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The Impacts of Technology, Trade and Outsourcing on Employment and Labour Composition

by

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Abstract

Since the late 1970s, there has been a shift in compensation and labour composition in favour of highly educated workers. A number of recent papers have identified trade, technology, and outsourcing as possible "causes" of these changes. Most of these studies have been based on a simple production or cost function framework and limited information on investment in technology and labour composition. In this paper, we examine the relationship between trade, technology, and outsourcing and shifts in labour demand using dynamic cost function estimation and more comprehensive measures of labour composition and technological advance. Our findings indicate that technological change has had the greatest effect on changes in labour composition. However, the indirect impact of foreign trade on employment patterns augments its direct impact because trade stimulates computerisation, which leads to further reductions in the demand for workers without a college degree and increases in the demand for workers with a college degree.

Outline

Non-Technical Summary

Studies of the determinants of recent shifts in labour demand in favour of highly educated workers suffer from several important limitations. The first is that they do not simultaneously consider the impact of technology, trade, and outsourcing on labour composition. A related concern is that they are typically based on a simple cost or production function framework, which precludes an analysis of the interactions among conventional inputs and external factors, such as trade, technology, and outsourcing. Also, these models cannot distinguish between short and long run behaviour because they assume that capital adjustment instantaneously reaches a steady-state long run equilibrium. An additional problem is a lack of detailed information on labour force composition.

In this paper, we address some of these limitations by specifying a dynamic flexible cost function, which obviates the need to impose the tenuous assumption that firms can freely adjust their capital stocks in response to price changes. That is, the dynamic model recognises the quasi-fixity of capital and, thus, the difference between temporary and long run equilibrium, through adjustment costs on capital. Our model also includes a more complete set of determinants of shifts in labour demand, which allows us to simultaneously assess the direct and indirect effects of trade, technology (R&D and computers), and outsourcing on productivity and labour demand. Finally, we provide more detailed estimates of labour compositional effects by including four types of labour, classified by educational level.

We estimate our model using detailed industry-level data on productivity and trade (NBER), technology (BEA and NSF), outsourcing (BLS), and education attainment of the workforce (BLS) for the years 1959-1989. Our findings indicate that technological change has a stronger impact on changes in labour demand than trade or outsourcing. An increase in investment in computers and R&D simultaneously reduces the demand for workers without a college degree and increases the demand for workers with at least some college. These results are consistent with several recent studies of skill-biased technological change, which attribute a greater role to technology than trade in explaining changes in the wage and employment structure. The effects of computers and R&D, our proxies for technology, do not appear to differ substantially. Trade also has a negative impact on the demand for less educated workers, but it is not associated with an increase in demand for more educated workers. Outsourcing appears to have a relatively small negative impact on demand across all education levels, with the strongest effects for workers with less than a college degree.

Perhaps our most interesting result concerns the interaction between trade and computers. Specifically, we find that trade stimulates computerisation, which exacerbates the negative impact that each factor has on the demand for workers without a college degree, and augments the positive effects that each factor has on the demand for workers with a college degree. Thus, models that ignore these indirect effects may underestimate the overall impact of trade on labour composition.

1 Introduction

Recent studies of shifts in relative wages and labour composition toward more highly educated workers have attributed these changes to rapid technological change or to an increase in the volume of foreign trade. Outsourcing is also hypothesised to have exacerbated these trends. Most of these papers have been based on a simple cost or production function framework and limited information on technological change and composition of the labour force.

In this study, we examine the effects of trade, technology and outsourcing on employment and labour composition using a dynamic cost function model and more detailed measures of labour composition and technical change. This framework provides for a more comprehensive analysis of labour demand because it allows us to incorporate adjustment costs for capital and interaction effects among trade, technology, and outsourcing, which have been ignored in existing studies. Our data also allow us to assess the impact of these factors on the demand for four types of workers, classified by level of education.

In the next section, we provide an overview of recent empirical studies of shifts in labour demand. We follow this with sections devoted to our theoretical model, empirical implementation, results, and conclusions.

