NBER WORKING PAPER SERIES

TRADE, WAGES AND REVOLVING DOOR IDEAS

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Working Paper No. 4716

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
April 1994

Support from NSF grant SES-9209845 is gratefully acknowledged. Thanks also to Karen Stephenson for some revolving door ideas, to Robert Murdock for able research assistance and comments, and to Frederico Sturzenneger for comments on an earlier draft. This paper is part of NBER's research programs in International Trade and Investment and Labor Studies. Any opinions expressed are those of the author and not those of the National Bureau of Economic Research.

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ABSTRACT

Recent discussions of the effects of globalization and technological change on U.S. wages have suffered from inappropriate or missing references to the basic international trade theorems: The Factor Price Equalization Theorem, the Stolper-Samuelson Theorem and the Samuelson Duality Theorem. Until the theory is better understood, and until the theory and the estimates are sensibly linked, the jury should remain out.

This paper gives examples of the misuse of the international micro theory linking technological change and globalization to the internal labor market. This international micro theory serves as a foundation for a reexamination of the NBER Trade and Immigration Data Base that describes output, employment and investment in 450 4-digit SIC U.S. manufacturing sectors beginning in 1970. Estimates of the impact of technological change on income inequality are shown to vary widely depending on the form of the model and the choice of data subsets, but uniformly the estimates suggest that technological change reduced income inequality not increased it. But the data separation of workers into "production" and "non-production" workers has little association with skill levels, and these data probably cannot be used to study income inequality.

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Trade, Wages and Revolving Door Ideas*

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The NAFTA debate filled the media with unsubstantiated economic and political theories. One of my favorites was "revolving door trade." According to some NAFTA opponents, "good" trade is when the United States sends exports to the Mexican consumer markets and we never see the stuff again. "Bad" trade, however, is revolving door trade. This occurs when we export parts to Mexico and those parts come back in the form of assembled products. I guess that a farmer who sells wheat to a miller, and later finds some of it back on the dinner table as bread, is made worse by the exchange, and would be better off to grind the wheat and bake the bread right at home. What century do we live in?

Revolving door trade in ideas is another matter altogether. In our business, the best one can hope for are ideas which are sent off to the intellectual marketplace that come back polished and improved, but still recognizable. It is distressing to send off ideas and have them come back abused and mutilated, for no good reason. The very worst are the ideas that are exported and never heard of again.

Early in the NAFTA debate Leamer(1993) offered the two-part argument that NAFTA amounts to an economic commitment to free trade and that free trade has and will continue to lower the wages of low-skilled workers in the United States. This was condensed by Jeff Faux and Thea Lee of the Economic Policy Institute into: NAFTA will lower the wages of low-skilled workers. This condensation earned Faux the wrath of Robert Wright(1993) of The New Republic[3], but it was the condensed form that generated the public attention. This was a revolving door idea that came back bent, but still working hard.[4]

Stolper and Samuelson(1941) and Samuelson(1949) sent off two important ideas concerning the impact of globalization on internal labor markets. These ideas have come back abused or not at all. Lawrence and Slaughter(1993) wrongfully attacked the (duality) theorem on which my estimates were made. Lawrence and Slaughter (1993) and later Krugman and Lawrence (1993) misuse both the Factor Price Equalization Theorem and the Stolper-Samuelson Theorem in their argument that trade has not played an important role in the income inequality trends. Worst of all, Krugman and Lawrence(1993) argue that "recent work indicates that growing international trade has played a minor role even in the declining real wages of less-educated US workers," but cite only Lawrence and Slaughter(1993), who distort the Stolper-Samuelson theorem,

3 (Wright, p.23): "The most striking assertion in Faux's paper is that 'NAFTA will reduce the real incomes of a majority of U.S. workers.' This belief is shared by almost no economists and, if true, is cause for real skepticism about NAFTA. What is its basis? Aside from some fairly informal argumentation by Faux, the only apparent basis is a paper by UCLA economist Edward Leamer. .. One place it doesn't show up is in a paper written by UCLA economist Edward Leamer."

4 For this I thank Faux and Lee, but the attention can be a mixed blessing.

and Katz(1993), who ignores altogether the Factor Price Equalization Theorem.

Lawrence and Slaughter's(1993) stimulating paper brings to our attention the interesting and important fact that the ratio of production to non-production workers has decreased substantially over the last couple of decades in almost all sectors even as the relative wages of the least skilled workers has declined. Unfortunately, the categories of "production" and "other" workers are diverse and are not clearly linked with skills, but for the sake of argument let us accept the Lawrence and Slaughter contention that the ratio of skilled to unskilled workers has risen as the relative wages of the unskilled has declined. As L&S correctly point out, globalization cannot be the explanation for this "fact" since lower wages for the unskilled workers brought about by globalization would be accompanied by an increase (or no change) in the ratio of unskilled to skilled workers, not the opposite. From this Lawrence and Slaughter *improperly* leap to the conclusion that globalization has had hardly any effect on income inequality - "a small hiccup, not a great sucking sound" - to use their title. Globalization may not explain a decrease in the ratio of unskilled to skilled workers, but from that alone it is inappropriate to conclude that globalization cannot explain anything else.

I continue to believe that the income inequality trends in the United States are driven largely by the interaction of three forces: increased supply of unskilled workers (education and immigration), technological change that is replacing humans with robots (computers), and globalization (lower prices for labor intensive products, less market power in autos and steel, and increased international mobility of physical capital and technology.) Measuring the relative contribution of these forces is no easy task, and no one yet knows the exact contribution of each to the income inequality trends. In Leamer(1993) I attempted to measure the impact of price declines of labor intensive products on wages, and came up with a number that is about 20% of the total amount of income redistributed.[5] That calculation is subject to the usual caveats: it is based on one special and untested theory which presumes the answer qualitatively if not quantitatively; it is based on data of questionable quality and relevance; even within it's own narrow intellectual confines, the number has a large standard error. However, the calculation is not subject to the criticism of Lawrence and Slaughter(1993) who argue that I used the international micro theory incorrectly. More on this in Section 4.

