0.10	0.90
	(0.03)	(0.03)
R^2	0.02	0.77
N	1584	1584

Notes:

Columns (1) and (2) show regressions of either the number of HS products imported by the U.S. per month, or the average import sales per HS product, on the industry share of imports at that border crossing and total imports from Mexico at that border crossing. The sample is the four Offshoring industries in Mexico, exporting to three land border crossings, with data at a monthly frequency from 1996:1 to 2006:12. All variables are in logs, expressed in real terms, deseasonalized, and HP filtered. All regressions include controls for industry fixed effects, which are not shown. Standard errors (clustered by industry) are in parentheses.

expenditures in the U.S. and Mexico to calibrate the demand shocks, and monthly data on the Solow residual to calibrate the supply shocks. Other parameters are drawn from the literature.[18]

The data for Mexico and the U.S. are shown in the first column of Table 2.7, and the results for the benchmark case of the model are summarized in the second column. Although my focus is on the offshoring sector, we can see that the volatilities for overall manufacturing employment are in the neighborhood of what is observed in the aggregate data, including the fact that overall employment volatility is somewhat lower in Mexico than in the U.S. But my main interest is in the volatility of the offshoring sector. The calibrated model can easily generate double or triple the volatility in the offshoring sector of Mexico relative to the corresponding U.S. sector, as shown in the second-last row, which matches what we found for the actual data.

The next three columns indicate the results obtained when just one of the four shocks is used. These results show that the home demand shock is the most important driver of the amplified volatility in the Mexican offshoring sector. Conversely, the productivity shocks generate much less volatility in employment, as seen from the top rows in the table, for the reasons I have discussed. I conclude that the simple offshoring model we have presented is capable of obtaining simulation results that closely match the data for the maquiladora industries in Mexico, and the corresponding industries in the U.S. That fact that the maquiladora industries are more volatile means that the U.S. is essentially exporting some of its business cycle, or more precisely, exporting the cyclical fluctuations due to demand shocks.

I have not reported the results for the correlation of employment across countries, but these correlations are all positive in the data and in the simulations. Furthermore, offshoring increases the size of these cross-country correlations. That result is consistent with the finding of

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[18] Details of the simulation methodology, including the parameters used, are described in Bergin, Feenstra and Hanson (2007, 2008b).

Table 2.7. Model Simulation for Production Worker Employment in the Offshoring Sector

	(1) Mexican or U.S. Data[a]	(2) Benchmark case	(3) U.S. demand shock	(4) Mexico demand shock	(5) U.S. supply shock	(6) Mexico supply shock
Standard deviations (%):						
$\sigma(L^*_M)$	4.44	4.54	3.80	2.63	0.59	1.86
$\sigma(L_M)$	2.04	1.52	0.59	0.56	0.27	1.21
$\sigma(L^*)$	0.89	0.94	0.48	0.57	0.39	0.26
$\sigma(L)$	1.15	1.22	0.90	0.66	0.44	0.20
$\sigma(L^*_M)/\sigma(L_M)$	2.21	3.01	6.45	4.77	2.15	1.54
$\sigma(L^*)/\sigma(L)$	0.77	0.77	0.53	0.87	0.90	1.29

Notes:
[a] All variables are in logs except as noted.
[b] The variable z' in this expression is in levels rather than logs.
[c] Holding the slope *A'(z)* constant at its benchmark value of -0.2677.
[d] *A(z)* distribution shifted by productivity shocks.

Linda Tesar (2008) for offshoring between Western and Eastern Europe. She argues that an increase in trade between these regions, due to the recent expansion of the European Union or a future expansion of the Euro zone, would lead to even greater output correlation between these economies. So this feature of offshoring models, which has only begun to be explored, is of interest from both policy and theoretical perspectives.

Prices and Inflation

Let me turn now to a second macroeconomic implication of offshoring, or of globalization more generally, and that is the impact on prices and inflation. The fact that inflation has moderated in many countries during the past two decades, while globalization has increased, has naturally led analysts to wonder whether one has caused the other. Officials in Japan have stated most clearly that they believe the deflation there has been imported from China. Writing in the *Financial Times* in 2002, the Vice Minister and Deputy Vice Minister for International Affairs at the Japanese Ministry of Finance said, [19]

> The entry of emerging market economies - such as China and other east Asian nations - into the global trading system is a powerful additional deflationary force. Their combined supply capacity has been exerting downward pressure on the prices of goods in industrialised economies…. China is exporting deflation and its effects are not limited to neighboring Hong Kong and Taiwan.

In Europe, too, there has been earlier discussion about the connection between increased trade and prices. Simulations done in the late 1980s by Alasdair Smith and Tony Venables (1988, 1991) predicted large gains to the 1992 Single Market reforms in Europe, allowing for

[19] Kawai, Masahiro and Haruhiko Kuroda, "Time for a Switch to Global Reflation," *Financial Times*, London, December 2, 2002, p. 23.

greater unification of the market. Smith and Venables expected that firms would be forced to equalize their selling prices across markets. In other words, rather than treating Europe as a collection of segmented markets, where firms could choose their prices in each country separately, Europe would instead become a unified market where firms could not price-discriminate. As price-discrimination is eliminated, then the average prices are expected to fall, providing benefits to consumers.

Given the 16 years since the Single Market reforms of 1992, and the much shorter period since the adoption of the Euro in 2002, we can ask whether the prediction of unified and lower prices within Europe has been realized. Some positive results are starting to appear. A recent paper by Harald Badinger (2007a) uses sectoral data from 1981 to 1999 and finds solid evidence of markup reductions in manufacturing and construction, but not in services. The service industry that we are all perhaps most familiar with is restaurants, where it is widely believed that prices increased following the adoption of the Euro. But another paper (Hobijn, Ravenna and Tombalotti, 2006) argues that this increase can be understood as making up for unusually small price changes prior to the adoption of the Euro, and in fact, the real puzzle is why such price increases were not more widespread. So I conclude that there is some evidence in favor of falling markups in Europe, but not in all sectors.

Evidence for the United States is summarized in a recent paper by Rick Mishkin (Mishkin, 2008). He strikes a cautionary note on the belief that globalization has affected inflation, quoting the maxim of Milton Friedman (1974). That idea has been stated most forcefully in recent times by Larry Ball (2006), who describes the import price as a *relative* price in the economy, and any decline in that price will by definition be matched by an increase in some other relative price; so there is really no connection whatsoever between import prices and inflation. That iron-clad rule is too strong for me, and perhaps for Mishkin, too, who cites research showing that import competition from China has played some role in lowering import prices, and therefore consumer prices, in the U.S. and the OECD more generally.[20] But at the same time, the demand from China for resources has also raised commodity prices, so the net impact on global prices is likely to be small.

I would like to address the question of what role China might have played in lowering U.S. prices by asking once again: what is the theory? The most common argument for why China can make a difference relies on its impact on the markups charged by firms. That is a difficult argument to assess because our most common model of monopolistic competition, using CES demand, has constant markups. So to make much headway we need to go beyond the CES case and allow for preferences where the elasticity changes with the number of competing firms. A new class of preferences – new at least to the monopolistic competition literature – that allows for such variable markups is the translog expenditure function.[21] The starting point for these preferences is the translog unit-expenditure function for a consumer:

$$\ln e(p) = \alpha_0 + \sum_{i=1}^{\tilde{N}} \alpha_i \ln p_i + \frac{1}{2}\sum_{i=1}^{\tilde{N}}\sum_{j=1}^{\tilde{N}} \gamma_{ij} \ln p_i \ln p_j ,$$

where without loss of generality we impose the symmetry restriction that $\gamma_{ij} = \gamma_{ji}$. The parameter $\tilde{N}$ is the maximum number of possible products, but many of these might not be produced: the prices used for products not available should equal their reservation prices (where demand is zero). Notice that in the CES case the reservation prices are infinite, so these prices drop out of the CES expenditure function (where the infinite prices are raised to a negative power). But in the translog case we need to explicitly solve for the reservation prices.

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[20] See the references in Mishkin (2008) and also the recent work of Auer and Fischer (2008).

In order for the translog expenditure function to be homogeneous of degree one, we need to impose the conditions,

$$\sum_{i=1}^{\tilde{N}} \alpha_i = 1 \text{, and } \sum_{i=1}^{\tilde{N}} \gamma_{ij} = 0 \text{.}$$

I will further impose a strong form of symmetry on the γ_{ij} coefficients, which is:

$$\gamma_{ii} = -\gamma\left(\frac{\tilde{N}-1}{\tilde{N}}\right), \text{ and } \gamma_{ij} = \frac{\gamma}{\tilde{N}} \text{ for } i \neq j, \text{ with } i, j = 1,\ldots,\tilde{N}\text{.}$$

That is, I require that the Γ matrix has the same negative value on the diagonal, and the same positive value on the off-diagonal terms, with the rows and columns summing to zero as needed for the expenditure function to be homogeneous of degree one. Notice that it does no harm to make these parameters depend on $\tilde{N}$, which is just a fixed maximum number.

Now suppose that some of the varieties are not available, so the prices faced by the consumer equal his or her reservation prices. Then using these strong symmetry restrictions we can solve for the reservation prices for goods not available, substitute these back into the expenditure function, and obtain a reduced-form expenditure function that is very convenient to work with. In particular, this reduced-form expenditure function remains valid even as the number of available products – which we denote by N – varies. The following Theorem shows that the reduced form expenditure function is still a symmetric translog:

Theorem (Feenstra, 2003; Bergin and Feenstra, 2008)

Suppose that the strong symmetry restrictions, with $\gamma > 0$, are imposed on the expenditure function. In addition, suppose that only the goods i=1,…,N are available, so that the reservation prices $\tilde{p}_j$ for j=N+1,…, $\tilde{N}$ are used. Then the expenditure function becomes:

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[21] The translog unit-cost function was introduced by Diewert (1976, p. 120).

$$\ln e(p) = a_0 + \sum_{i=1}^{N} a_i \ln p_i + \tfrac{1}{2}\sum_{i=1}^{N}\sum_{j=1}^{N} c_{ij} \ln p_i \ln p_j .$$

where,

$$c_{ii} = -\gamma(N-1)/N, \quad \text{and} \quad c_{ij} = \gamma/N \ \text{ for } i \neq j \ \text{ with } i, j = 1,\ldots,N,$$

$$a_i = \alpha_i + \tfrac{1}{N}\left(1 - \sum_{i=1}^{N} \alpha_i\right), \qquad \text{for } i = 1,\ldots,N,$$

$$a_0 = \alpha_0 + \left(\frac{1}{2\gamma}\right)\left\{\sum_{i=N+1}^{\tilde{N}} \alpha_i^2 + \left(\frac{1}{N}\right)\left(\sum_{i=N+1}^{\tilde{N}} \alpha_i\right)^2\right\},$$

Notice that this reduced form expenditure function looks like a conventional translog function, but now defined over the *available* goods i=1,…,N, while the strong symmetry restrictions on γ_{ij} continue to hold on the coefficients c_{ij}, but using N rather than $\tilde{N}$. To interpret the coefficient a_i, they imply each of the coefficients α_i is increased by the same amount to ensure that the coefficients a_i sum to unity over the available goods i=1,…,N. Finally, the term a_0 incorporates the coefficients α_i of the unavailable products. If the number of available products N rises, then a_0 falls, indicating a welfare gain from increasing variety.

With this Theorem, we can work with the reduced-form expenditure function, knowing that the reservation prices for unavailable goods are being solved for in the background. We can differentiate the unit-expenditure function to obtain the expenditure shares,

$$s_i = a_i + \sum_{j=1}^{N} c_{ij} \ln p_j .$$

The elasticity of demand is obtained by differentiating these shares,

$$\eta_i = 1 - \frac{\partial \ln s_i}{\partial \ln p_i} = 1 - \frac{c_{ii}}{s_i} = 1 + \frac{\gamma(N-1)}{s_i N}$$

We see that the elasticity of demand is inversely related to the market share of each firm: as the market share approaches zero then the elasticity is infinite. With equal-sized firms charging the same prices, the market share is $s_i = 1/N$, and in that case the elasticity is simplified as:

$$s_i = 1/N \quad \Rightarrow \quad \eta_i = 1 + \gamma(N-1),$$

which is linearly related to the number of firms in the market. If we also chose $\gamma = 1$, which is an allowable choice for the translog parameter, then we find that the elasticity of demand equals the number of firms in the market, $\eta_i = N$.