2 Brief Review of Recent Studies on Shifts in Labour Demand

In recent years, there has been a widening of the wage differential between low-skilled and high-skilled workers (Bound and Johnson (1992)). This has occurred despite a large increase in the number of highly educated workers. One explanation for this increase in the "rate of return" on investment in education is skill-biased technological change (Nelson and Phelps (1966) and Welch (1970)). This hypothesis maintains that the value of education is enhanced by technological change, because greater knowledge or skill enables firms to implement new technologies more effectively. Bartel and Lichtenberg (1987) modify this theory by asserting that the comparative advantage of highly educated workers in implementing new technologies arises from their ability to solve problems and adapt to change in the work environment. These models predict that technical change is biased or non-neutral with respect to labour, with disproportionate effects on different classes of workers.

Trade and outsourcing are also alleged to have increased the earnings gap. According to this view, cheap imports (produced by low-skilled workers) will reduce the wages of low-skilled U.S. workers. This follows from the standard Hecksher-Ohlin-Samuelson model, which predicts that an increase in the volume of foreign trade will simultaneously lead to a convergence in the gap between wages in the U.S. and those outside the U.S. and a widening of the gap between the wages of low and high skilled workers within the U.S. Outsourcing is hypothesised to further exacerbate compositional changes in the workforce that favour highly-educated workers, since companies engage in this activity, at least in part, to exploit wage differentials between developed and developing countries or between the manufacturing and service sectors.

Recent industry-based studies provide strong empirical support for skill-biased technological change.[1] Berman, Bound, and Griliches (1994) report a positive association between investments in computers and R&D and changes in non-production workers' share of the industry wage bill. The latter is interpreted as indicative of "skill upgrading." In a similar vein, Berndt, Morrison, and Rosenblum (1992) find a positive correlation between high-tech office equipment and the demand for white-collar workers. Using detailed industry data, Siegel (1997) reports a positive association between proxies for labour quality and computers.

The international evidence appears to confirm the U.S. findings. Berman, Bound, and Machin (1998) report that changes in the employment structure towards more highly educated workers are evident across many developed countries and that these shifts can be linked to technological change. They also find that the magnitudes of these linkages are quite similar across countries. Park (1996) also reports a positive correlation between labour productivity growth and the proportion of multi-skilled workers in Korean manufacturing industries. Betts (1997) estimates a cost function model and finds evidence of biased technical change away from blue-collar labour in 18 out of 20 Canadian manufacturing industries. Haskel (1999) and Haskel and Heden (1999) report that computerisation increases the demand for skilled workers in the U.K. manufacturing sector.

A standard model that is used to test for skill-biased technological change is based on estimation of a reduced-form version of a cost or production function in which some proxy for technology is included as an argument. This enables the researcher to test for the non-neutrality of technical change by examining the sign (and significance) of the coefficient on the technology variable, or any other "external" factor. Under the null hypothesis of "neutrality," the coefficients would be zero. For example, Berman, Bound, and Griliches (1994) test for capital-skill complementarity based on a restricted labour cost function:

$$(1)\ \ln LC = f(\ln p_i, \ln K, \ln Y, t),$$

where LC is labour cost, p_i is the wage of the ith type of worker, K is the stock of capital, Y is output, t is time, and f is assumed to have a translog form.

Invoking cost minimisation for variable inputs and Shephard's lemma ($s_N = \partial \ln LC/\partial \ln p_N$, where s_N is the share of non-production labour in total employment or labour cost), constant returns to scale, homogeneity of degree one in prices, and taking first differences yields the estimating equation:

[1] See Siegel (1999) for a review of 27 recent studies of skill-biased technological change.

$$(2)\ ds_N = \beta_0 + \beta_1\, d\ \ln (p_N/p_j) + \beta_2\, d\ \ln(K/Y) + u$$

where (K/Y) reflects capital intensity, and u is a classical disturbance term. If $\beta_2 > 0$, we have "capital-skill complementarity," a term coined by Griliches (1969) in his seminal article. Berman, Bound, and Griliches (1994) included the following proxies for technological change in equation (2), R&D intensity (R/Y) and the ratio of expenditures on computers to total investment (C/I):

$$(3)\ ds_N = \beta_0 + \beta_1\, d\ \ln(p_N/p_j) + \beta_2\, d\ \ln (R/Y) + \beta_3\, d\ \ln (C/I) + u\ .$$