The Heckscher-Ohlin model that is the foundation of my calculation takes the technology as fixed, and is therefore materially at odds with Lawrence and Slaughter's observation concerning the large decrease in the ratio of production to nonproduction workers. However, explicit treatment of technological change is not required to ask and answer correctly the conditional question: "What happens to wages as product prices change, holding fixed the technology?" But questions concerning the impact of technological change and, most importantly, the interaction between globalization and technological change require a model with both. It is not difficult explicitly to allow for technological change in a Heckscher-Ohlin-Samuelson model, which I will do below. Section 2 contains the simple algebra of the well-known two-

[5] This percentage is found by translating my 1985$ estimate of the income transferred away from low-skilled workers into a current dollars value equal to $60b, and comparing that number to Heckman's $300b total transfer.

sector model. That model is used in the international trade literature to derive the proposition that the impact of technological improvement on the wages of the unskilled depends on the sector in which the technological change occurs. If the technological change is neutral, reducing "equally" the unskilled inputs in both unskilled-intensive and skill-intensive sectors, then both unskilled and skilled wages increase proportionately and the relative wage remains exactly the same. The data presented by Lawrence and Slaughter(1993) and repeated in Krugman and Lawrence(1993) look pretty neutral, and seem initially compatible with the notion that technological change has had no impact on income inequality. This makes globalization seem more important as a source of income inequality, completely contrary to the conclusions of Lawrence and Slaughter(1993) and Krugman and Lawrence(1993). I will pursue this idea more formally in Section 3 which reports a variety of estimates of the effects of technological change on wages. As it turns out, the technological change appears to work in favor of the production workers not against them. But in the data base used by Lawrence and Slaughter the classification of workers into "production" and "non-production" doesn't have much to do with "unskilled" and "skilled." More appropriate data may provide very different answers.

My purpose here, however, is not to provide an estimate of the impact of technological change on income inequality, but rather to suggest a method that could be used to compute estimates of the effects of technological change and globalization. Lawrence and Slaughter's scatter diagrams comparing estimates of TFP growth with input ratios do not adequately support their conclusions regarding either the effect of technology on income inequality or about the relative size of the technological and globalization effects. Nor should their non-findings be used as a basis for Krugman and Lawrence's(1993) otherwise unsupported conclusions.

Incidentally, a very interesting feature of the simple model of Section 2 is that globalization and technological change interact multiplicatively to increase income inequality, which suggests that studies, including my own, which attempt to measure one effect, holding fixed the others, may be missing an important part of the story.

1.0 THEORY AND MEASUREMENT

The recent debate concerning the effects of globalization on U.S. wages has generally neglected theory altogether or has used a very distorted form of international micro economic theory. The contributions of Lawrence and Slaughter(1993) and Krugman and Lawrence(1993) are an example of the latter, and are selected here for dissection because of their prominence, but not because they are otherwise special in their misuse of the theory.

Here is Krugman and Lawrence's(1993, p 14) version of the factor price equalization theorem:

> "According to the theory of factor-price equalization, then, a rising relative wage for skilled workers leads all industries to employ a <u>lower</u> ratio of skilled to unskilled workers; this is necessary in order to allow the economy to shift its industry mix toward skill-intensive sectors. Or to put it differently, the skilled workers needed to expand the skill-intensive sector are made available because industries economize on their use when their relative wage rises; and conversely the shift in the industry mix ratifies the change in relative wages.
>
> This analysis carries two clear empirical implications: if growing international trade is the main force driving increased wage inequality, then we should see the ratio of skilled to unskilled employment declining in all industries, and a substantial shift in the mix of employment toward skill-intensive industries."

This quotation represents a misunderstanding of basic international trade theory. First of all neither the Factor Price Equalization theorem nor the Stolper-Samuelson theorem depend at all on substitution of inputs within sectors and apply even if the input ratios are technologically fixed. Secondly, the Factor Price Equalization theorem is the wrong choice for studying the impact of increased foreign competition on the U.S. economy. The FPE theorem is concerned with the changes in wage rates caused by changes in factor supplies, for example increases in the labor force. No change is the surprising answer. The theorem has nothing to do with *increased external* competition. Quite the contrary, it is based explicitly on the small-country assumption that external product prices can be taken as fixed even as the internal supply of product is varying. The FPE theorem would be appropriate for studying the impact of migration. Many economists believe that immigration lowers wages by making labor relatively plentiful. If the FPE theorem were correct, an influx of Mexican unskilled workers into the United States would be met by a shift in the U.S. output mix toward the products that employ unskilled Mexicans intensively, just enough of a shift to increase the demand for unskilled workers in the U.S. to keep wages at their original level. This bears little resemblance to Krugman and Lawrence's version: "Or to put it differently, the skilled workers needed to expand the skill-intensive sector are made available because industries economize on their use when their relative wage rises; and conversely the shift in the industry mix ratifies the change in relative wages."

As I argued in Leamer(1993), the right theorem for studying the impact of (one form of) globalization on wages is the Stolper-Samuelson

Theorem, which indicates how wages change as international prices change. According to this theorem, a decline in the relative price of products made intensively by low-skilled workers lowers the real wage of these workers. This lowering of wages can occur without any change in output levels or any change in factor input ratios, completely contrary to Krugman and Lawrence's(1993) assertion: "This analysis carries two clear empirical implications: if growing international trade is the main force driving increased wage inequality, then we should see the ratio of skilled to unskilled employment declining in all industries, and a substantial shift in the mix of employment toward skill-intensive industries."

It is true that a lower relative wage of unskilled workers, absent other forces, would be met in each sector by a substitution of low-skilled workers for capital and high-skilled workers, if substitution were technologically feasible. The fact that from 1979 to 1989 there has been a big decrease in the ratio of production to nonproduction workers in most sectors accordingly cries out for an explanation. Lawrence and Slaughter (1993) seem on the right track when they point to technology, but they offer no theory of the link between technology and wages. Even absent a theory, Krugman and Lawrence(1993) are able to offer an estimate of the impact of technology on wages, referring elliptically to scatter diagrams comparing the increase in nonproduction employment to wage changes and to initial employment shares:

> "The evidence in Figures 9 and 10 suggests that the decline in blue-collar wages must be attributed, not to international trade, that changes the country's industrial mix, but to other factors that have reduced the relative demand for less-skilled workers throughout the economy. Technological change, especially the growing use of computers is a likely candidate; but in any case international trade cannot have played the dominant role."

They must have different glasses from mine, since I can't see anything like that in those figures. A standard result in elementary trade theory is that the impact of technological change on wages depends on the sector in which the innovation occurs. An innovation in the skill-intensive sector causes reductions in wages of unskilled, but technological change in the unskilled-intensive sector causes an increase in wages of the unskilled. Their scatter diagram looks pretty neutral to me.

In any case, I am a strong believer in having a well-defined theory as a basis for a data analysis and I will review below the standard, simple, general equilibrium theory that allows for both the increase in skill-intensity from technological change and also the decline in wages of the unskilled from globalization. Before I get to that, I have one more comment on measurement without theory. According to Lawrence and Krugman(1993, p. 15)

> "It is possible to reach the same conclusion by another route. Recent work by Lawrence Katz and others has calculated the skilled and unskilled "embodied" in US trade -- that is the labor inputs that were used to produce exports, and that would have been used to produce our imports if they had been made domestically. If the increase in U.S. exports had embodied considerably more skilled and less unskilled labor than the increase in imports, this would have reduced the relative demand for less-educated workers. (This embodiment approach is not quite equivalent to the Stolper-Samuelson approach described above, but may be viewed as a close approximation.) In fact, however, the net embodied labor flows are very small."