These observations I have made on the elasticity carry over to the markups charged by firms. The optimal prices under monopolistic competition are:

$$p_i = w_i\left(\frac{\eta_i}{\eta_i - 1}\right) = w_i\left(1 + \frac{s_i N}{\gamma(N-1)}\right),$$

so the markups are increasing in each firm's market share. As the shares approach zero then we approach the perfectly competitive equilibrium, and when there are fewer firm then the markups correspondingly rise.

Competition between China and Mexico in the U.S. Market

Let me now use this framework to return to the question of how a growing China can impact prices in the United States. The observation made by many researchers at the Federal Reserve Bank in the U.S. is that as the dollar has depreciated in recent years, the impact on import prices has been less than expected: instead of rising by 50% of the appreciation in foreign currencies, import prices have risen by only 20%, so pass-through has declined from 0.5 in the 1980s to something like 0.2 today. This decline in the pass-through of the exchange rate to import prices is attributed to the presence of China as a competitor in many markets. It can be reasoned the China's presence, together with its essentially fixed exchange rate to the dollar, limits the increase in prices that might occur from other, flexible rate countries such as Mexico. So it is really the interaction of fixed and floating rate countries, in a model with endogenous markups, that has led to the declining pass-through of exchange rates to import prices.

We can make this argument formally by using the translog preferences, together with a three country model: Mexico, denoted by x; China, denoted by y (for yuan); and the United States, denoted by z. We abstract from many of the features of our earlier offshoring model, including the continuum of intermediate inputs. Instead, we simply assume that Mexico and China compete for sales in the United States, which is realistic enough. We model the U.S. demand for the products of these two countries as following the translog preferences, and for simplicity, suppose that the U.S. produces a separate homogeneous good. Then with a depreciation of the dollar, the question is how the Mexican and Chinese firms will respond.

We assume that Mexican firms are symmetric, facing marginal cost of w_x and charging the prices of p_x in peso. Their dollar prices are then $e_x p_x$, where e_x is the floating \$/peso exchange rate. Likewise, Chinese firms are symmetric and face marginal costs of w_y while charging the prices p_y in yuan, so their dollar prices are $\bar{e}_y p_y$, where $\bar{e}_y$ is the fixed \$/yuan exchange rate. From the translog share equations, the market shares of each Mexican and Chinese firm in the U.S. are given by:

$$s_x = a_x - \frac{\gamma N_y}{N}\left[\ln(e_x p_x) - \ln(\bar{e}_y p_y)\right],$$

$$s_y = a_y - \frac{\gamma N_x}{N}\left[\ln(\bar{e}_y p_y) - \ln(e_x p_x)\right],$$

where N_x or N_y denotes the number of Mexican or Chinese varieties sold in the U.S. market, with $N_x + N_y = N$. I will assume that there is a U.S. taste bias towards products from Mexico, meaning that:

$$\alpha_x > \alpha_y \quad \Leftrightarrow \quad a_x > a_y.$$

This assumption is strongly supported by results from gravity equations, for example, which give a bias in favor of countries sharing a border with the importer.

The pricing equation for each firm gives us their optimal prices as a function of market shares, and using the log approximation, $\ln[1 + s_i N / \gamma(N-1)] \approx s_i N / \gamma(N-1)$ which is valid for small shares, we can write the optimal prices as:

$$\ln p_x \approx \ln w_x + \frac{a_x N}{\gamma(N-1)} - \frac{N_y}{(N-1)}\left[\ln(e_x p_x) - \ln(\bar{e}_y p_y)\right],$$

$$\ln p_y \approx \ln w_y + \frac{a_y N}{\gamma(N-1)} - \frac{N_x}{(N-1)}\left[\ln(\bar{e}_y p_y) - \ln(e_x p_x)\right].$$

These are two equations to solve for the two prices – of Mexican and Chinese goods – depending on their marginal costs. We can solve this system for the dollar prices:

$$\ln(e_x p_x) = \frac{1}{\gamma(N-1)} + \ln(e_x w_x) + \frac{N_y}{(2N-1)}\frac{A}{\gamma},$$

and

$$\ln(\bar{e}_y p_y) = \frac{1}{\gamma(N-1)} + \ln(\bar{e}_y w_y) - \frac{N_x}{(2N-1)}\frac{A}{\gamma},$$

where the parameter A reflects the bias in favor of Mexican firms:

$$A \equiv [(\alpha_x - \alpha_y) - \gamma[\ln(e_x w_x) - \ln(\bar{e}_y w_y)].$$

Notice that this parameter depends in part on an assumed taste bias in favor of Mexican as compared to Chinese products, $\alpha_x > \alpha_y$, and also depends on the marginal costs in the two locations, which we assume does not overturn the initial taste bias favoring Mexico. That is, we will assume that $A > 0$.

Holding wages fixed, the effect of a dollar depreciation on the dollar prices of Mexican and Chinese goods can be easily solved as:

$$\frac{d\ln(e_x p_x)}{d\ln e_x} = 1 - \frac{N_y}{(2N-1)} > 0,$$

and,

$$\frac{d\ln(\bar{e}_y p_y)}{d\ln e_x} = \frac{N_x}{(2N-1)} > 0.$$

We see from the first equation that the dollar depreciation raises the dollar price of Mexican goods, but by an amount *less than unity.* The greater is the number of Chinese varieties N_y – reflecting more competition from China – the smaller is this pass-through coefficient. From the second equation, the rise in the dollar price of Mexican goods also induces a rise in the dollar price of Chinese goods, even though its exchange rate is fixed. The result is obtained because Chinese firms respond to the rise in Mexican prices by increasing their own prices. The amount by which Chinese prices rise is smaller, however, as the number of Mexican varieties shrinks.

Pass-through of the multilateral exchange rate

So far, I have solved for the pass-through of the dollar/peso rate to the dollar prices of Mexican and Chinese goods. In practice, pass-through is often measured using multilateral (aggregate) import prices and exchange rates. To achieve that here, define the import price and multilateral exchange rate by taking trade-weighted shares:

$$\ln P_m \equiv (s_x N_x)\ln(e_x p_x) + (s_y N_y)\ln(\bar{e}_y p_y),$$

$$\ln E_m \equiv (s_x N_x)\ln(e_x) + (s_y N_y)\ln(\bar{e}_y).$$

The weights using in these aggregates are the total share of U.S. imports coming from Mexico, $(s_x N_x)$, and the total share of imports coming from China, $(s_y N_y)$. We shall treat these shares as constant when differentiating the aggregates (as they would be in any price index). So we obtain the total change in import prices and the multilateral exchange rate:

$$d\ln P_m = (s_x N_x) d\ln(e_x p_x) + (s_y N_y) d\ln(\bar{e}_y p_y),$$

$$d\ln E_m = (s_x N_x) d\ln(e_x),$$

where I make use of the fact that the yuan exchange rate is fixed. Dividing these equations, we obtain the multilateral pass-through of the exchange rate:

$$\frac{d\ln P_m}{d\ln E_m} = 1 - \frac{N_y}{(2N-1)}\left(\frac{s_x - s_y}{s_x}\right) < 1 \text{ iff } (s_x - s_y) > 0.$$

Thus, the pass-through of the multilateral exchange rate is less than unity provided that the per-firm (or per-product) share of Mexico exports to the U.S. exceeds that for China, $(s_x - s_y) > 0$. This condition is guaranteed to hold provided that A > 0, so there is a “North American bias” in favor of Mexico, which we have already assumed. Furthermore, we see that the pass-through is reduced when the number of Chinese firms selling into the U.S. market expands. Let me now consider how to estimate the pass-through including this type of interaction effect.

Estimating Equation

Using these various theoretical results, the import price index P_m can be solved as:

$$\ln P_m = \frac{1}{\gamma(N-1)} + [1 - B(s_y N_y)]\ln \tilde{E}_m + B(s_y N_y)\ln(\bar{e}_y w_y) + \left(\frac{\alpha_x - \alpha_y}{\gamma}\right) B(s_y N_y)(s_x N_x),$$

where the multilateral exchange rate is,

$$\ln \tilde{E}_m \equiv [(s_x N_x)\ln(e_x w_x) + (s_y N_y)\ln(\bar{e}_y w_y)],$$

and the coefficient B is given by,

$$B \equiv \frac{(s_x - s_y)}{s_x s_y (2N-1)} > 0 \text{ provided that } A > 0.$$

We see that the translog expenditure function leads to an approximately log-linear equation for the import price: it is only approximately log-linear because the term B is not a constant, but is an endogenous variable that depends on relative wages and numbers of firms.

Notice that the pass-through equation includes an interaction term between the multilateral exchange rate and the Chinese import share. An increase in the number of Chinese firms selling in the U.S. market will definitely reduce the pass-through of the exchange rate. Stated differently, an increase in the Chinese share will lower the pass-through of the exchange rate, provided that the increase in the share reflects an increase in the number of Chinese firms, that is, reflects the extensive margin of Chinese exports rather than the intensive margin.[22]

The data I use to estimate this equation is drawn from a set of monthly import prices across 5-digit Enduse industries (Feenstra, Reinsdorf and Slaughter, 2008). I have used the same data to analyze the Information Technology Agreement, which eliminated tariffs on all high-technology products beginning in 1997, as I will discuss a bit later. Because the high-tech products require special treatment for tariffs, I omit them here.

I will gauge Chinese competition by the share of U.S. import purchases coming from China plus Hong Kong. Figure 2.5 shows that average share of Chinese imports grew steadily from 10% in 1993 to 22% in 2006. We can broaden our analysis to consider the share of imports from not just China, but from all countries with a peg to the U.S. dollar (Klein and Shambaugh, 2006). As seen in Figure 2.5, this share initially falls from 20% to about 15%, which is explained

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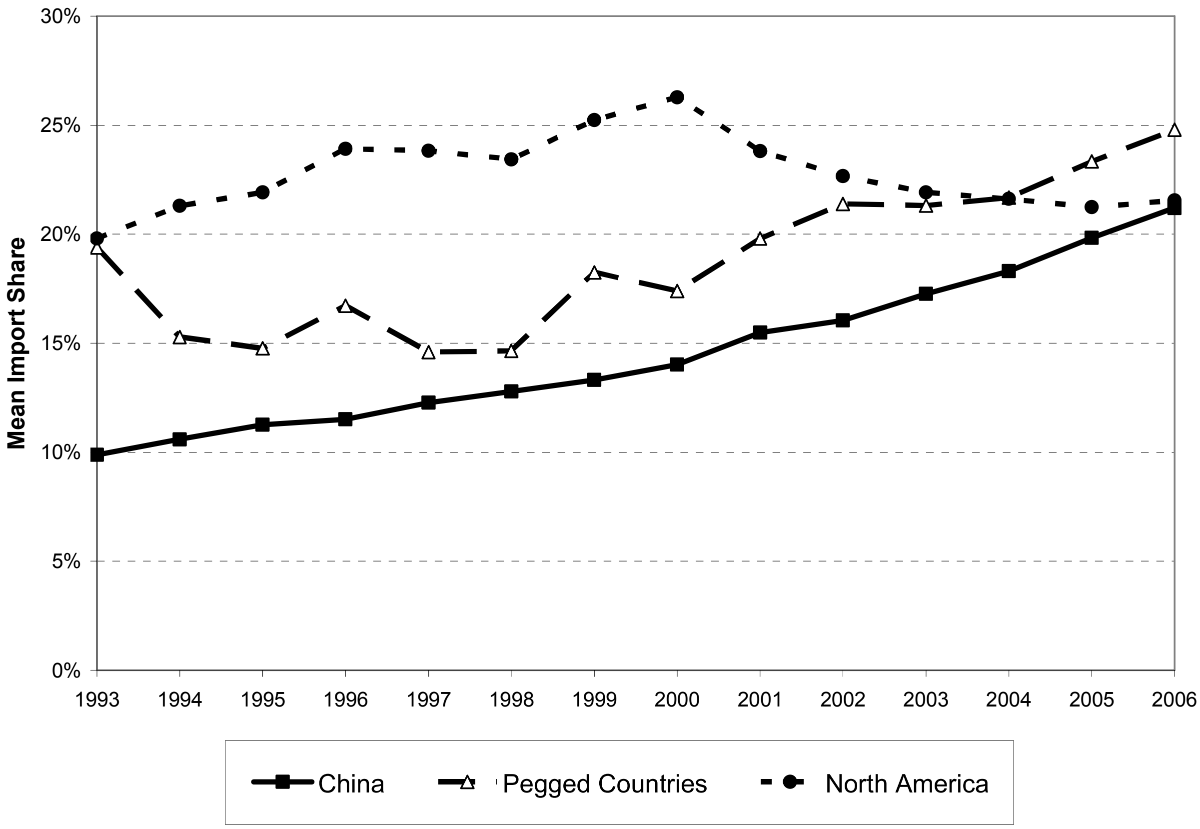
22 But an increase in the per-firm share s_y from China will increase rather than reduce pass-through, taking into account the endogeneity of the term B. Because I cannot measure the number of Chinese firms or the per-firm share in the data, the interaction term I shall use simply relies on the overall Chinese import share.