Another procedure for examining the labour demand impacts of trade or technology involves estimating a wage or employment equation with a trade or technology measure as an argument (see Revenga (1992), Bernard and Jensen (1995), Van Reenen (1996), and Krueger (1993)). This approach has also provided evidence of skill-biased technological change. Bartel and Lichtenberg (1990) find that the wages of highly educated workers are inversely related to proxies for the age of an industry's technology. Krueger (1993) reports that workers who use a computer at work earn a wage premium (10-15%) relative to observationally equivalent workers.

Empirical evidence on the impact of trade and outsourcing on labour demand is much more mixed. Katz and Murphy (1992) find that increasing import intensity was not an important determinant of relative wage changes. Lawrence and Slaughter (1993), who focus on Stolper- Samuelson effects, find little labour demand impact from trade across industries. [2] Sachs and Shatz (1994) conclude that while trade explains some changes in labour demand, technological change has more explanatory power. On the other hand, Revenga (1992) finds that an increase in import competition had a negative impact on employment and wages in U.S. manufacturing industries. Abraham and Taylor (1996) report that firms outsource services to smooth production cycles, to benefit from specialisation, and most importantly, to realise labour cost savings.

Existing studies, while useful, have several limitations for a comprehensive analysis of the impact of technology, trade, and outsourcing on labour demand. The first is that they are typically based on a simple cost or production function framework, which precludes an analysis of the interactions among inputs and external factors such as trade, technology, and outsourcing. Also, these models cannot distinguish between short and long run behaviour because they assume that capital adjustment instantaneously reaches a steady-state long run equilibrium. An additional problem is a lack of detailed information on labour force composition. Most datasets, even the establishment-level files

[2] Evidence against the trade-based explanation of changing skill structures in OECD countries is also presented in Desjonqueres, Machin, and Van Reenen (1999).

examined by Doms, Dunne and Troske [1997] and Dunne, Haltiwanger and Troske [1997] identify only *two* types of labourers -- production and non-production workers.[3]

In this paper, we address some of these limitations by specifying a dynamic flexible cost function, which obviates the need to impose the tenuous assumption that firms can freely adjust their capital stocks in response to price changes. That is, the dynamic model recognises the quasi-fixity of capital and, thus, the difference between temporary and long run equilibrium, through adjustment costs on capital. Our model also includes a more complete set of determinants of shifts in labour demand, which allows us to simultaneously assess the direct and indirect effects of trade, technology, and outsourcing on productivity and labour demand. Finally, we provide more detailed estimates of labour compositional effects by including four types of labour, classified by educational level.

3 The Methodology

Our model is based on a dynamic variable cost function specification incorporating quasi-fixity of some internal inputs, non-constant long run returns to scale, and external "shift" factors: $G=G(\mathbf{p},Y,\mathbf{x},\Delta\mathbf{x},\mathbf{T})$, where $\mathbf{p}$ is a vector of J variable input prices, Y is output, $\mathbf{x}$ is a vector of K quasi-fixed inputs, $\Delta\mathbf{x}$ represents adjustment costs for the $\mathbf{x}$ inputs, and $\mathbf{T}$ is a vector of N external technological and trade factors. Thus, total costs are equal to $C=G(\mathbf{p},Y,\mathbf{x},\Delta\mathbf{x},\mathbf{T})+\Sigma_k x_k p_k$, where p_k is the market price of quasi-fixed (internal) input x_k.

The T_n variables are defined as any factor that could potentially affect the cost function, which is not under the direct choice of the firm. In our model, this includes a trade or openness factor (the import/output ratio), two specific indicators of technological change (high-tech capital and R&D), a standard time trend (state of technology) variable "t"; and an outsourcing variable (the cost share of purchased services). Our analysis therefore accommodates a much more complete specification of trade and technology determinants than is found in the existing literature.