I don't know what Krugman and Lawrence mean by "not quite equivalent" to the Stolper-Samuelson approach. I would have said "fundamentally in conflict with," as I tried to explain in Leamer(1993). *The very essence of the factor price equalization theorem is that vast changes in the factors embodied in trade leave completely unchanged the compensation that these factors command.* Factors embodied in trade can change because of internal factor supply changes or because of changes in the demand for foreign products (including a trade deficit). Provided these changes do not alter the prices of the goods that are produced by the economy in question, there will be no change in factor prices. I am *not* saying it is impossible to present a theory that underlies the calculations done by various labor economists including Katz. I am saying that, although *I don't know* what it is, *I do know* it isn't the standard Heckscher-Ohlin-Samuelson general equilibrium theory. Lawrence and Slaughter get it right: "Although the approach of Borjas, et.al. enjoys a long tradition, it is weakly grounded in standard trade theory. Standard trade theory says nothing about effective factor supplies. Indeed it suggests that trade deficits per se have no necessary relationship to factor returns."

2.0 TECHNOLOGICAL CHANGE AND GLOBALIZATION IN THE TWO-SECTOR MODEL

It is not difficult to produce a model that allows us to discuss the effects of both technology and globalization on the wages of the unskilled. The simple model in this section is useful for exposition, but a more complicated model would surely be required as a foundation for a serious effort to measure the size of the effects. But the simple algebra now to be presented is illuminating because it helps make clear that the qualitative impact of technological change depends on the sector that experiences the greatest percentage reduction in unskilled workers and the quantitative impact of technological change depends on the degree of similarity of the two sectors. With two goods (Textiles and Machinery) and two factors of production (skilled and unskilled) the zero profit conditions in matrix form are

$$\begin{bmatrix} A_{sT} & A_{uT} \\ A_{sM} & A_{uM} \end{bmatrix} \begin{bmatrix} w_s \\ w_u \end{bmatrix} = \begin{bmatrix} p_T \\ p_M \end{bmatrix}$$

where A_{ij} is the input of factor i used to produce a unit of product j. These factor intensities are taken as fixed with no material effect on the content of this discussion except that it prevents us from erroneously concluding that substitutability of inputs is somehow an important aspect of the problem, one of the errors of Krugman and Lawrence(1993). Inverting this system we obtain the Stolper-Samuelson system mapping product prices into wages

$$\begin{bmatrix} w_s \\ w_u \end{bmatrix} = (A_{sT}A_{uM} - A_{sM}A_{uT})^{-1} \begin{bmatrix} A_{uM} & -A_{uT} \\ -A_{sM} & A_{sT} \end{bmatrix} \begin{bmatrix} p_T \\ p_M \end{bmatrix}$$

From this system we can extract the equation that determines the wages of the unskilled:

$$w_u = (A_{sM}p_T - A_{sT}p_M)/ A_{sT}A_{sM} (A_{uT}/A_{sT} - A_{uM}/A_{sM}) \tag{1}$$

and the relative wages of the skilled and unskilled:

$$w_s/w_u = (A_{uT}p_M - A_{uM}p_T \quad) / (A_{sM}p_T - A_{sT}p_M) \tag{2}$$

Please note that according to these equations, wages and income inequality depend on <u>both</u> the technology (A_{uT}, A_{uM}, A_{sM}, A_{sT}) and on the product prices(p_T,p_M). If one were to discover that technological change had an important impact on wages, this wouldn't mean that globalization effects are absent. Properly, we need to measure the quantitative size of each effect before making sweeping statements about their relative magnitudes.

In Leamer(1993) I provided a measure of the derivative of wages with respect to changes in the prices of labor-intensive products. With the factor shares defined as

$$\theta_{uM} = w_u A_{uM}/p_M \ ,$$
$$\theta_{uT} = w_u A_{uT}/p_T \ ,$$
$$\theta_{sM} = w_s A_{sM}/p_M = (1-\theta_{uM})$$
$$\theta_{sT} = w_s A_{sT}/p_T = (1-\theta_{uT}),$$

the percentage change in wages of the unskilled in response to a percentage change in the price of the unskilled-intensive textiles price is[6]

$$(\partial w_u/w_u) \ / \ (\partial p_T/p_T) = \theta_{sM}/ \ (\theta_{sM}-\theta_{sT}), \tag{3}$$

Leamer(1993) uses an estimate of this derivative together with a (casual) estimate of the effect of globalization on prices of labor-intensive products (dp_T/p_T) to obtain an estimate of the effect of globalization on wages. An analogous equation applies to wages of the skilled:

$$(\partial w_s/w_s) \ / \ (\partial p_T/p_T) = \theta_{uM}/ \ (\theta_{uM}-\theta_{uT}),$$

The difference in these expressions is the impact on income inequality

$$(d(w_s/w_u)/(w_s/w_u))/(\partial p_T/p_T) = (\theta_{sT}\theta_{uM} - \theta_{sM}\theta_{uT})/(\theta_{uT}-\theta_{uM})(\theta_{sM}-\theta_{sT}) \tag{4}$$

The system of equations that determine wages can also be used to study the effects of technological change. One kind of technological change that is consistent with the reduction in the ratio of unskilled to skilled workers in both sectors is a reduction in the unskilled inputs in both machinery and textiles, $dA_{uM}<0$ and $dA_{uT}<0$. This will be referred to below as technological change*, the "*" serving to remind the reader that one special form of technological change is being considered. It is straightforward to compute the effects of these or other technological changes. Differentiating the formulae above we can obtain[7]

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[6] $\partial\log(w_u)/\partial p_T = A_{sM}/ \ (A_{sM}p_T - A_{sT}p_M)$
$\partial\log(w_s)/\partial p_T = A_{uM}/ \ (A_{uT}p_M - A_{uM}p_T)$

[7] $d\log(w_u) = (A_{sT}dA_{uM} - A_{sM}dA_{uT}) \ / \ (A_{sM}A_{uT} - A_{sT}A_{uM})$

$$dw_u/w_u = [(dA_{uM}/A_{sM})-(dA_{uT}/A_{sT})] \; / \; [(A_{uT}/A_{sT})-(A_{uM}/A_{sM})] \tag{5}$$

Thus with machinery as the skill-intensive sector, $(A_{uT}/A_{sT})>(A_{uM}/A_{sM})$, we have wage reductions for the unskilled

$$dw_u < 0 \text{ iff } dA_{uM}/A_{sM} < dA_{uT}/A_{sT}.$$

In words, *the wages of the unskilled fall if the technological change* is concentrated in the skill-intensive machinery sector,* specifically if the reduction in the ratio of unskilled to skilled is greater in the machinery sector than in the textiles sector. *The amount of the wage reduction is greater the more similar are the technologies in the two sectors* as measured by $1/[(A_{uT}/A_{sT})-(A_{uM}/A_{sM})]$.