Figure 2.5: Shares of U.S. Imports by Region of Origin



by the December 1994 peso crisis in Mexico which led to the abandonment of the dollar peg. The peg share subsequently rises to 25% by 2006, which follows the growth in the China share.

I initially consider a regression of import prices on industry fixed effects, along with a current monthly value and 6 lags of the effective exchange rate $\text{ExchPPI}_j^{t-\ell}$. The effective exchange rate is the nominal exchange rate times the Producer Price Index from each country, and then averaged over exporting countries. The pass-through regressions should also include prices of goods that compete with the imports, such as domestic U.S. prices. Here I include the U.S. export prices P_{Xj}^t in each 5-digit Enduse industry.

The estimate of this regression, reported in the first column of Table 2.8, shows incomplete pass-through of exchange rates of 0.21, with a similar coefficient on the export price. The remaining specifications test the effect of Chinese competition on pass-through, by interacting the exchange rate with the share of Chinese imports in each Enduse category:

$$\ln P_{Mj}^t = \alpha_j + \sum_{\ell=0}^{6} \beta_\ell \text{ExchPPI}_j^{t-\ell} + \sum_{\ell=0}^{6} \delta_\ell [\text{ExchPPI}_j^{t-\ell} \times \text{Share}_{jchina}^t] + \gamma \ln P_{Xj}^t + \theta' Z_j^t + \varepsilon_{jt}.$$

The sum of the coefficients δ_ℓ on the interaction term is the incremental pass-through due to changing the China share from zero to one. The additional terms Z_j^t appearing in this regression are control variables such as imports tariffs, the Chinese share of imports and other terms suggested by the theory.

In the second regression of Table 2.8, I include the interaction between the exchange rate and the Chinese import share. The estimate of the interaction term is negative but small in magnitude. In third regression I include the Chinese import share itself as a control. We also include import tariffs; even though the import prices are tariff-free, changes in the tariff levels will still affect import prices under imperfect competition, as in our model. In that case, the

Table 2.8: Pass-through Regressions using the Multilateral Exchange Rate Dependent Variable – Import Price Index

	(1)	(2)	(3)	(4)
	Using China Share			
Exchange rate	0.208**	0.241**	0.341**	0.348**
	(0.009)	(0.009)	(0.012)	(0.012)
Export price	0.224**	0.275**	0.224**	0.157**
	(0.016)	(0.016)	(0.016)	(0.016)
China share *Exch. Rate		-0.035**	-0.565**	-0.340**
		(0.003)	(0.043)	(0.043)
China share			2.593**	2.056**
			(0.212)	(0.205)
Import Tariff				-0.013
				(0.084)
China share *time				-0.001**
				(0.000)
China share *(1-China share)				-0.007
				(0.052)
R^2	0.81	0.82	0.83	0.85
Observations	2694	2694	2694	2694

Notes: * significant at 5%, ** significant at 1%; standard errors are in parentheses.
Regression specification is run over 23 5-digit Enduse categories within consumer goods, capital goods, autos and chemicals (Enduse 2-4) for which no imports are covered by the Information Technology Agreement, from September 1993 – December 2006. OLS is estimated with 6 lags of the exchange rate and fixed effects for 5-digit Enduse categories.

interaction term of the exchange rate with the Chinese share becomes much larger in magnitude, with a coefficient of –0.57, and is statistically significant. In the next regressions we consider further adding other controls suggested by the theory. Including these additional controls reduces the magnitude of coefficient on the interaction term somewhat.

I next consider broadening the import share beyond just China to include all countries with pegged exchange rates to the dollar. The results, reported in Table 2.9, show pass-through coefficients that are similar to the earlier specification. We conclude that our analysis applies more broadly than just to China, but to trade with pegged countries more generally.

To summarize, I have shown here that the increased exports from China to the U.S., which consist in large part of offshored activities, play a significant role in the pass-through of the dollar exchange rate to U.S. import prices. As the dollar has fallen in recent years, import prices have not risen by as much as expected. My argument is that the competition from Chinese producers has limited the price increases that could be expected from other, floating rate countries, such as Mexico. Depending on the exact regression, the rising share of trade from China, or from all countries with fixed exchange rates, can explain a decline in pass-through between one-sixth and one-third of its initial size. Of course, with import prices rising less than expected, overall U.S. inflation is also moderated, which is a macroeconomic consequence of increased globalization.

Terms of Trade and Productivity

Let me turn now to a third macroeconomic consequence of offshoring, and that is its impact on the terms of trade and productivity. This impact has been the focus of some attention in the popular press in the U.S., with an article in *Business Week* entitled "The Real Costs of Offshoring." The costs that its author, Michael Mandel, is referring to is the import competition

**Table 2.9: Pass-through Regressions using the Multilateral Exchange Rate
Dependent Variable – Import Price Index**

	(1)	(2)	(3)	(4)
	Using Peg Share			
Exchange rate	0.208** (0.009)	0.227** (0.009)	0.349** (0.013)	0.341** (0.013)
Export Price	0.224** (0.016)	0.229** (0.016)	0.187** (0.015)	0.204** (0.015)
Peg share *Exch. Rate		-0.015** (0.002)	-0.510** (0.037)	-0.264** (0.039)
Peg share			2.376** (0.176)	1.363** (0.185)
Import Tariff				-0.012 (0.086)
Peg share *time				-0.001** (0.000)
Peg share *(1-Peg share)				0.032 (0.041)
R^2	0.81	0.81	0.83	0.84
Observations	2694	2694	2694	2694

Notes: * significant at 5%, ** significant at 1%; standard errors are in parentheses.
See Table 2.8 for further notes.

created by offshoring, and the potential impact on unemployment. I would instead see that import competition as a benefit rather than a cost, because it lowers import prices and therefore raises the terms of trade. The link between terms of trade changes and productivity growth is a topic of current research that I will summarize. But before that, let me digress to consider the potential unemployment that might be created by import competition. Does this unemployment create social costs that we are missing in our trade models?

Current research on unemployment in trade models depends on either "fair wages," that are above the market clearing level, or on search frictions.[23] Recent theoretical work has put these search frictions in models of offshoring. One paper (Mitra and Ranjan, 2007) finds that unemployment is actually reduced due to offshoring, because the cost-savings for firms leads them to expand employment. More general treatments of trade and unemployment are provided by Elhanan Helpman *et al* (2007, 2008a,b), who find that openness to trade may increase unemployment, but the gains from trade are still positive.

With this range of theoretical results, the real test comes from the empirical side. On the one hand, we have the numbers of Alan Blinder (2007), who believes that two or three times the number of jobs in U.S. manufacturing (which are now 14 million) are "offshorable," meaning that they consist of tasks that are routine enough to be done in another country. That very high estimate of offshorable jobs is best thought of as conjecture. On the other hand, we have the careful empirical work of Liu and Trefler (2008), who utilize the Current Population Survey in the U.S. to link workers who are switching jobs, or becoming unemployed to their original industries. They find only very small effect of offshoring in either switching or unemployment,

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[23] For fair wage models, see Kreickemeier and Nelson (2006) and Egger and Kreickemeier (2008a,b,c). Search frictions builds building on the early work of Davidson, Martin and Matusz (1988, 1999). There is also work combining "fair wages" with offshoring; see Grossman and Helpman (2008).

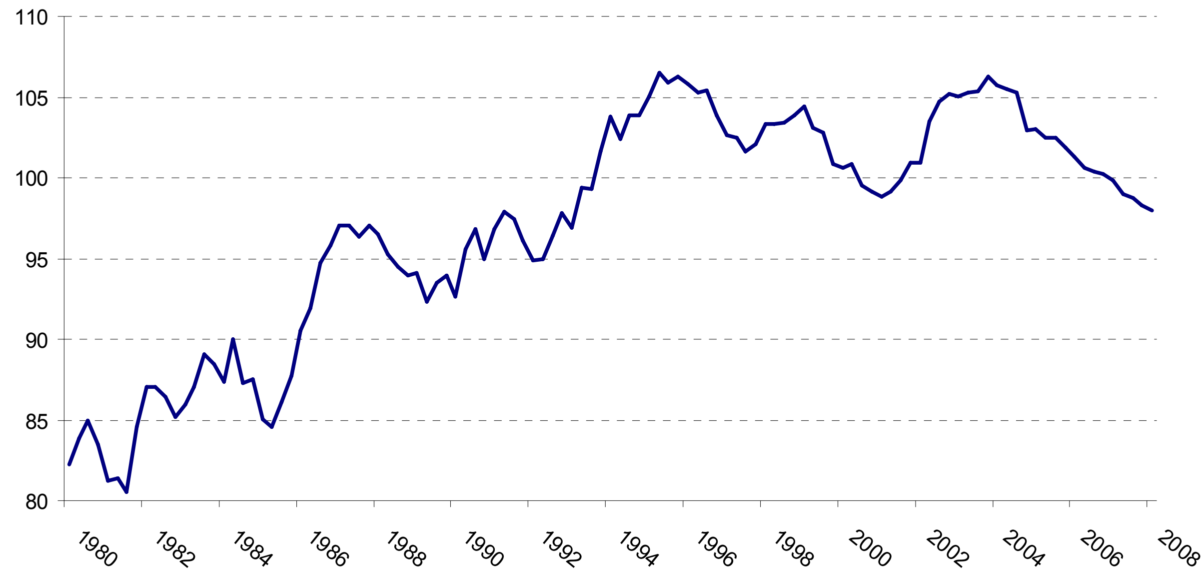
with an offsetting positive impact of "inshoring" on employment rates and earnings. Likewise, very small impacts of offshoring on either job switching or unemployment is found by work of Peter Egger *et al* (2007) for Austria and Jakob Munch (2008) for Denmark. In all these country studies, the unemployment impact of offshoring is not as bad as might be feared.

Terms of Trade

Let me now return to my main topic, which is the impact of the terms of trade on productivity, either in the U.S. or other countries. There is a very interesting motivation for this topic, which is the project on "Great Depressions of the 20th Century," which has been running at the University of Minnesota since 2000 under the direction of Tim Kehoe and Ed Prescott (Kehoe and Prescott, 2002, 2007). In addition to the experience of many countries during the 1930s, this project identifies a number of modern day great depressions: Argentina, Brazil, Chile and Mexico from sometime in the 1970s through the 1990s, New Zealand and Switzerland over the same period, and to a lesser extent Finland and Japan during the 1990s. Depressions are defined by a large negative deviation from the balanced growth path, and the driving force behind these modern day Great Depressions are exogenous falls in productivity.