Note that the elements of the **T** vector are assumed to represent the technological base underlying production in the sector as a whole, rather than the level of high technology investment undertaken within a sector. That is, the **T** variables are considered to be exogenous, rather than endogenous or "choice" factors. If these variables were characterised as internal factors, they would instead appear as components of the **x** vector. The main differences in the resulting analysis would therefore be the level of aggregation at which the variables were represented, and the explicit recognition of the payment for the factor by the firms within the industry. We are instead searching for the general impact on the industry, incorporating spillover effects.

[3] These papers describe interesting patterns of innovation and skilled labor interactions, including a distinction between correlating technology usage and *levels* as compared to *changes* in wages, but do not include trade impacts and therefore are not highlighted more here.

Including these external variables in a cost or production function model is consistent with "new" growth theories (Romer (1986), Grossman and Helpman (1991)), which assert that economic growth may depend on the presence of spillovers or other sources of social increasing returns. These authors identify a potential role for technology and trade policies in enhancing the spillover mechanism. Some authors have attributed these externalities to scale effects which arise from "thick markets" (Hall (1990)). Others (Helpman (1998)) point to "general purpose technologies," or drastic innovations, such as the steam engine, electricity, or computers, which benefit many downstream sectors as they are diffused throughout the economy.

Some recent studies provide empirical support for certain aspects of these theories. Morrison and Siegel (1997) find that investments in computers and R&D undertaken in a major sector (2–digit SIC) as a whole can potentially result in higher productivity in 4-digit industries within that sector. There are numerous studies, most notably papers by Sachs and Warner (1995) and Edwards (1998), which report that more "open" countries experience higher productivity growth. ten Raa and Wolff (1994) report a positive association between the rate of outsourcing and economic performance in manufacturing industries.

In our empirical analysis, we assume that the variable cost function G(**p**, Y, **x**, Δ**x**, **T**) can be approximated by the generalised Leontief (GL) form:[4]

$$(4)\quad G(\mathbf{p}, Y, \mathbf{K}, \Delta\mathbf{K}, \mathbf{T}) = Y[\Sigma_i\Sigma_j\, \alpha_{ij}\, p_i^{.5}\, p_j^{.5} + \Sigma_i\Sigma_m\, \delta_{im}\, p_i\, s_m^{.5} + \Sigma_i p_i\, \Sigma_m\Sigma_n\, \gamma_{mn}\, s_m^{.5}\, s_n^{.5}] + Y^{.5}[\Sigma_i\, \delta_{iK}\, p_i K^{.5} + \Sigma_i p_i\, \Sigma_m\, \gamma_{mK}\, s_m^{.5}\, K^{.5}] + \Sigma_i p_i\, \gamma_{KK}\, K$$

where capital (K) is the only quasi-fixed (x_k) input; p_i and p_j index the prices of variable inputs: energy (E), materials (M), and labour (L_i), where i indexes the four types of workers [L_1=no high school diploma, L_2=a high school diploma, L_3=some college, and L_4 = a college degree]; s_m, s_n depict the remaining arguments (Y, ΔK and **T**); and **T** includes measures of trade, high-tech capital (computers), R&D, and outsourcing. In addition to the cost function, we also estimate input demand equations from Shephard's lemma: $v_j=\partial G/\partial p_j$, where $j=L_i$,E,M; and the Euler equation reflecting investment for K: $p_K = -\partial G/\partial K - r\partial G/\partial \Delta K + \Delta K\partial^2 G/\partial K\partial \Delta K + \Delta\Delta K\partial^2 G/\partial(\Delta K)^2$ (where ΔΔK is the second difference of K, Δ(ΔK), and r is a long run discount rate]. The flexible form of the cost function (equation (4)) allows for a comprehensive analysis of the direct and indirect effects of technology and trade on cost and labour composition. Our estimates of these effects will be based on the calculation of a broad set of elasticity measures of cost and labour demand with respect to the T_n variables.

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[4]See Morrison [1988a] for more details about the construction and use of this function, and Morrison and Siegel [1997] for further discussion of the representation of external effects through the components of the **T** vector.