We can also use these equations to discuss the effect of technological change* on income inequality. The derivative of the wage ratio with respect to the technological change* can be written as[8]

$$d(w_s/w_u))/(w_s/w_u) = -[(dA_{uM}/A_{uM})-(dA_{uT}/A_{uT})(\theta_{uT}/\theta_{uM})] \; / \; [(\theta_{uT}/\theta_{uM})-1] \tag{6}$$

where the ratio of factor shares is $(\theta_{uT}/\theta_{uM}) = A_{uT}p_M/A_{uM}p_T$. Thus with textiles the sector that uses the unskilled intensively, $(\theta_{uT}/\theta_{uM}) > 1$, we have increases in income inequality

$$d(w_s/w_u) > 0 \quad \text{iff} \quad (-dA_{uM}/A_{uM})/(-dA_{uT}/A_{uT}) > \theta_{uT}/\theta_{uM}$$

In words, *income inequality increases if the technological change* is concentrated in the skill-intensive machinery sector,* specifically if the proportional reduction in unskilled inputs in machinery compared with textiles $(-dA_{uM}/A_{uM})/(-dA_{uT}/A_{uT})$ exceeds the ratio of the unskilled share in textiles to the unskilled share in machinery $\theta_{uT}/\theta_{uM} >1$. *The change in income inequality is greater the more similar are the technologies in the two sectors* as measured by $1/[\theta_{uT}-\theta_{uM})$.

[8] $d\log(w_s/w_u) = (p_M dA_{uT} - p_T dA_{uM}) \; / \; (A_{uT}p_M - A_{uM}p_T)$

These derivatives look separately at the effects of technological change* and globalization, but this simple model also has something very interesting to say about interactions. Interactions are evidenced by prices entering the technological change* derivatives (5) and (6), and factor intensities entering the globalization derivatives (3) and (4). Note that product prices enter the income inequality derivative (6), but not the wage level derivative (5). Equivalently, contrast directly the wage level equation (1) with the income inequality equation (2). The income inequality equation (2) has the interaction term $A_{uM}p_T$ in the numerator but the wage level equation (1) has the globalization effect p_T and the unskilled input levels A_{uT} and A_{uM} entering separately (after logarithmic transformation). In that sense, *globalization and technological change* (in the skill-intensive sector) interact multiplicatively to cause increases in income inequality, but globalization and technological change* have separate effects on the real wage levels of the unskilled.*

One last point: These derivatives for studying technological change 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.

3.0 SOME VERY PRELIMINARY EMPIRICAL RESULTS

I will now stick my own neck out by doing a data analysis to which I will attach the adjectives "simple" and "preliminary" for personal protection. (Decoding: I am not too sure about this.)

A preliminary data analysis can neglect the effect of technological change on product prices, but it cannot avoid confronting the obvious fact that there are many more industries than two, and more factors as well. The simple theory will now be extended to allow more inputs and more commodities, as a precursor to a reexamination of the NBER (Katz and Freeman) data studied by Lawrence and Slaughter(1993).

A typical zero profit condition can be written in vector form as $p_{it} = \mathbf{A}_{it}'\mathbf{w}_t$ where p_{it} is the price of product i in period t, $\mathbf{w}_t$ is the vector of factor costs and $\mathbf{A}_{it}$ is the vector of input intensities. Differentiating this zero profit condition and rewriting it produces the following result indicating on the left side the change in profits if there were no changes in factor rewards and on the right side the changes in factor prices needed to eliminate this profit

$$dp_{it} - (d\mathbf{A}_{it})'\mathbf{w}_0 = \mathbf{A}_{i0}'(d\mathbf{w}_t).$$

Using this equation as motivation, we can find the change in factor rewards that are induced by changes in technology ($d\mathbf{A}$), holding fixed the product prices, $dp = 0$

$$(d\mathbf{A}_{it})'\mathbf{w}_0 = -\mathbf{A}_{i0}'(d\mathbf{w}_t) \tag{7}$$

Regressions motivated by condition (7) are reported in Table 3. These have dependent variables that are the earnings reductions associated with the technological improvements, $(d\mathbf{A}_{it})'\mathbf{w}_0$, and explanatory variables that are the initial input levels, $\mathbf{A}_{i0}$. You may find this to be peculiar kind of regression since the left-hand side variable measures an aspect of technological progress and is conceptually "exogenous." The conceptually endogenous variables are the changes in the factor costs ($d\mathbf{w}_t$) which are on the right hand side, but these are treated as uncertain parameters, not variables. Don't worry about this. Equation (7) would hold exactly for some values of the parameters (dw_t) if the technological change were compatible with constant product prices. Then the regression would estimate just what we want: the changes in factor costs induced by the technological change absent price changes from any source. Difficulties do arise however if there are no parameters at which (7) holds exactly, in which case the technological change has to induce some product price changes. Difficulties also arise if the data are measured with error, or if the theory is not perfectly accurate, or a combination. With a sheepish look on my face, I will now proceed as if (7) held exactly for the true technological change and that the failure empirically is due entirely to mismeasurement of the left-hand side variable $(dA_{it})'w_0$.

Table 1 has the full list of variables and Table 2 has some univariate statistics. These univariate statistics are worth taking a closer look at before proceeding since they by themselves offer very mixed support for the notion that technological change or any other change is adversely affecting production workers compared with nonproduction workers. During the period from 1976 to 1986 there was a 18% increase in the average capital input per unit of value added, which was accompanied by reductions in the averages of both labor inputs, an 9.% per cent reduction of nonproduction workers and a 21% reduction in production workers.[9] This gives the distinct impression of a lower relative demand for production workers. *On the other hand the wages of production workers grew 96% compared with 89% for nonproduction workers.*

[9] The average number of production workers (p) per $1000(1976) value added was .0329 in 1976 but fell to .0262 in 1986, a 20% reduction. The number of nonproduction workers (o) fell from .009376 to .008594, an 8.3% reduction. At the same time the capital per unit of value added increased from .73 to .84, a 15% increase.

This seems startling since it is completely at odds with the increasing income inequality that has instigated this cluster of papers. The end year matters a lot, as can be seen in Lawrence and Slaughter's(1993) Figure 5 (reproduced here as Figure 2) which has declining relative wages of the non-production workers from 1966 until 1982, and substantial increases through 1989, with most of the increase in 1986 to 1989. This peculiar behavior of relative wages should raise eyebrows and make one question the data base. Another symptom is the strong negative correlation between the intensity of the industry in production workers (Au76) and the wages of production workers (wu76). According to the theory there should be no relationship, and this correlation is suggestive of either a measurement or an aggregation problem. An aggregation problem would occur if the production workers category included both skilled and unskilled workers with substantially different economic experiences. The negative correlation between Au76 and wu76 is compatible with the hypothesis that the skill level is negatively correlated with Au76. Also supportive of this idea is the substantial negative correlation between Au76 and the change in wages (wu86-wu76). Another "anomaly" in Table 2 is the correlation between the wages of production workers and wages of nonproduction workers: Sectors with high pay for one group of workers tend to have high pay for the other group. This is true even more strongly for the changes than the levels.