Let me focus here on the experience of Switzerland. Stagnant growth in GDP from 1974-2000 qualifies Switzerland as having a depression (Kehoe and Ruhl, 2003, 2005). But at the same time, Switzerland experienced a substantial rise in the terms of trade, as shown in Figure 2.6, from 1980 to the mid-1990's. Because of that rise in the terms of trade, living standards in Switzerland did not suffer the same slowdown as real GDP, as conventionally measured. In order to capture this rise in the terms of trade on living standards, it is necessary to define a different concept of real GDP, which we can call real Gross Domestic Income. It is obtained by deflating nominal GDP *not* by the GDP price deflator, but instead by a deflator that reflects that

Figure 2.6: Terms of Trade for Switzerland



purchasing power of consumers, such as the consumer price index or the domestic absorption price index. That approach is favored by Ulrich Kohli, chief economist at the Swiss National Bank, as well as by Erwin Diewert (Kohli, 2004; Diewert and Morrison, 1986). Official practice in Switzerland is now to publish real GDI, which is similar to what is called command-basis GDP in the United States. The ratio of real GDI to real GDP is a measure of trading gains for the economy. These calculations show that real GDI rose in the period since 1980 in Switzerland, despite the stagnant growth of real GDP. So if we instead use real GDI as the yardstick for assessing a depression, then arguably it did not occur in Switzerland at all.[24]

The distinction between real GDI and real GDP helps us to understand what happened to living standards over time in Switzerland, and a similar distinction can also be made to cross-country measures of real GDP (Feenstra *et al*, 2008). But there is still the puzzle as to why real GDP or aggregate productivity, as *conventionally* defined, appears to be correlated with the terms of trade. That correlation has been noted in large panel studies of country growth, where adverse terms of trade shock are often associated with slow growth, as in the work of Easterly, Islam and Stiglitz (2001). That finding runs contrary to the predictions of neoclassical models, as studied by Kehoe and Ruhl (2007), where changes in the terms of trade should not have a first-order impact on real GDP or productivity, at least when tariffs are small.

Evidence from the United States

To resolve this puzzle, I have suggested in joint work with Marshall Reinsdorf and Matthew Slaughter (2008) that there are several reasons to think that the terms of trade for countries are *mismeasured*, and that this problem will spillover into mismeasurement of

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24 Kehoe and Ruhl (2005) calculate that when adjustment is made for the terms of trade, then the case for Switzerland being in a depression over 1974-2000 is borderline,

productivity growth. To understand this argument, let us consider the data for the United States, in Figure 2.7. The thin line is productivity growth for the United States. Prior to 1995, as Robert Solow famously observed, we could see computers everywhere except in the productivity statistics. That changed after 1995, when productivity growth picked up by about one percent per year. What is not as well known is that the terms of trade for the United States also began to improve at about the same time. That is shown by the bold squares in this figure, which divide the monthly export price index from the Bureau of Labor Statistics by the monthly import price index, excluding petroleum. Finally, the open squares are my reconstructed version of the U.S. terms of trade from 1993 to 1999, using the disaggregate prices collected from exporting and importing firms, and the same Laspeyres price index formula used by the BLS.

We can see from this diagram that simultaneously with the increase in U.S. productivity growth there was an improvement in the terms of trade, leading to the obvious question as to whether these are connected. Theoretically, terms of trade changes should not impact productivity when tariffs are zero. But when tariffs are being reduced, there is a connection between the two. The efficiency gains from a drop in tariffs can be thought of as a movement *around* the production possibilities frontier. Normally, we would distinguish such efficiency gains from productivity growth *per se*, which is an *outward shift* in the production possibilities frontier. But that distinction is not made in practice when measuring aggregate productivity growth, because the prices that are used to deflate nominal imports when measuring GDP are themselves *tariff-free* prices. That is, when the BLS measures import prices indexes, and likewise for the statistical agencies in any other country, they ignore tariffs. The reason is that imports within nominal GDP are themselves measured at world prices, and so it is reasoned that the import deflator should be likewise reflect tariff-free prices. But the problem with this

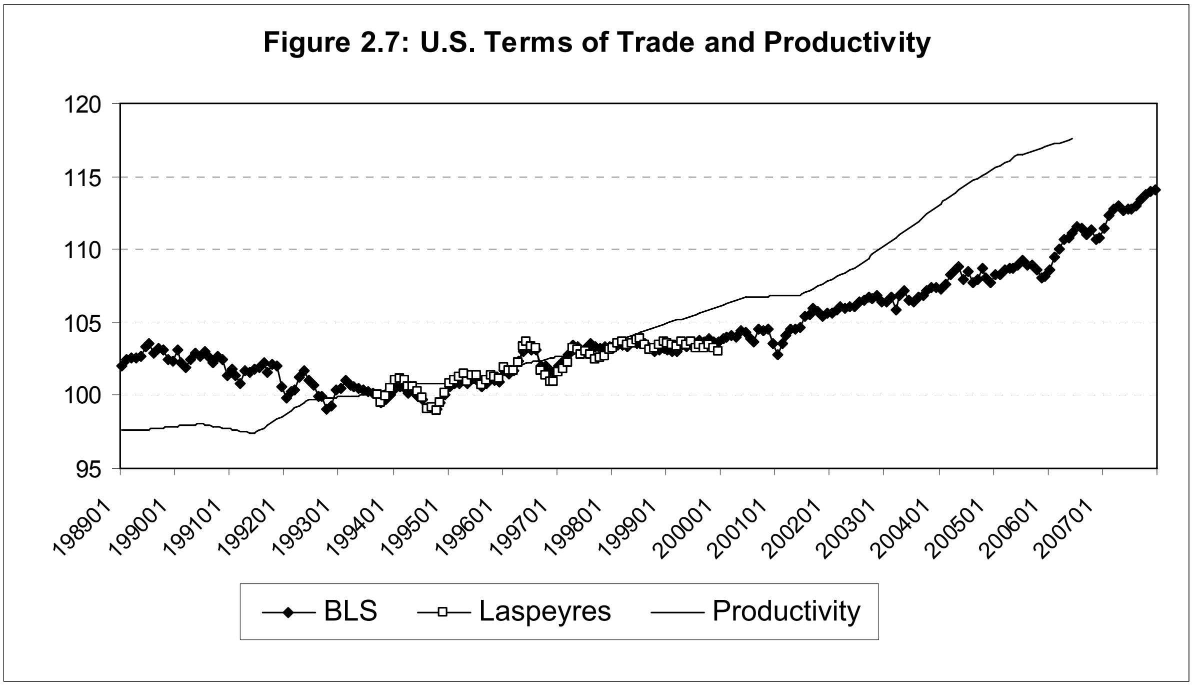


Figure 2.7: U.S. Terms of Trade and Productivity
120
115
110
105
100
95
198901
199001
199101
199201
199301
199401
199501
199601
199701
199801
199901
200001
200101
200201
200301
200401
200501
200601
200701
BLS
Laspeyres
Productivity

conventional accounting practice is that the efficiency gains arising from tariff removal get conflated with productivity gains: in other words, we are not making a clear distinction between the gains from tariff removal, that apply to an open economy, and other sources of productivity gain that apply to a closed economy.

In fact, there were some important tariff reductions that occurred in the United States during this period. From 1997 to 1999, tariffs on high-technology goods were eliminated under the Information Technology Agreement (ITA) of the WTO, which was agreed to by nearly all importing countries. Because this was a multilateral agreement, and the production of many high-tech goods is fragmented across multiple countries, the tariff reduction can have a *magnified* effect on reducing prices. That theoretical result due to Kei-Mu Yi (2003) is confirmed when we look at evidence from the ITA. Specifically, I examine regressions of U.S. import prices for high tech goods on tariffs, exchange rates, and other variables, as shown in Table 2.10.

The first regression is run over those industries where 100% of the import commodities are covered by the ITA; these industries are computers, peripherals and semiconductors. The second regression is run over those industries where 50 – 99% of the import value covered by the ITA, and the third regression is run over those industries where 1 – 49% of the import value is covered by the ITA (0 < ITA < 0.5). The fourth regression is run over a control group of industries that include no high-tech commodities, which are the same manufacturing industries that I used in the earlier pass-through regressions.

Looking first at the regression where 100% of the import commodities are covered by the ITA, the indicator variables for the ITA tariff cuts (July 1997, January 1998 and January 1999) are all negative, indicating a drop in prices that is not accounted for by the tariff variable. The

Table 2.10: Pass-through Regressions, Dependent Variable – Import Price

	(1)	(2)	(3)	(4)
	By portion of products covered by the ITA:			
	ITA=1	0.5≤ITA<1	0<ITA<.5	ITA=0
ITA1	-0.036	-0.017*	-0.033**	-0.005
	(0.027)	(0.007)	(0.005)	(0.004)
ITA2	-0.037	-0.002	-0.011	0.002
	(0.029)	(0.007)	(0.006)	(0.004)
ITA3	-0.158**	0.003	-0.030**	-0.015**
	(0.023)	(0.005)	(0.004)	(0.003)
Tariff	22.60**	2.50**	1.02**	0.86**
	(1.19)	(0.28)	(0.35)	(0.10)
Exchange Rate (6 lags)	0.35**	0.083**	0.10**	0.34**
	(0.10)	(0.027)	(0.02)	(0.01)
Exch. Rate x Peg Share	-0.61**	-0.36**	-0.66**	-0.52**
	(0.24)	(0.13)	(0.08)	(0.04)
Peg Share	2.57*	1.51**	2.97**	2.43**
	(1.15)	(0.64)	(0.36)	(0.17)
Export Price	0.67**	1.01**	1.072**	0.24**
	(0.05)	(0.03)	(0.02)	(0.02)
Observations	439	474	1659	2694
R^2	0.98	0.97	0.92	0.80

Notes: * significant at 5%, ** significant at 1%; Standard errors are in parentheses.

Regressions are run over 5-digit Enduse industries, with monthly data from September 1993 – December 2006. Regressions with ITA=1 are run over those industries where 100% of the imports are covered by the ITA; regressions with 0.5 ≤ ITA <1 are run over those industries where 50 – 99% of the import value covered by the ITA; and regressions with 0< ITA < 0.5 are run over those industries where 1 – 49% of the import value is covered by the ITA. The final regressions with ITA=0 are run over a control group of industries (Enduse 2,3,4) that do not include any ITA commodities as imports. Regressions are estimated with OLS, including fixed effects for 5-digit Enduse industries and include 6 lags of the exchange rate.

cumulative drop due to the indicator variables exceeds 20%. The tariff variable itself has a "pass-through" coefficient of 22.6, which is much larger than normally found and indicates that the tariff declines have a *highly magnified* effect on lowering the import prices. Admittedly, the tariffs themselves are very low in these industries, so even with the very large pass-though coefficient, the impact of the tariff cuts on import prices is still modest.

Turning to the next regression in column (2), this is run over industries with 50 – 99% of the import value covered by ITA products. This regression indicates a tariff pass-through coefficient of 2.5, so again, there is a *magnified* impact of the ITA tariff cuts on the import prices. Our explanation for these results is that the ITA was a multilateral tariff reduction, with U.S. tariff cuts matched by those abroad, so with imports being processed in multiple countries their prices can easily fall by more than the drop in U.S. tariffs. The third regression includes industries where 1 – 49% of the import value is covered by the ITA, and it now has a tariff pass-through of unity.