We begin by defining some cost elasticities. The direct cost effect of any T_n variable can be expressed as $\partial C/\partial T_n$, or, in elasticity (proportional) terms, $\partial \ln C/\partial \ln T_n = \varepsilon_{CTn} = \partial G/\partial T_n (T_n/C)$. This is an estimate of the (potential) percentage decline in input costs due to increased availability of the external technology/trade factor. Note that this derivative is the elasticity version of a shadow value, typically defined as $Z_n= -\partial G/\partial T_n$, where the negative sign is included to make the number positive. Thus, $\varepsilon_{CTn}<0$ implies a positive shadow value (marginal product) of T_n.[5]

A more complete analysis of the impact of the T_n variables on cost and labour demand requires the specification of additional elasticity measures. In the cost context, interactions among the elements of the **T** vector can be derived by assessing the impact of changes in *other* elements of **T** (e.g., T_2) on the ε_{CTn} elasticity (or ε_{CT1}, for T_1): $\varepsilon_{CT12} = \partial \varepsilon_{CT1} /\partial \ln T_2$.[6] This measure shows whether a cost change associated with a change in T_1 is attenuated or exacerbated by a change in T_2. For example, if trade (T_1) reduces costs, but is associated with further declines in costs from increasing computerisation (T_2), both ε_{CT1} and ε_{C12} would be negative. This complementarity implies that even a small *direct* effect of trade might be associated *indirectly* with significantly increasing efficiency. Note also that since the ε_{CT12} elasticity is a second derivative, it must be symmetric with ε_{CT21}; i.e. if one is negative, the other is negative. In our example, this implies that increased openness will cause the cost impact of computerisation ($\partial \ln C/\partial \ln T_2 = \varepsilon_{CT2} = \partial G/\partial T_2 (T_2/C)$) to be larger. This, in turn, implies that the impact of T_1 may be indirect, occurring through the impact of trade on computerisation, and thus, masked by measured (direct) technological impacts.

Characterising the associated labour demand patterns begins with another cost elasticity, derived from Shephard's lemma; $\partial C/\partial p_{Lj} = \partial G/\partial p_{Lj} = L_j$. Once this demand relationship is specified, it can easily be shown that the *share* of this type of labour in total costs is $\partial \ln C/\partial \ln p_{Lj} = p_{Lj}L_j/C = S_{Lj} = \varepsilon_{CLj}$. It is also clear that the determinants of either the level of demand or share of this labour component can be specified in terms of elasticities that allow a full characterisation of the determinants of input and labour demand and composition patterns.

The elasticity of labour demand with respect to a T_n factor is $\partial \ln L_j/\partial \ln T_n = \varepsilon_{LjTn}$. Thus, if an increase in openness (T_1) reduces employment of labour type L_j, then $\varepsilon_{LjT1}<0$. If this is further augmented by increases in computerisation (i.e., low-skilled labour is "hurt" by openness and computerisation and

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[5]Note that this elasticity, since it is expressed in terms of total costs, would also include a market price if the variable were internal rather than external -- the costs were incurred by, and the variable were under control of, the firm/industry in question. I.e., the cost elasticity is in terms of the *net* value $p_n- Z_n$ rather than the gross value Z_n if the firm incurs costs p_n for purchases of T_n, but (as noted above) here the implicit assumption is $p_n=0$. See Morrison and Siegel [1997] for further discussion of these types of elasticities.

[6]Note that the logarithm appears only in the denominator to be consistent with typical specification of biases. See Morrison [1988b] for further elaboration of different bias specifications.

their impacts are interrelated), the cross-effects are reflected in a negative value for the cross elasticity term $\varepsilon_{LjT12} = \partial\, \varepsilon_{LjT1} / \partial \ln T_2$. The indirect effects are interpreted in a manner similar to those affecting costs, captured in the ε_{CT12} measure described above.