In light of these peculiar results, it seems appropriate to take a closer look at exactly which workers are classified as "production" workers and which are "non-production" workers. Here are the definitions taken from the Annual Survey of Manufactures:

Production Workers: This item includes workers (up through the line-supervisor level) engaged in fabricating, processing, assembling, inspecting, receiving, storing, handling, packing, warehousing, shipping (but not delivering), maintenance repair, janitorial and guard services, product development, auxiliary production for plant's own use (e.g., power plant), recordkeeping, and other services closely associated with these production operations at the establishment covered by the report. Employees above the working-supervisor level are excluded from this item.

All other employees: This item covers nonproduction employees of the manufacturing establishment including those engaged in factory supervision above the line-supervisor level. It includes sales (including driver sales-persons), sales delivery (highway truck drivers and their helpers), advertising, credit, collection, installation and servicing of own products, clerical and routine office function, executive, purchasing, financing, legal, personnel (including cafeteria, medical, etc.), professional, and technical employees. Also included are employees on the payroll of the manufacturing establishment engaged in the construction of major additions or alterations to the plant and utilized as a separate work force.

In these descriptions I have underlined what seem like misclassifications if these categories are meant to separate skilled from unskilled, or even white-collar from blue-collar. The low-skilled category includes supervisors and product development personnel. The high-skilled category includes sales, delivery, clerical, cafeteria and construction.

These categories are pretty clearly inappropriate for what follows, but I will follow the lead of Lawrence and Slaughter(1993) and plow ahead anyway.

The first regression reported in Table 3 parallels the simple theory discussed in the previous section by making the assumptions that the technological change affects only the blue collar inputs and that physical capital is not an input. Under those assumptions, equation (7) can be written with only unskilled inputs changing, and with only labor inputs as $(dA_{ui})w_{u0} = -A_{u0}(dw_{ut}) - A_{s0}(dw_{st})$, which can be rewritten as

$$w_{u0}(dA_{ui}/A_{s0}) = -\beta\ (A_{u0}/A_{s0}) - \alpha\ .$$

where $\beta = dw_{ut}$ and $\alpha = (dw_{st})$. On the left hand side of this equation is the "normalized payroll savings", namely the payroll savings on unskilled workers divided by the skilled input intensity. On the right is the ratio of unskilled to skilled workers (A_{u0}/A_{s0}) times a coefficient equal to the increase in the wages of the unskilled workers plus a constant equal to the increase in unskilled wages.

The theory that we are operating with does not allow sectoral differences in wages and for that reason the dependent variables in these regressions are computed using the average wage level in 1976. The first estimated regression has a negative slope of -2.83, suggesting that this technological change raised the earnings of production workers by \$2.83. The constant, however, is positive, suggesting that the technological change lowered the earnings of non-production workers by \$1.5. These are translated into percentages in the bottom of Table 3.

The regressions in Table 3 do not have any adjustment for heteroscedasticity and allow the larger sectors to greatly determine the results. The regressions in Table 4 are all adjusted for industry size measured by the size of the "skilled" labor force or value added. Figure 1 is the scatter plot associated with the first regression in Table 4. On the horizontal axis is the 1976 ratio of production to nonproduction workers, Au76/As76. On the vertical axis is the payroll savings 11.62 (Au86-Au76) divided by the initial production workers input As76. This scatter does not seem unduly affected by any outliers and from it you can perceive that the intercept is not estimated precisely. (Check the standard error in Table 4.)

The next columns in Tables 3 and 4 extend the model to include capital as an input and to allow technological changes in all three input requirements. When we extend the model to allow capital as an input a problem arises since we have no initial rate of return that is needed to calculate the capital contribution to the payrolls savings on the left side. To deal with this we can move the change in capital to the right-hand side, hoping that this variable is very accurately measured. As it turns out, it gets the wrong sign (positive) in several cases. The last column of both tables has a regression with the rate of return to capital forced to be equal to 10%.

Now take a look at the last two rows of both these tables. These contain estimates of the effect of technological change on wages of both "blue-collar" (production workers) and "white-collar" (non-production workers). These numbers vary a lot but one thing doesn't vary. In every case, technology has led to a larger increase in wages for the production (unskilled?) than for the nonproduction (skilled?), completely the opposite of the conclusions of Lawrence and Slaughter(1993) and Krugman and Lawrence(1993).

But, frankly, I really question the usefulness of data categorized in this way for addressing the question of the determinants of income inequality.

4.0 DUALITY BETWEEN THE STOLPER-SAMUELSON AND RYBCZYNSKI EFFECTS

Finally, I need to deal with the duality between the Stolper-Samuelson effects and the Rybczynski effects in models with more goods than factors, an essential feature of the estimates provided by Leamer(1993). There I argued that changes in the global market are properly linked to the internal labor market through product price changes, as suggested by the micro-economic international theory, particularly the Stolper-Samuelson theorem. This observation meets with the approval of Lawrence and Slaughter(1993), but they find my approach nonetheless faulty. According to Lawrence and Slaughter (1993, footnote 24):

> "The one exception is Leamer(1991), who does acknowledge the role of terms of trade. His analysis is flawed in another way, however. He attempts to exploit the reciprocity between the Rybczynski and Stolper-Samuelson theorems by first estimating Rybczynski partial derivatives in production functions and then calling these estimates of Stolper-Samuelson partial derivatives. This approach is flawed because reciprocity cannot be applied empirically. Reciprocity requires firms to have a revenue function with well-defined first and second derivatives. Such derivatives exist in higher dimensions if and only if the number of factors of production equals or exceeds the number of goods produced. As discussed earlier, in reality the number of goods probably far exceeds the number of factors. Leamer himself estimates Rybczynski partial derivatives with 3 factors and 37 goods."

I take the word-combinations "revenue function", "well-defined", and "if and only if" to be a Cambridge challenge to compare the length and girth of our derivatives, which is such a delicious opportunity to expose myself that I cannot resist.

There are plenty of flaws in my approach, but Lawrence and Slaughter haven't hit on one, which I will demonstrate below by exposing one of my own derivatives. In a model with more goods than factors, price variability is limited in dimension to the number of factors, and the economy (after aggregation) behaves as if it had equal numbers of factors and commodities. Moreover, the reference to 3 factors and 37 goods is off the point. I do not pretend to know how many of each there are. The commodity categories conform to one level of aggregation. Finer disaggregation of course is possible. Doubtless, there are more than three relevant factors. Neither of these empirical limitations deserves special comment since the approach is impervious to aggregation over commodities, provided that major relative price changes are not disguised, and the approach suffers only the usual shortcomings of linear regression if the list of factors excludes some that are correlated with the ones included, or if by aggregation over factors an errors-in-variables problem is created.