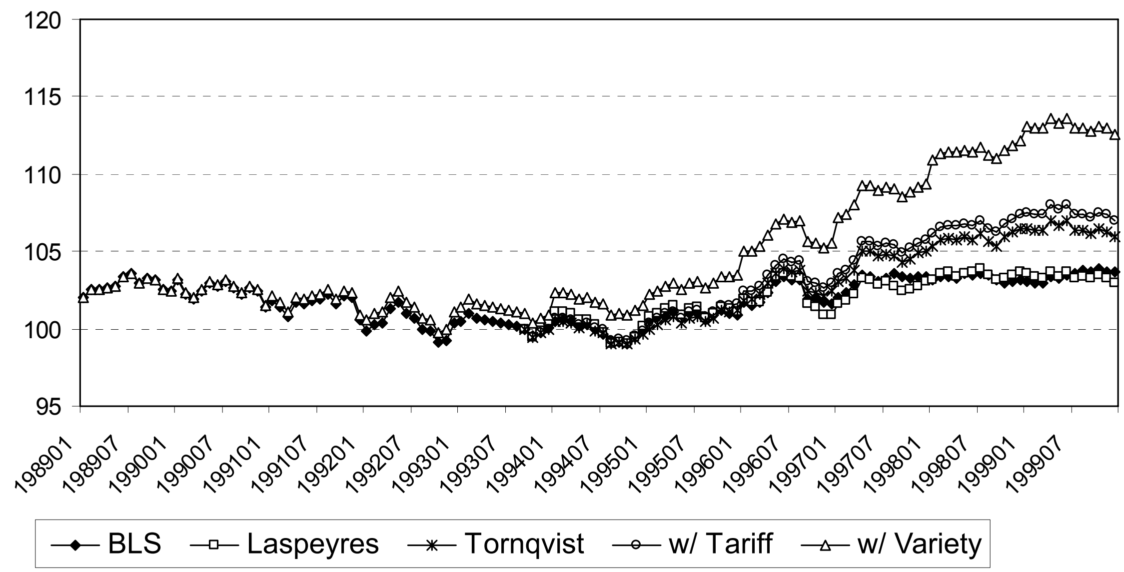
The final regression in Table 2.10 is for the control group of capital and consumer goods industries that do not include any commodities affected by the ITA tariff cuts. For these industries, we find a tariff coefficient of 0.86, but this is insignificantly different from unity. The fact that this control group provides the "small country" result for tariff pass-through gives us confidence that the magnified tariff effects found for industries impacted by the ITA show that those tariff cuts really do reflect the multilateral nature of this agreement.

The fact that import price deflators do not reflect tariffs changes can be though of as one source of mismeasurement in these indexes. There are several other sources of mismeasurement as well. Import price indexes typically use Laspeyres formulas, which have a conventional upward bias, leading to a downward bias in the terms of trade. In addition, import price indexes do not reflect the increased *range* of import varieties that are obtained when, for example, there are new supplying countries. As in the Armington assumption, we can presume that countries sell differentiated varieties of a product, so that having more trading countries leads to greater import varieties. That increase in the range of varieties would reduce a “true” import price index, but is not reflected in conventionally measured import prices indexes.

We can see the impact of these various sources of mismeasurement on the terms of trade in Figure 2.8, for the period up to 2000. I repeat the BLS and my computed Laspeyres terms of trade indexes from Figure 2.7, and also show several additional series: (i) an exact Törnqvist index for the terms of trade; (ii) the Törnqvist index that also incorporates tariffs into the import prices; (iii) the Törnqvist index that incorporates tariffs and also import variety. The cumulative impact of these three adjustments to the terms of trade means that the Törnqvist index, incorporating tariffs and variety, rises at 2.1 percent per year over 1995-1999. This is twice as fast as the BLS terms of trade index, which rises 1.0 percent per year over 1995-2007. Evidently, the terms-of-trade gain for the United States since 1995 has been much higher than suggested by official price indexes.

With the “true” terms of trade rising faster than official calculations, it follows that the “true” GDP price deflator will also rise faster than the official numbers. That is because rising export prices and falling import prices both increase the GDP price deflator. By recalculating the GDP price deflator using our adjusted export and import prices, we find that prices rose by two-tenths of a percent *more* per year after 1995. It follows that real GDP, and therefore productivity growth, rose by two-tenths of a percent *less* per year. The speedup in U.S. productivity growth after 1995 was about one percent per year. So we believe that *one-fifth* of that amount actually reflects improved terms of trade, which are incorrectly counted as productivity growth.

Figure 2.8: Alternative Terms of Trade Indexes



Consumers have certainly gained from those terms of trade improvements, but they reflect the gains from trade rather than conventional productivity growth.

Microeconomic Structure Once Again

Setting aside this empirical work on the terms of trade and productivity, I would like to conclude my lecture today by returning to the theory in this area. Of course, my discussion yesterday included the impact of offshoring on productivity, with the most recent work incorporating the complementarity between workers of differing skills, or supermodularity of the production function. In that case, the mix of workers within and across firms will have substantial effects on productivity. We can expect that offshoring would provide firms with this ability to adjust the skill-mix of workers, and thereby raise productivity.

A second way that openness to trade can affect productivity is through the endogenous selection of firms, as occurs in the Melitz (2003) model, or changes in the scale of firms, as in the work of Melitz and Ottaviano (2008). There is strong evidence supporting the selection of firms after trade liberalization. In the Canadian case, Daniel Trefler (2004) finds overwhelming evidence that the Canada-U.S. free trade agreement resulted in the self-selection of Canadian firms, with only the more productive firms surviving. Productivity in Canadian manufacturing overall rose six percent. There is less evidence for a positive impact of openness on the scale of surviving firms. But one study for the OECD finds that countries with larger markets exhibit lower markups and higher productivity (Badinger, 2007b), in line with the model of Melitz and Ottaviano, and also the translog model I discussed earlier.

There is also a third way that trade can impact productivity, which has received less attention, and that is through the endogenous choice of effort by workers themselves. This is the topic of an overlooked paper by Edward Leamer (1999), who embeds the choice of effort into a two-sector Heckscher-Ohlin model. He identifies worker effort as the fundamental source of productivity within firms. While the model he develops is certainly microeconomic in its structure, it might be considered as macroeconomic in its breadth, including: “implications for growth, openness, minimum wages, collective bargaining, public support of education, efficiency of state enterprises, the distribution of wealth, childbearing, and much more” (Leamer 1999, p. 1127). I would like to conclude my talk today by sketching a model that combines the endogenous choice of effort with the two other features I mentioned: monopolistic competition and supermodularity of the production function. I will suggest that a model of this type can have dramatic implications for the impact of trade on productivity.

Endogenous Choice of Effort and Product Variety

Consider an economy with two sectors, and for the moment just a single country. The first sector, denoted by y, consists of a homogeneous good which is mass-produced using an O-Ring type of production function (Kremer, 1993). For convenience, I will adopt a CES production function defined over the efforts of the various workers:

$$y = L_y \left(\frac{1}{L_y} \sum_{j=1}^{L_y} e_j^{\rho} \right)^{\alpha/\rho}, \quad \alpha > \rho > 0.$$

where L_y is the number of workers hired and they each work with effort e_j. This production function is supermodular in the effort levels of the workers, which are complementary:

$$\frac{\partial^2}{\partial e_j \partial e_k} \left(\frac{1}{L_y} \sum_{j=1}^{L_y} e_j^{\rho} \right)^{\alpha/\rho} > 0, \quad \text{for } \alpha > \rho > 0, \quad j \neq k.$$

Workers are identical, and in equilibrium will supply the same effort level e_y to this sector. Then the production function is simplified as:

$$y = L_y e_y^{\alpha},$$

with marginal product:

$$w = \frac{\partial y}{\partial L_y} = e_y^{\alpha},$$

which is the wage, where I use the mass-produced good as the numeraire.

The other sector, denoted by x, produces differentiated goods with handicraft production. Think of each good as produced by one worker, who must exert a fixed effort level of e_0 and then addition effort e_{xi} to obtain the output:

$$x_i = e_{xi} - e_0 \ , \quad i = 1,\ldots,N.$$

The number of workers engaged in handicraft production will equal the number of product varieties, N, so that the full employment condition is:

$$L = L_y + N.$$

Utility for the typical worker comes from consuming c_{xi} of each varieties i = 1,…,N of the differentiated good, along with c_y of the homogeneous good, with the utility function

$$U = \left(\sum_{i=1}^{N} c_{ix}^{(\sigma-1)/\sigma}\right)^{\beta\sigma/(\sigma-1)} c_y^{1-\beta} - \phi(e),$$

satisfying $\phi' > 0$, $\phi'' > 0$, $\sigma > 1$, and $0 < \beta < 1$. Suppose that a worker has the income of w, and that all the differentiated goods sell of the same price p_x. Then the indirect utility function defined over the price index P is:

$$V = \left(\frac{w}{P}\right) - \phi(e), \quad P \equiv B p_x^{\beta} N^{-\beta/(\sigma-1)},$$

where $B \equiv \beta^{-\beta}(1-\beta)^{\beta-1}$ is a constant.

Workers can choose to work in handicraft production or in mass-production, and in equilibrium must be indifferent between the two. In mass-production they earn the wage of w, while in handicraft production they earn the sales revenue from their own differentiated product, which is $p_{xi}x_i = p_{xi}(e_{xi} - e_0)$. Then the optimal choice of effort in handicraft production is obtained where the marginal revenue from effort equals the marginal cost:

$$\max_{e_{xi}} \left(\frac{p_{xi}(e_{xi} - e_0)}{P}\right) - \phi(e_{xi}) \quad \Rightarrow \quad \frac{p_x}{P}\left(\frac{\sigma - 1}{\sigma}\right) = \phi'(e_x),$$

where I drop the subscript i in the symmetric equilibrium. For the homogeneous good, the wage is $w = e_y^{\alpha}$, so the optimal choice of effort is also obtained where the marginal revenue from effort equals the marginal cost:

$$\max_{e_y} \left(\frac{e_y^{\alpha}}{P}\right) - \phi(e_y) \quad \Rightarrow \quad \left(\frac{\alpha w}{P e_y}\right) = \phi'(e_y).$$

We can use these two first-order conditions to solve for the real earnings of workers in each activity:

$$\frac{p_x(e_x - e_0)}{P} = \left(\frac{\sigma}{\sigma - 1}\right)\phi'(e_x)(e_x - e_0) \text{ and } \frac{w}{P} = \frac{e_y \phi'(e_y)}{\alpha}.$$

Then the first equilibrium condition is that workers should earn the same in each industry:

$$\left(\frac{\sigma}{\sigma - 1}\right)\phi'(e_x)(e_x - e_0) - \phi(e_x) = \frac{e_y \phi'(e_y)}{\alpha} - \phi(e_y).$$

A second equilibrium condition comes from the equality of demand and supply within the differentiated goods sector, using the expenditure share β:

$$\beta(wL_y + Np_x x) = Np_x x.$$

Using the expression for earnings in the two industries, this condition is simplified as,

$$e_y \phi'(e_y) = \left(\frac{N}{L}\right)\left[\frac{\alpha\sigma(\beta-1)}{(\sigma-1)\beta}\phi'(e_x)(e_x - e_0) + e_y \phi'(e_y)\right].$$

A final equilibrium condition comes by solving for real earnings within the mass-produced good:

$$\frac{w}{Bp_x^{\beta} N^{-\beta/(\sigma-1)}} = \frac{e_y \phi'(e_y)}{\alpha}.$$

Also making use of the price of the differentiated good, $p_{xi}[(\sigma-1)/\sigma] = P\phi'(e_x)$, and the wages $w = e_y^{\alpha}$, this condition becomes:

$$e_y^{1-\alpha}\phi'(e_y) = \alpha\left[\left(\frac{\sigma-1}{\sigma}\right)N^{1/(\sigma-1)} \Big/ B^{1/\beta}\phi'(e_x)\right]^{\frac{\beta}{(1-\beta)}}.$$

These are three equilibrium conditions to solve for the two effort levels and the number of differentiated products. In Figure 2.9, I show a possible equilibrium for the economy. The indifference curve U is tangent to the curve of real revenue from selling a differentiated product, $p_x y_x / P$, at point A, and to the curve of real wages, $w/P = e_y^{\alpha}/P$, at point B. In this case we will have that the effort in the mass-produced good exceeds that in the handicraft good, $e_0 < e_x < e_y$. I will refer to this outcome as a high-effort equilibrium.

These is another possible equilibrium, however, which I show in Figure 2.10. In this case there are many fewer varieties of the differentiated product, so the price index is higher and real earnings in either sector are much lower. The indifference curve is now tangent to the curve of real revenue from selling a differentiated product at point C, and is tangent to the curve of real wages at point D. In this case we will have that the effort in the mass-produced good is less than in the handicraft good, $e_y < e_0 < e_x$. I will refer to this outcome as a low-effort equilibrium.