A Simple 3-Good 2-Factor Model

The simplest way to make the point is to begin with the model with two goods (T and M) and two factors (capital and labor). Obviously, everything is working fine here, including the duality between the Stolper-Samuelson and the Rybczynski derivatives. Next split the good M arbitrarily into two goods M_1 and M_2, each produced with the same technology as M. We now have a model with three goods and two factors, about which Lawrence and Slaughter assert, "Reciprocity requires firms to have a revenue function with well-defined first and second derivatives. Such derivatives exist in higher dimensions if and only if the number of factors of production equals or exceeds the number of goods produced." I am not sure what Lawrence and Slaughter mean by firms, since this kind of model with constant returns to scale has industries but no firms (in a meaningful sense). What they might have said is that the economy cannot solve uniquely for the separate output levels of M_1 and M_2; therefore the derivatives of outputs with respect to inputs are not well defined...

Wait a minute; not so fast; nothing has really changed by splitting M into two separate but identical goods. Although the components cannot be uniquely determined, their sum can be. To get back to the 2 × 2 model we just need to aggregate M_1 and M_2, which is completely legitimate since the prices of M_1 and M_2 must be identical. The Stolper-Samuelson counterfactual accordingly must keep the prices of these two identical goods identical. The change in the wage rate caused by an equal increase in the price of these identical goods is indeed equal to the derivative of the sum of their outputs with respect to the labor supply, as in the 2×2 model. Thus the duality between the Stolper-Samuelson effects and the Rybczynski effects applies provided that the hypothetical makes reference to legitimate variation in product prices.

The remaining loose thread in this argument is empirical. What happens if we run regressions of these three output levels q on factor supplies v when two of the components are not theoretically determinable? The answer is that the magic of regression will get right that which is determinable, namely the sum of the coefficients for the two identical products. (Proof left to reader.) There is no telling what the separate coefficients will be, but there is no reason why we would be interested in them, if the legitimate Stolper-Samuelson counterfactual is used.

A General n-Good k-Factor Model

This discussion extends straightforwardly. The following notation will be used.

$\mathbf{q}$ = the n×1 vector of outputs.

$\mathbf{v}$ = the k×1 vector of inputs.

$\mathbf{A}$ = the k×n matrix of input requirements.[10]

$\mathbf{w}$ = k × 1 vector of factor prices.

$\mathbf{p}$ = n × 1 vector of commodity prices.

The usual factor market equilibrium conditions which equate factor demand to factor supply are

[10] I have taken the input intensities to be fixed, but nothing of substance depends on whether they vary with factor prices.

$A\ q = v$: k equations in n unknowns(q)

The zero profit conditions which set price to production costs are

$p = A'\ w$: n equations in k unknowns (w)

If the number of factors and goods were equal, and if the matrix A were invertible, then we may solve these two systems of equations for quantities, $q = A^{-1}v$, and factor prices, $w = A'^{-1}p$, given factor supplies v and product prices p. The duality between the Rybczynski effects and the Stolper-Samuelson effects follows straightforwardly,

$$\partial q/\partial v = A^{-1} = (\partial w/\partial p)'.$$

This duality result obviously does not apply if A is not invertible, in particular if there are more goods than factors. This apparently is what led to the conclusion of Lawrence and Slaughter(1993) quoted above. But that is giving up too easily. If there are more commodities than factors, $n > k$, the system $A\ q = v$ is underdetermined and the system $p = A'w$ is overdetermined. Although one cannot solve the underdetermined system uniquely for q, there are k independent linear combinations of outputs that are uniquely determined. Write the underdetermined system as

$$A_1\ q_1 + A_2 q_2 = v,$$

where q_1 is an arbitrarily chosen subset including k commodities. Since A_1 is square (and by assumption full rank) we may write this equation in terms of a k-dimensional aggregate q* that is uniquely determined [11]

$$q^* = q_1 + A_1^{-1} A_2 q_2 = A_1^{-1}v.$$

[11] Incidentally it is sometimes but not always possible for this aggregate to be formed from positive combinations of the basic commodities, that is with $A_1^{-1} A_2$ strictly positive. This will occur if the selected subset 2 technologies are interior to the subset 1 technologies. But aggregates q* that include negative weights on components create only an ascetic problem and do not affect at all the method used in Leamer(1993), a point made clear below.

In particular, the following matrix of derivatives is well defined

$$(dq^*) = A_1^{-1}(dv).$$

The implication of the set of overdetermined profit conditions is that prices are constrained to vary in a k dimensional subspace. The overdetermined system

$$p_1 = A_1' w, \; p_2 = A_2' w$$

can be rewritten to make the overdetermination clear as

$$p_1 = A_1' w, \; p_2 = A_2'(A_1')^{-1}p_1.$$

Now we may carry out the steps needed to implement the duality between the Stolper-Samuelson and Rybczynski effects. Suppose that we begin with hypothetical price changes dp_1 and $dp_2 = A_2'(A_1')^{-1}(dp_1)$. Corresponding to this change in prices is a change in factor earnings equal to

$$dw = (A_1')^{-1}(dp_1). \tag{8}$$

At issue is whether we get the right answer if we ignore the dimensionality issues and plow ahead using the duality result. The (doubtful?) duality result is

$$dw = (\partial q^{\sim}/ \partial v)'(dp) = (\partial q^{\sim}_1/\partial v)'(dp_1) + (\partial q^{\sim}_2/\partial v)'(dp_2)$$

where $q^{\sim}$ refers to the estimated system formed when the outputs are regressed on factor supplies. With the assumed change in product prices this can be written as

$$\begin{aligned} dw &= (\partial q^{\sim}_1/\partial v)' \; (dp_1) + (\partial q^{\sim}_2/\partial v)' \; A_2'(A_1')^{-1}(dp_1) \\ &= [\; (\partial q^{\sim}_1/\partial v)' + (\partial q^{\sim}_2/\partial v)' \; A_2'(A_1')^{-1}] \quad (dp_1) \\ &= (\partial q^{*\sim}/\partial v)' \; (dp_1) = (A_1')^{-1} \; (dp_1), \end{aligned}$$

which is the same as (8), provided only that we get the right estimate of the derivative of q^* with respect to v, $((\partial q^{*\sim}/\partial v) = (A_1')^{-1})$, which is a consequence of the magic of regression in a system with identical explanatory variables (again left to the reader). Thus we get the right answer even though $\partial q/\partial v$ is not well defined!

4.0 CONCLUSION

We are a long way from obtaining good empirical estimates of the relative effects of technological change, globalization and education on the U.S. labor markets, but we are most likely to make progress if the estimates are linked clearly with some understandable theory. The Stolper-Samuelson theorem offers one clear framework that identifies commodity prices variability as the only signal through which global shocks are communicated to local economies. Empirical estimates are often computed in ways that are in direct conflict with this theorem.

The casual conclusion of Lawrence and Slaughter that income inequality is being driven primarily by technological change and not much by globalization does not stand up to a more rigorous examination of the same data base, but the categorization of workers into "production" and "nonproduction" workers in the L&S data base is doubtfully connected with skill levels.

Finally, the duality between the Stolper-Samuelson effects and the Rybcyzynski effects applies in models with more goods than factors, if the result is properly stated.

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Table 1
Sources and Definitions of Data

Source:	National Bureau Trade and Immigration Data Base, July 1989 Compiled by Lawrence Katz and Richard Freeman

Coverage: 450 U.S. manufacturing industries, 1972 SIC codes

Data from NBER data base

emp	(ASM) employment/1000
prodemp	(ASM) employment of production workers/1000
valueadd	(ASM) value added by manufacture, million$
deflator	(ASM) shipments deflator
capital	(ASM) real capital stock (Plant and Equipment), $millions 1972$
payroll	(ASM) annual payroll, $millions
prodpayr	(ASM) annual payroll, production employees, $millions

Transformations

v_{it}	Valueadd
Au_{it}	Production workers(blue-collar)per $1000 1976 Value Added prodemp / (valueadd (deflator(1976)/deflator(t))
As_{it}	Nonproduction (office?) workers per $1000 1976 Value Added (emp-prodemp) / (valueadd (deflator(1976)/deflator(t))
Ak_{it}	Capital per $1976 Value Added capital/(valueadd (deflator(1976)/deflator(t))
wu_{it}	Production workers average earnings, $1000 prodpayr/prodemp
ws_{it}	Nonproduction average earnings, $1000 (payroll-prodpayr)/(emp-prodemp)
Y_{it}	Payroll savings induced by technological change $(Au_{it} - Au_{i0})\ 11.62 + (As_{it} - As_{i0})\ 16.86$
y_{it}	Production payroll savings induced by technological change $(Au_{it} - Au_{i0})\ 11.62$

Table 2. Basic Statistics for Factor Inputs and Wages

	Au76	*As76*	*Ak76*	*wu76*	*ws76*	*(Au86-76)*	*(As86-76)*	*(Ak86-76)*	*(wu86-76)*	*(ws86-76)*	*Y*	*y*
Weighted Mean	.0255	.00905	.750	11.62	16.86	-.0053	-.00083	.137	11.15	15.05	-.0760	-.0620
Manufacturing	.0257	.00950	.692	12.11	17.63	-.0046	-.00063	.191	11.52	15.70	-.0639	-.0532
Mining	.0253	.00847	.826	10.99	15.85	-.0063	-.00108	.066	10.66	14.21	-.0918	-.0736

Unweighted Correlations

	Au76	*As76*	*Ak76*	*wu76*	*ws76*	*(Au86-76)*	*(As86-76)*	*(Ak86-76)*	*(wu86-76)*	*(ws86-76)*	*Y*	*y*
Au76	1.000											
As76	.118	1.000										
Ak76	-.162	-.140	1.000									
wu76	-.764	-.236	.318	1.000								
ws76	-.470	-.232	.122	.599	1.000							
(Au86-76)	-.492	-.047	.011	.393	.257	1.000						
(As86-76)	.003	-.276	-.235	.059	.212	.462	1.000					
(Ak86-76)	-.049	.058	.450	.158	.000	.176	-.062	1.000				
(wu86-76)	-.663	-.220	.310	.788	.491	.163	-.082	.031	1.000			
(ws86-76)	-.433	-.123	.062	.484	.149	.091	-.194	-.203	.610	1.000		
Y	-.376	-.141	-.081	.323	.277	.941	.734	.111	.094	-.004	1.000	
y	-.492	-.047	.011	.393	.257	1.000	.462	.176	.163	.091	.941	1.000

Table 3
Regressions of Payroll Savings on Initial Input Mixes
(Not adjusted for potential heteroscedasticity)

Regress: $Y_{it} = \beta_k Ak_{io} + \beta_p Au_{io} + \beta_o As_{io} + \gamma(Ak_{it} - Ak_{io})$

Dep. Variable	y	Y	Y	Y
Initial Year	1976	1976	1976	1976
Final Year	1986	1986	1986	1986
Omitted Data	none	none	2794	2794
<u>Estimates</u>				
Initial Capital (β_k)		-0.034(.01)	-0.02(.01)	-0.0035(.013)
Initial Blue Collar[1] (β_p)	-2.83(.22)	-2.3(.3)	-2.49(.28)	-2.55(.37)
Initial White Collar[2] (β_o)	1.5(.8)	-0.046(1.2)	-0.60(1.1)	-0.34(1.5)
Change in Capital (γ)		0.023(.007)	0.11(.01)	-0.10
R^2	0.49	0.41	0.55	0.34
<u>Estimated Effect on Wages</u>				
Blue Collar	24.4%	19.8%	21.4%	21.9%
White Collar	-8.8%	0.3%	3.6%	2.0%

[1] Non-Production Workers
[2] Production Workers

Table 4
Regressions of Payroll Savings on Initial Input Mixes
(Adjusted for potential heteroscedasticity)

Regress: $Y_{it}/z_{io} = (\beta_k Ak_{io} + \beta_p Au_{io} + \beta_o As_{io} + \gamma(Ak_{it} - Ak_{io}))/z_{io}$

Dep. Variable	y	y	Y	Y	Y
Initial Year	1976	1976	1976	1976	1976
Final Year	1986	1986	1986	1986	1986
z_{io}	As	v	v	v	v
Omitted Data	none	2292	none	2292	2794
		2794		2794	2292
		3263		3263	3263
				3031	3031
<u>Estimates</u>					
Initial Capital (β_k)			-0.009(.011)	-0.032(.01)	-0.064(.013)
Initial Blue Collar[1] (β_p)	-2.6(.2)	-2.27(.36)	-5.05(.63)	-2.15(.41)	-2.21(.42)
Initial White Collar[2] (β_o)	1.0(1.1)	1.62(1.8)	6.99(4.0)	-1.37(2.3)	-0.76(2.4)
Change in Capital (γ)			-.0005(.0001)	.0004(.0001)	-0.10
R^2	0.46	0.53	0.68	0.63	0.45
<u>Estimated Effect on Wages</u>					
Blue Collar	22.4%	19.5%	43.5%	18.5%	19%
White Collar	-5.9%	-9.6%	-41.5%	8.1%	4.5%

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[1] Non-Production Workers
[2] Production Workers