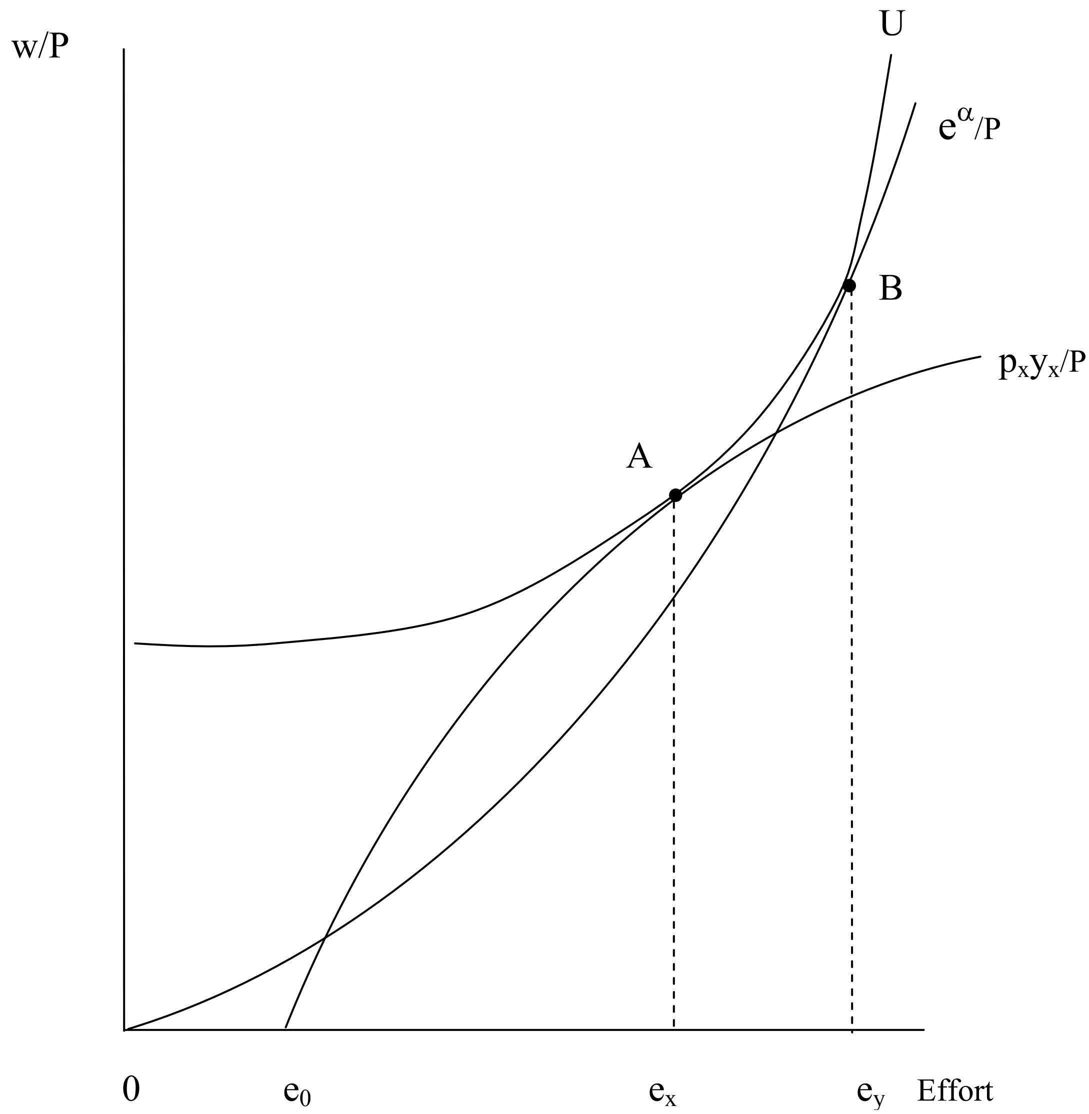


Figure 2.9: High-Effort Equilibrium

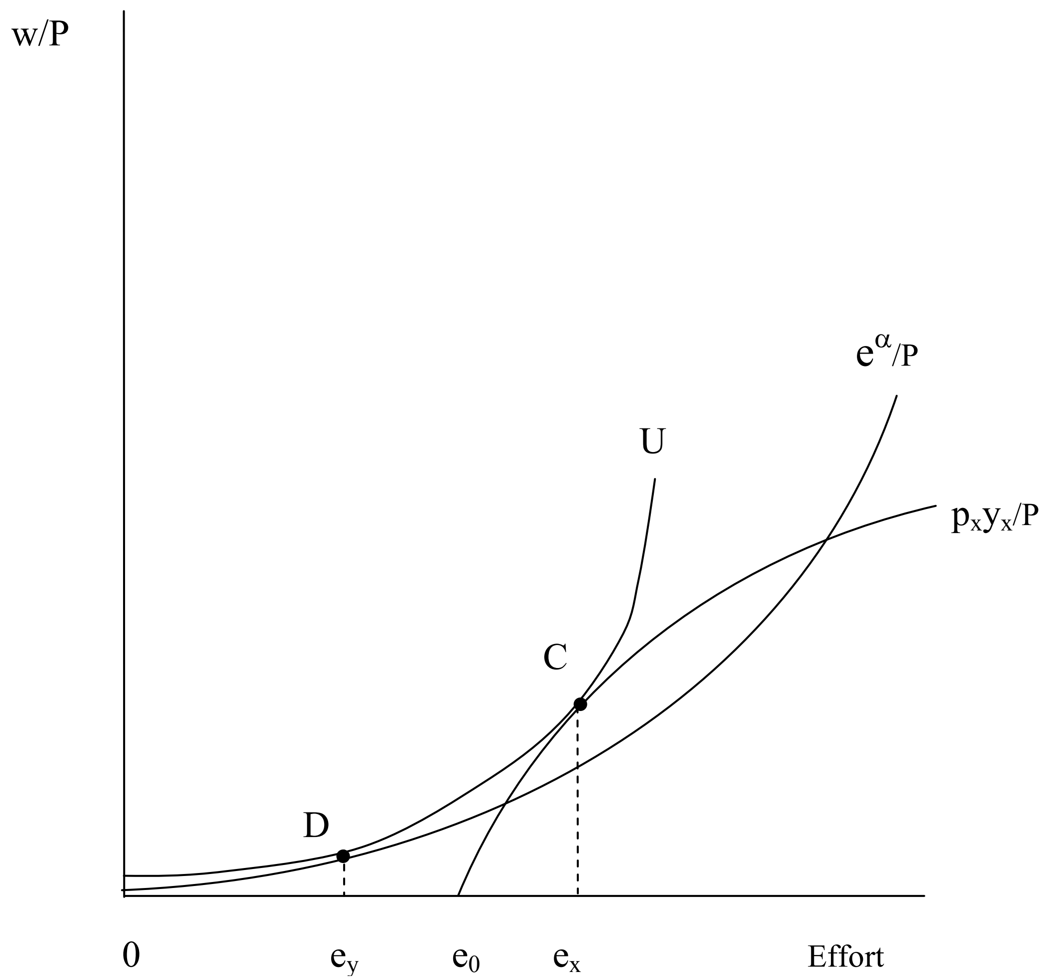


Figure 2.10: Low-Effort Equilibrium

To distinguish these two equilibria, we can solve for the borderline case where effort levels in the two activities are equal, $e_x = e_y = e$. In that case, the equality of utility in the two activities, together with effort levels implies that:

$$\left(\frac{\sigma}{\sigma-1}\right)(e-e_0) = \frac{e}{\alpha} \quad \Rightarrow \quad e = \bar{e} \equiv e_0\left(\frac{\alpha\sigma}{\sigma-1}\right)\bigg/\left(\frac{\alpha\sigma}{\sigma-1}-1\right).$$

This borderline case is well-defined only if α, which is the parameter of the production function, is sufficiently large:

$$\alpha > \left(\frac{\sigma-1}{\sigma}\right), \text{ so that } \bar{e} \text{ exists.}$$

This parameter condition is necessary to observe a low-effort equilibrium, but not sufficient. To determine whether both of these equilibria actually occur, I adopt a specific disutility of effort, which is:

$$\phi(e) = \left(\frac{1}{1+\gamma}\right)e^{1+\gamma}, \quad \gamma \geq 0.$$

An additional restriction on α is needed to ensure that the second-order conditions for the choice of effort levels are satisfied:

$$\alpha < 1+\gamma .$$

I have investigated the equilibria for a number of parameter values, which can be summarized by the overall parameter Δ:

$$\Delta \equiv \underbrace{[\alpha-(1+\gamma)]}_{(-)}\left[\frac{(\sigma-1)(1-\beta)}{\beta}\right] + \underbrace{(1+\gamma)}_{(+)}$$

If the differentiated goods sector is not too important in consumption, so that β is small or σ is big, then this Δ parameter is negative. In that case, we have the following result (as proved in the Appendix):

Proposition 2.1

If $\Delta < 0$, then there exists a unique equilibrium, with e_x and e_y positive and increasing in L.

The equilibrium in this case can be either a low-effort equilibrium or a high-effort equilibrium, though only one of these holds for given L. With a sufficiently small labor force the economy starts in a low-effort equilibrium, and then moves smoothly to a high-effort equilibrium as the labor force increases. By making the differentiated goods sector not too important, we have eliminated the possibility of multiple equilibria.

On the other hand, if β is large or σ is small, we obtain the following result:

Proposition 2.2

If $\Delta > 0$ then there can be three equilibria: (i) a zero-effort equilibrium with $e_x = e_y = 0$; (ii) a low-effort equilibrium with $e_y < e_0 < e_x$; (iii) a high-effort equilibrium with $e_0 < e_x < e_y$. As $L \to \infty$, effort e_y in the low-effort equilibrium approaches zero, while efforts e_x and e_y in the high-effort equilibrium approach infinity.

I have established this proposition by computing the equilibria for various special cases of the parameters. The low-effort equilibrium certainly gives lower utility to workers than does the high-effort equilibrium, and the zero-effort level gives the lowest utility of all. We might think of the zero-effort equilibrium as the outcome in a pre-industrial society, where individuals expend just enough effort to survive (which I have not really modeled), but do not contribute towards the market economy. The fact that this model gives rise to multiple equilibria is suggestive of the findings of Clark (1987), who observes differing levels of effort on the same industrial machines in different locations. One problem with this interpretation, however, is that we expect to find that the low-effort equilibrium is unstable, in the sense that slightly increasing the number of differentiated products would lead to higher returns and more entry into this activity. We have not proved that result formally, but the structure of the model is consistent with an odd number of equilibria, with the "middle" equilibrium being unstable, as we presume is the case. Then this proposition says that a given economy can have both a stable, pre-industrial equilibrium, and a stable, high-effort equilibrium. For a large country, however, the zero-effort equilibrium is stable only in a very small neighborhood, because the unstable, low-effort equilibrium is very close to it. So nearly any shock would be enough to move the economy up to the high-effort equilibrium. So for large countries, we should expect to see them in high-effort equilibrium, but small countries might be in the zero-effort case.

Let us now bring international trade into the picture. Free trade between countries with identical tastes and technology, in the absence of transport costs, has the same impact as an increase in country size. If there is an unique equilibrium, then opening trade will raise the effort levels in both countries, due to the greater variety of goods available. Utility in both countries will go up due to increased product variety, and due to the induced rise in effort and productivity. The endogenous rise in effort is a source of welfare gain over and above the familiar gains due to increased product varieties.

If there are multiple equilibria, then the story is a bit more complicated. Assuming that one country is in the high-productivity equilibrium, then it will not be possible for the other country to be in the zero-productivity equilibrium. Rather, the availability of imported goods, as well as the opportunity to market differentiated products abroad, will create an incentive to raise effort levels. So a country that is initially in a pre-industrial, zero-effort equilibrium will find that its welfare increases dramatically as it shifts to a high-effort equilibrium. We might think of this shock as an industrial revolution, facilitated by the availability of new differentiated goods.