FIGURE 1

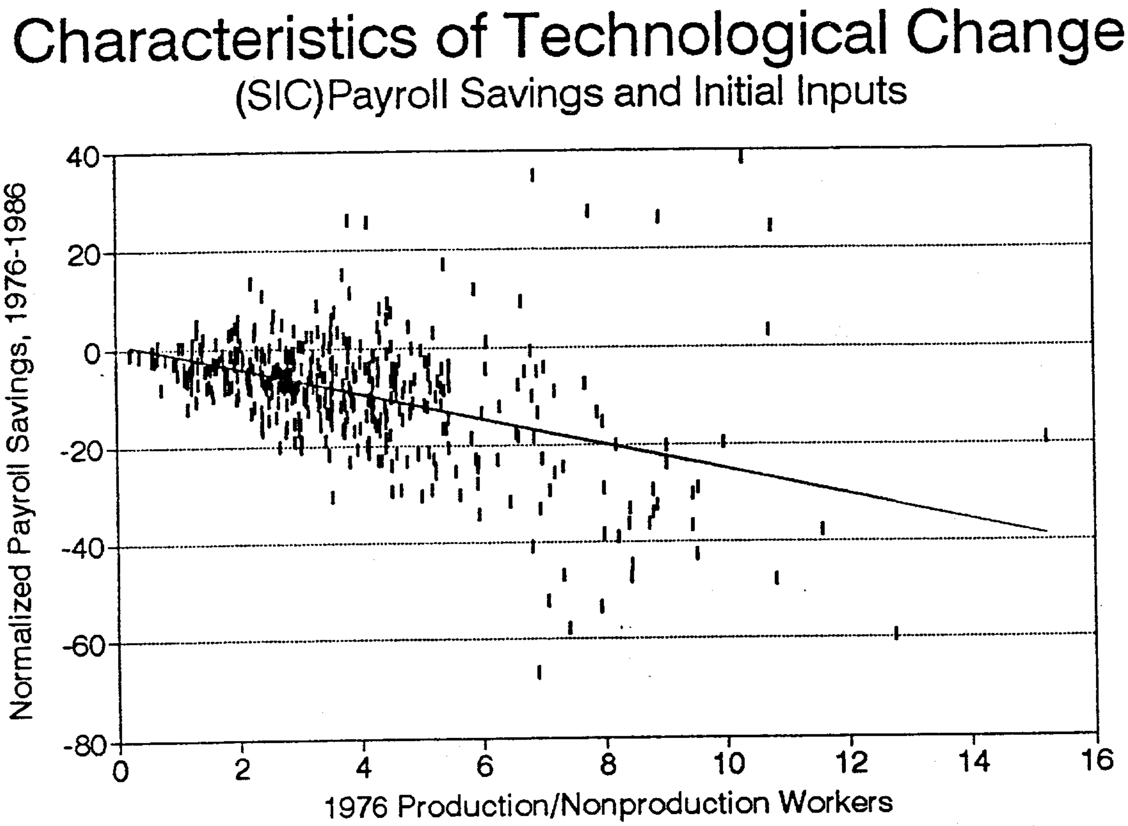
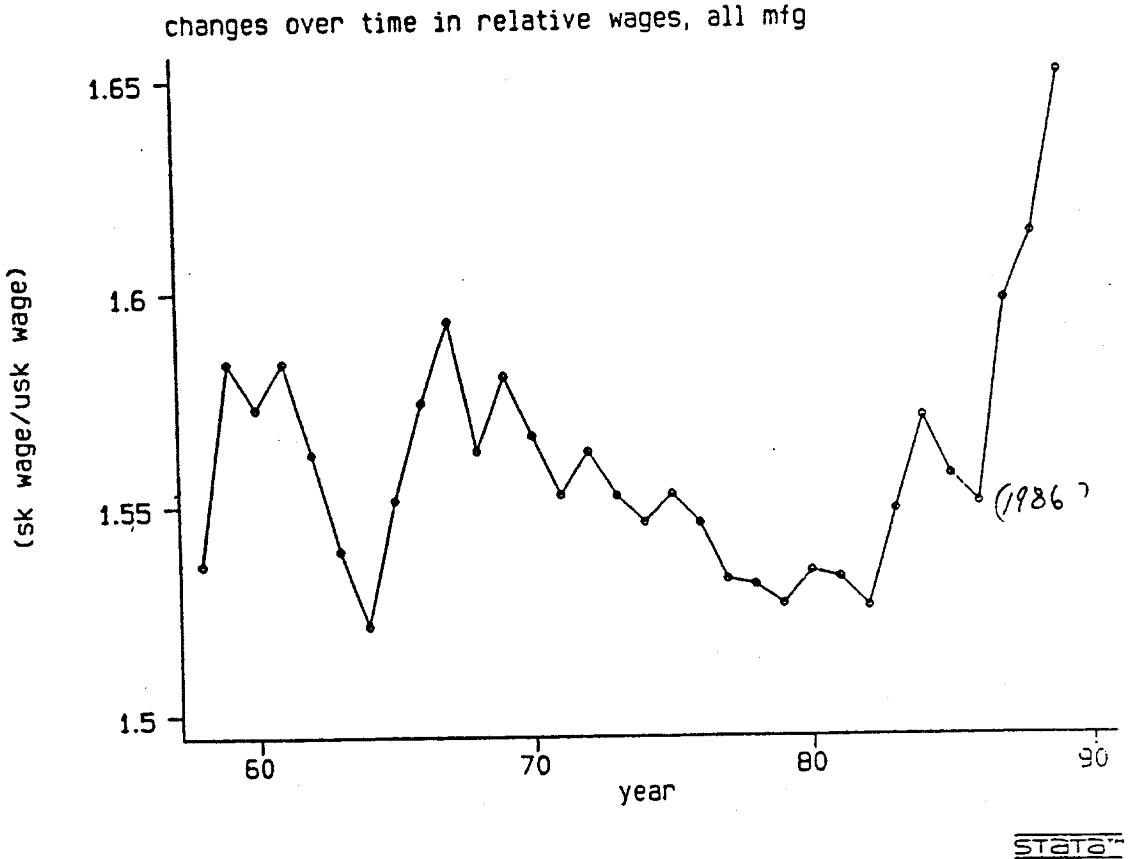

Characteristics of Technological Change
(SIC)Payroll Savings and Initial Inputs
Normalized Payroll Savings, 1976-1986
40
20
0
-20
-40
-60
-80
0
2
4
6
8
10
12
14
16
1976 Production/Nonproduction Workers

FIGURE 2

Figure #5: Evolution of Non-Production Versus Production Wages In Manufacturing



Sources: Wage data comes from the NBER's Trade and Immigration Data Base.
Average wage of non-production workers is "sk wage."
Average wage of production workers is "usk wage."