Along these lines, Jan de Vries (1994, 2008) has argued persuasively that the Industrial Revolution was actually an "industrious revolution," made possible by a reorganization of production within the household, shifting from non-market to market activities. As workers engaged in factory work, they could use the earnings to purchase an expanding range of products available to middle-income consumers, such as art, books, clocks, fine furniture, and the like. The simple model I have presented is consistent with this story.

There are many directions that one can take this simple model. The first might be to introduce worker heterogeneity, perhaps by giving them differing disutility of effort. Then, we could also allow for the offshoring of production, getting back to the issue of segregation of workers across firms that I discussed yesterday, as raised by Kremer and Maskin (1996, 2006). I would expect that offshoring would enable firms to narrow the skill-distribution of their workers, by shifting some production overseas. In that case, I would further expect that the slope of the wage-effort schedule would steepen, as the marginal product of high-effort individuals is increased when their co-workers have similar levels of effort. Indeed, Edward Leamer (Leamer and Thornberg, 2000) has shown that the wage-effort schedule in the United States steepened during the 1970s, which he attributes to globalization, meaning a declining price of labor-intensive tradables. I would suggest that such an outcome could also be the result of offshoring.

Conclusions

To briefly summarize my lectures, yesterday I raised the question of whether offshoring requires a new paradigm for trade. To that question I gave an affirmative answer, in the sense that models of offshoring incorporate features beyond those familiar from the Heckscher-Ohlin framework. Those features included the costs involved with shifting production overseas, and complementarities between workers that can arise in a model with multiple skills. Current research is making headway on those issues.

Today, I have strayed far beyond the questions normally asked of a trade model, let alone the Heckscher-Ohlin model. At times I have even strayed beyond offshoring to consider the impact of globalization in general. That is certainly true for the model I just presented, which argues that international trade and the increased variety of goods could have played a role in the industrial revolution.[25] The model might tell us something about the first golden age of trade, but is still too rudimentary to shed much light on the second golden age. Setting aside those theoretical results, let me return to the macroeconomic issues which were the focus of this lecture, and ask what the specific contribution of offshoring is to each issue.

For business cycle volatility, there is no question that offshoring is important. The ability to shift production rapidly across borders, as firms frequently do, cannot help but to amplify volatility along with it. My evidence was only for Mexico and the U.S., but this issue is equally important in a European context. Just as I ended the lecture yesterday by arguing that the variance of the skill distribution was important to offshoring, so too, offshoring will impact the variance of earnings and employment over time.

For price determination, I have argued that China is too big a player to ignore. That is certainly the view in Japan, and is receiving attention in the U.S. as well. The model I presented relied on variable markups (which can also influence business cycle fluctuations; see Bilbiie, Ghironi and Melitz, 2007), but did not explicitly model the role of China as a destination for offshoring. That was a simplification in the theory: the fact that China has been a major source for offshoring is one of the reasons why its exports have grown so fast. And as we have seen, the

[25] Other work emphasizing the role of trade in the industrial revolution includes O'Rourke, Rahman and Taylor (2007); see also Greenwood and Uysal (2004) who emphasize the role of new goods in a later period.

growing share of China in U.S. imports has contributed to the fall in the pass-though of the exchange rates, and therefore kept down prices. Additional evidence on the role China has played in moderating U.S. inflation is provided by the recent work of Christian Broda and John Romalis (2008). They show that the rising share of imports from China has contributed to lower prices in the basket of goods purchased by low-income consumers, in particular, as well as increased variety in that basket. So to Richard Freeman's (1995) provocative title to his *Journal of Economic Perspectives* article, "Are Your Wages Set in Beijing," I would respond only half in jest, "Are Your Prices Set in Beijing?"

The final issue I have explored today is the link between the terms of trade and productivity. That link does not necessarily depend on offshoring, and reflects globalization more generally. But recall the specific evidence that I showed for the Information Technology Agreement. These multilateral tariff cuts had *magnified* effects on prices in the United States, leading to a fall in import prices that was many times higher than the tariff cut itself. That is exactly the outcome that we expect in an offshoring model, as shown by Kei-Mu Yi (2003). He argues that in the presence of fragmented production – or vertical specialization – even modest tariff cuts can result in large increases in world trade, as has occurred in recent decades. So I conclude that offshoring and the globalization we have seen in this second golden age are two sides of the same coin, which is a new paradigm for trade indeed.

Appendix to Lecture 1:

Proof of Proposition 1.1:

We follow Grossman and Rossi-Hansberg (2008a) in assuming that there are two sectors and two factors, and that the technology in the foreign country is uniformly worse than at home. Let A*>1 be the Hicks-neutral technological inferiority that applies to both industries in the foreign country. Then as explained by Grossman and Rossi-Hansberg (2008a), the free trade equilibrium with offshoring satisfies several properties:

(i) there is “adjusted factor price equalization”, that is: $w\Omega = w^* A^*$ and $q = q^* A^*$;

(ii) if follows that the relative factor prices $w\Omega / q$ and w^* / q^* are identical in the two countries, so that $a_{Li} = a_{Li}^*$ and $a_{Hi} = a_{Hi}^*$, $i = 1,2$, where $A^* a_{Li}^*$ and $A^* a_{Hi}^*$ are the foreign labor requirements per unit of output;

(ii) combining $w\Omega = w^* A^*$ with the equilibrium condition $w = \beta t(I) w^*$, we obtain the equilibrium condition $A^* = \beta t(I)\Omega(I) = \beta\left[(1-I)t(I) + \int_0^I t(i)di\right]$, so that a fall in β implies a rise in I and a fall in $\Omega(I)$;

(iii) the world output of the two goods are:

$$y_1 + y_1^* = \frac{a_{L2}\left(H + \frac{H^*}{A^*}\right) - a_{H2}\left(\frac{L}{\Omega} + \frac{L^*}{A^*}\right)}{\Delta_a}$$

$$y_2 + y_2^* = \frac{a_{H1}\left(\frac{L}{\Omega} + \frac{L^*}{A^*}\right) - a_{L1}\left(H + \frac{H^*}{A^*}\right)}{\Delta_a}$$

where $\Delta_a \equiv a_{H1}a_{L2} - a_{H2}a_{L1} > 0$, with good 1 intensive in high-skilled labor. These expressions are identical to that obtained in a closed economy with endowments $\left(H + \frac{H^*}{A^*}\right)$ and $\left(\frac{L}{\Omega} + \frac{L^*}{A^*}\right)$.

Making use of all these properties, we see that the equilibrium with free trade is identical to a single economy with "effective" wages $\omega = w\Omega = w^*A^*$ and $q = q^*A^*$. Suppose that the two countries have identical Cobb-Douglas utility functions with consumption shares α_1 and α_2 for the two goods. Then the world payments to skilled and unskilled labor are:

$$\frac{q(H + \frac{H^*}{A^*})}{G} = \alpha_1\theta_{H1} + \alpha_2\theta_{H2} \ ,$$

and,
$$\frac{\omega(\frac{L}{\Omega} + \frac{L^*}{A^*})}{G} = \alpha_1\theta_{L1} + \alpha_2\theta_{L2} \, ,$$

where G denotes world GDP, $\theta_{Li} \equiv w\Omega a_{Li} / p_i = w^* A^* a^*_{Li} / p_i$ is the share of unit-costs going to low-skilled labor, and $\theta_{Hi} \equiv q a_{Hi} / p_i = q^* A^* a^*_{Hi} / p_i$ is the share going to high-skilled labor, for $i = 1,2$. Dividing these two expressions we obtain:

$$\frac{q(H + \frac{H^*}{A^*})}{\omega(\frac{L}{\Omega} + \frac{L^*}{A^*})} = \left(\frac{\alpha_1\theta_{H1} + \alpha_2\theta_{H2}}{\alpha_1\theta_{L1} + \alpha_2\theta_{L2}} \right) .$$

Taking natural logs and differentiating, we have:

$$(\hat{q} - \hat{\omega}) = -\hat{\Omega}\frac{L/\Omega}{(\frac{L}{\Omega} + \frac{L^*}{A^*})} + \left(\frac{\alpha_1\theta_{H1}}{\alpha_1\theta_{H1} + \alpha_2\theta_{H2}} \right)\hat{\theta}_{H1} + \left(\frac{\alpha_2\theta_{H2}}{\alpha_1\theta_{H1} + \alpha_2\theta_{H2}} \right)\hat{\theta}_{H2}$$
$$- \left(\frac{\alpha_1\theta_{L1}}{\alpha_1\theta_{L1} + \alpha_2\theta_{L2}} \right)\hat{\theta}_{L1} - \left(\frac{\alpha_2\theta_{L2}}{\alpha_1\theta_{L1} + \alpha_2\theta_{L2}} \right)\hat{\theta}_{L2}$$

The cost shares all depend on the relative wage q/ω, with derivatives $\hat{\theta}_{Hi} = \theta_{Li}(1 - \sigma_i)(\hat{q} - \hat{\omega})$ and $\hat{\theta}_{Li} = -\theta_{Hi}(1 - \sigma_i)(\hat{q} - \hat{\omega})$, where σ_i is the elasticity of substitution, $i = 1,2$. Substituting these above, and grouping terms involving $(\hat{q} - \hat{\omega})$, we obtain:

$$(\hat{q} - \hat{\omega})\left\{ 1 - \left[\frac{(1-\sigma_1)\alpha_1\theta_{H1}\theta_{L1} + (1-\sigma_2)\alpha_2\theta_{H2}\theta_{L2}}{(\alpha_1\theta_{H1} + \alpha_2\theta_{H2})(\alpha_1\theta_{L1} + \alpha_2\theta_{L2})} \right] \right\} = -\hat{\Omega}\frac{L/\Omega}{(\frac{L}{\Omega} + \frac{L^*}{A^*})} \ .$$

Defining the expression in brackets on the left as B, it satisfies:

$$0 \le B \equiv \left[\frac{(1-\sigma_1)\alpha_1\theta_{H1}\theta_{L1} + (1-\sigma_2)\alpha_2\theta_{H2}\theta_{L2}}{(\alpha_1\theta_{H1} + \alpha_2\theta_{H2})(\alpha_1\theta_{L1} + \alpha_2\theta_{L2})} \right] < 1 \text{ for } 0 \le \sigma_i \le 1,\ i = 1,2,$$

where the upper bound of unity is obtained because the denominator can be simplified as:

$$(\alpha_1\theta_{H1} + \alpha_2\theta_{H2})(\alpha_1\theta_{L1} + \alpha_2\theta_{L2}) = \alpha_1\theta_{H1}\theta_{L1} + \alpha_2\theta_{H2}\theta_{L2} + \alpha_1\alpha_2(\theta_{H1} - \theta_{H2})^2 .$$

Since $\hat{\Omega} < 0$ from property (ii) above, then $(\hat{q} - \hat{\omega}) > 0$. However, we are interested in not just the change in the ratio of efficiency wages, but change in the actual home wage, q/w. To obtain that we use $\hat{\omega} = \hat{w} + \hat{\Omega}$ and rewrite the above expressions as:

$$(\hat{q} - \hat{w})(1-B) = -\hat{\Omega}\frac{L/\Omega}{(\frac{L}{\Omega} + \frac{L^*}{A^*})} + \hat{\Omega}(1-B) = \hat{\Omega}\left[1 - B - \frac{L/\Omega}{(\frac{L}{\Omega} + \frac{L^*}{A^*})} \right] .$$

With $\hat{\Omega} < 0$, it follows that $(\hat{q} - \hat{w}) > 0$ provided that $(1-B) < (L/\Omega)/(\frac{L}{\Omega} + \frac{L^*}{A^*})$. Using the results above, this condition is simplified as:

$$\frac{\sigma_1\alpha_1\theta_{H1}\theta_{L1} + \sigma_2\alpha_2\theta_{H2}\theta_{L2}}{(\alpha_1\theta_{H1} + \alpha_2\theta_{H2})(\alpha_1\theta_{L1} + \alpha_2\theta_{L2})} < \frac{L/\Omega}{(\frac{L}{\Omega} + \frac{L^*}{A^*})} - \frac{L^*/A^*}{(\frac{L}{\Omega} + \frac{L^*}{A^*})}\left[\frac{\alpha_1\alpha_2(\theta_{H1} - \theta_{H2})^2}{\alpha_1\theta_{H1}\theta_{L1} + \alpha_2\theta_{H2}\theta_{L2}} \right]$$

The condition stated in Proposition 1.1 is sufficient to ensure that the above inequality holds.

QED

Proof of Proposition 1.2:

The first term in the aggregation bias for factor j is:

$$\sum_{g=1}^{G} N_g \operatorname{cov}_g\left(T_i, a_{ij}\right) \equiv \sum_{g=1}^{G} \sum_{i \in I_g} \left(T_i - \sum_{i \in I_g} \frac{T_i}{N_g}\right)\left(a_{ij} - \sum_{i \in I_g} \frac{a_{ij}}{N_g}\right)$$

$$= \sum_{g=1}^{G} \sum_{i \in I_g} T_i a_{ij} - \sum_{g=1}^{G} N_g \left(\sum_{i \in I_g} \frac{T_i}{N_g}\right)\left(\sum_{i \in I_g} \frac{a_{ij}}{N_g}\right)$$

$$= \sum_{i=1}^{N} T_i a_{ij} - \sum_{g=1}^{G} \overline{T}_g \left(\sum_{i \in I_g} \frac{a_{ij}}{N_g}\right),$$

where $\overline{T}_g \equiv \sum_{i \in I_g} T_i$. The second term in the aggregation bias for factor j is:

$$\sum_{g=1}^{G} \overline{T}_g \sum_{i \in I_g} \left(\frac{1}{N_g} - \lambda_{ig}\right) a_{ij} = \sum_{g=1}^{G} \overline{T}_g \left(\sum_{i \in I_g} \frac{a_{ij}}{N_g}\right) - \sum_{g=1}^{G} \overline{T}_g \left(\sum_{i \in I_g} \lambda_{ig} a_{ij}\right)$$

$$= \sum_{g=1}^{G} \overline{T}_g \left(\sum_{i \in I_g} \frac{a_{ij}}{N_g}\right) - \sum_{g=1}^{G} \overline{T}_g \overline{a}_{gj},$$

where $\overline{a}_{gj} \equiv \left(\sum_{i \in I_g} \lambda_{ig} a_{ij}\right)$ denotes a typical element of $\overline{A}$. Summing these two terms, we obtain $\sum_{i=1}^{N} T_i a_{ij} - \sum_{g=1}^{G} \overline{T}_g \overline{a}_{gj}$, which equals the elements of $AT - \overline{A}\overline{T}$ for factor j. QED

Appendix to Lecture 2

Proof of Proposition 2.1:

We make use of the disutility of effort:

$$\phi(e) = \left(\frac{1}{1+\gamma}\right) e^{1+\gamma}, \quad \gamma \geq 0.$$

Substituting this into the equilibrium conditions, the first condition that workers earn the same in each industry becomes:

$$\alpha\left(\frac{\sigma}{\sigma-1}\right) e_x^{\gamma}(e_x - e_0) - \left(\frac{\alpha}{1+\gamma}\right) e_x^{1+\gamma} = \left[1 - \left(\frac{\alpha}{1+\gamma}\right)\right] e_y^{1+\gamma}. \tag{A1}$$

The second equilibrium condition arising from the equality of demand and supply within the differentiated goods sector becomes:

$$e_y^{1+\gamma} = \left(\frac{N}{L}\right)\left[\frac{\alpha\sigma(\beta-1)}{(\sigma-1)\beta} e_x^{\gamma}(e_x - e_0) + e_y^{1+\gamma}\right]. \tag{A2}$$

The final equilibrium condition obtained by solving for real earnings within the mass-produced good becomes:

$$e_y^{1-\alpha+\gamma}\, e_x^{\gamma\beta/(1-\beta)} = \alpha B^{\frac{-1}{(1-\beta)}} \left(\frac{\sigma-1}{\sigma}\right)^{\frac{\beta}{(1-\beta)}} N^{\frac{\beta}{(1-\beta)(\sigma-1)}}. \tag{A3}$$

which can be rewritten as:

$$NA\left(\frac{\sigma-1}{\sigma}\right)^{\sigma-1} = e_y^{(1-\alpha+\gamma)(\sigma-1)(1-\beta)/\beta}\, e_x^{\gamma(\sigma-1)}, \tag{A4}$$

where $A \equiv \alpha^{\frac{(\sigma-1)(1-\beta)}{\beta}} B^{\frac{-(\sigma-1)}{\beta}}$.

Substituting (A4) into (A2), we obtain:

$$e_y^{\Delta} = \left(\frac{1}{AL}\right)\left(\frac{\sigma}{\sigma-1}\right)^{\sigma-1} e_x^{\gamma(\sigma-1)}\left[\frac{\alpha\sigma(\beta-1)}{(\sigma-1)\beta} e_x^{\gamma}(e_x - e_0) + e_y^{1+\gamma}\right], \tag{A5}$$

where: $$\Delta \equiv [\alpha - (1+\gamma)]\left[\frac{(\sigma-1)(1-\beta)}{\beta}\right] + (1+\gamma).$$

From (A1) we can write $e_y = f(e_x)$, with $f' > 0$ for $f(e_x) \geq 0$, with the properties $e_y = 0$ as $e_x = \tilde{e} \equiv e_0 \frac{(1+\gamma)\sigma}{(\sigma-1)} / \left[\frac{(1+\gamma)\sigma}{(\sigma-1)} - 1\right]$ and $e_y \to \infty$ as $e_x \to \infty$. Substituting this function into (A5), we obtain:

$$AL = \left(\frac{\sigma}{\sigma-1}\right)^{\sigma-1} e_x^{\gamma(\sigma-1)}\left[\frac{\alpha\sigma(\beta-1)}{(\sigma-1)\beta} e_x^{\gamma}(e_x - e_0) + f(e_x)^{1+\gamma}\right] f(e_x)^{-\Delta}. \qquad \text{(A6)}$$

For $\Delta < 0$ the right-hand side of this equation is strictly increasing in e_x, and ranges between zero and infinity as e_x ranges between $\tilde{e}$ and infinity. It follows that for any positive value of L, there exists a unique, positive solution for e_x and therefore e_y.

By inspection, it appears that another solution to the three equilibrium conditions is N = $e_x = e_y = 0$. But we can show that solution is not valid for $\Delta < 0$. Specifically, we will argue that for $\Delta < 0$, then N = $e_x = e_y = 0$ cannot be a valid solution to the optimal choice of effort in handicraft production, which is obtained when the marginal revenue from effort equals the marginal cost:

$$\max_{e_{xi}} \left(\frac{p_{xi}(e_{xi} - e_0)}{P}\right) - \left(\frac{1}{1+\gamma}\right) e_{xi}^{1+\gamma} \;\Rightarrow\; \frac{p_x}{P}\left(\frac{\sigma-1}{\sigma}\right) = e_x^{1+\gamma}. \qquad \text{(A7)}$$

To make this argument, we solve for the real revenue (R_x/P) obtained from selling the amount $(e_x - e_0)$ of the differentiated product. Notice that the first-order condition in (A7) is:

$$\frac{R_x}{P(e_x - e_0)}\left(\frac{\sigma-1}{\sigma}\right) = e_x^{1+\gamma}. \qquad \text{(A7')}$$

Using various equations from the model, real revenue is obtained as:

$$\left(\frac{R_x}{P}\right)^{\sigma} = B^{\frac{-(\gamma+1)}{(1-\beta)(1-\alpha+\gamma)}} \alpha^{\left[\frac{(\gamma+1)}{(1-\alpha+\gamma)}-1\right]} \left(\frac{\sigma}{\sigma-1}\right)^{\left[\frac{\beta(\gamma+1)}{(1-\beta)(1-\alpha+\gamma)}+\sigma-1\right]}$$
$$\times MN^{\left[\frac{\beta(\gamma+1)}{(1-\beta)(1-\alpha+\gamma)(\sigma-1)}-1\right]} e_x^{\left[\gamma(1-\beta)(\sigma-1)-\frac{\gamma\beta(\gamma+1)}{(1-\beta)(1-\alpha+\gamma)}\right]}. \tag{A8}$$

Notice that the exponent on N has the same sign as Δ, using our assumption that $\alpha < 1+\gamma$. Then for $\Delta < 0$, as $N \to 0$ we see that $(R_x/P) \to \infty$. It follows that as $N \to 0$ and $e_x \to e_0$, then the left-hand side of (A7') approaches infinity, whereas the right-hand side is finite. It follows that we cannot obtain a corner solution where $e_x = e_0$, since an individual obtains higher utility by choosing $e_x > e_0$. By the same argument, choosing $e_x = 0$ is not a valid corner solution to the first-order condition, so the zero-effort equilibrium does not occur. QED

Proof of Proposition 2.2:

We provide an example in Table A1 with $\Delta > 0$. Initially for small L the economy has only one equilibrium, with $N = e_x = e_y = 0$. When $L = 30$, there are two equilibria, and when $L=200$ there are three equilibria: (i) the zero-effort case $N = e_x = e_y = 0$; a low-effort equilibrium with $e_y < e_0 < e_x$; (iii) a high-effort equilibrium with $e_0 < e_x < e_y$. As L grows, effort e_y in the low-effort equilibrium falls and effort levels in the high-effort equilibrium rise, as shown by the $L=1000$ case.

The finding that effort e_y in the low-effort equilibrium falls in L, while effort levels in the high-effort equilibrium rise in L, are general features of the equilibria when $\Delta > 0$. To show this, we use (A6) and (A3) to obtain;

$$AL = \left(\frac{\sigma}{\sigma-1}\right)^{\sigma-1} e_x^{\gamma(\sigma-1)} \left\{ \left[\frac{1}{\beta} - \left(\frac{1-\beta}{\beta}\right)\left(\frac{\alpha}{1+\gamma}\right)\right] f(e_x)^{1+\gamma-\Delta} + \left(\frac{1-\beta}{\beta}\right)\left(\frac{\alpha}{1+\gamma}\right) e_x^{1+\gamma} f(e_x)^{-\Delta} \right\}. \tag{A9}$$

As L→∞, the left-hand side approaches infinity. This implies that $e_y = f(e_x)$ on the right-hand side cannot approach a finite, positive value (since in that case the right-hand side would also approach a finite, positive value). Rather, it must be that $e_y = f(e_x)$ either approaches zero or infinity: both cases are consistent with L→∞ on the left, since $1+\gamma-\Delta > 0$. The case $e_y = f(e_x)$ approaches zero is the low-effort equilibrium, and the case $e_y = f(e_x)$ approaches infinity is the high-effort equilibrium. QED

Table A1: Parameter Choices and Equilibria

Parameter	value
Alpha α	1.0
Beta β	0.5
Gamma γ	1.0
Sigma σ	2.0
Initial effort in x industry e_0	1.0
Calculated delta value Δ	1.0
Equilibria	
L=10	
equilibrium: $e_x = 0$, $e_y = 0$, N = 0.	
L=30	
equilibrium 1: $e_x = 0$, $e_y = 0$, N = 0.	
equilibrium 2: $e_x = 1.47$, $e_y = 0.77$, N = 9.05.	
L=200	
equilibrium 1: $e_x = 0$, $e_y = 0$, N = 0.	
equilibrium 2: $e_x = 1.33$, $e_y = 0.05$, N = 0.51.	
equilibrium 3: $e_x = 3.25$, $e_y = 4.32$, N = 112.19.	
L=1000	
equilibrium 1: $e_x = 0$, $e_y = 0$, N = 0.	
equilibrium 2: $e_x = 1.33$, $e_y = 0.01$, N = 0.10.	
equilibrium 3: $e_x = 6.86$, $e_y = 10.67$, N = 585.87.	

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