Compositional changes in labour demand are instead represented in terms of the bias, which is, in turn, defined in terms of a share. The bias depends on the relative difference between the overall cost effect and the impact on a specific type of labour of a change in T_n: $B_{LjTn} = \partial \varepsilon_{CLj} / \partial \ln T_n = \partial S_{Lj} / \partial \ln T_n = S_{Lj}(\varepsilon_{LjTn} - \varepsilon_{CTn})$. Thus, if increasing openness (T_1) is relatively input L_j-saving (Lj declines more than other inputs as a whole, or increases less than inputs overall), then $B_{LjT1}<0$. This bias measure can be adapted in two ways to focus on relative (total) labour use as compared to other inputs as a whole, or relative use of different labour types as compared to total labour demand. The first measure requires computing an "overall" labour demand elasticity: $\varepsilon_{LTn} = \Sigma_j\ S'_{Lj}\varepsilon_{LjTn}$ (where $S'_{L1}=p_{L1}L_1/\Sigma_j.p_{Lj}L_j$), and constructing the measure: $B_{LTn} = \partial S_L / \partial \ln T_n = S_L(\varepsilon_{LTn} - \varepsilon_{CTn})$ (where $S_L=p_L L/C$ and $p_L L=\Sigma_j.p_{Lj}L_j$). An alternative bias measure is defined for one labour type (L_1), as compared to total labour: $B'_{L1Tn} = S'_{L1}(\varepsilon_{L1Tn}-\varepsilon_{LTn})$. This latter measure focuses on labour composition changes rather than overall input composition. The two measures together identify whether technology/trade factors are labour-saving or using, and whether there are differential effects across various types of labour.

The patterns of absolute and relative changes in labour composition can be fully represented by the complete set of bias measures. These interaction terms are computed as derivatives of the biases with respect to the T_n variables: $I_{LjT12} = \partial B_{LjT1} / \partial \ln T_2$. The I_{LiT12} measure, for example, shows whether a trade bias might be exacerbated/attenuated by increased computerisation, in a manner similar to the cost- and demand- based measures (ε_{CT12} and ε_{LjT12}) described above.

The elasticities we have identified reflect short run adjustments only, because they are based on an *existing* level of K. We can gain further insights by computing the difference between elasticities at *given* levels of K, and those that can *potentially* be reached in the long run, when K reaches its long run desired or cost minimising level. This requires adapting all elasticity measures to accommodate capital adjustment.

For example, the long run cost elasticity with respect to a technological/trade variable is $d\ln C/d\ln T_n = \partial \ln C/\partial \ln T_n + \partial \ln C/\partial \ln K\ (\partial \ln K^*/\partial \ln T_n) = \varepsilon^L_{CTn}$, where K* is defined as the level of capital level where the shadow value and market price of capital are equal, so the market is in equilibrium (so $\varepsilon_{CK}=\partial \ln C/\partial \ln K = (\partial G/\partial K+p_K)K/C = (p_K-Z_K)K/C = 0$)[7]. Similarly, for the measure $\varepsilon_{LjTn} = \partial \ln L_j/\partial \ln T_n$, the long run measure is $d\ln L_j/d\ln T_n = \partial\ln L_j /\partial\ln T_n + \partial\ln L_j /\partial\ln K\ (\partial \ln K^*/\partial \ln T_n) = \varepsilon^L_{LjTn}$, The interaction effects associated with these two types of measures therefore become: $\varepsilon^L_{CT12} = \partial\, \varepsilon^L_{CT1} / \partial \ln T_2$, ε^L_{LT12}

= $\partial \varepsilon^{L}_{LT1} / \partial \ln T_2$. Finally, the long run bias can be specified as: $B^{L}_{LjT} = \partial S^{L}_{Lj} / \partial \ln T = S^{L}_{Lj}(\varepsilon^{L}_{LjT} - \varepsilon^{L}_{CT})$ [where $S^{L}_{Lj} = \varepsilon^{L}_{CLj} = d\ln C/d\ln L_j = \partial \ln C/\partial \ln L_j + \partial \ln C/\partial \ln K\ (d\ln K^*/d\ln L_j)$]; and similarly for B^{L}_{LT} and B'^{L}_{LjT} .

The elasticity measures we have presented provide a more complete picture of absolute and relative labour demand changes than those presented in existing papers. That is, our framework allows us to identify direct and indirect effects, and short and long run impacts, of trade, technology, and outsourcing on employment and labour composition.

4 Empirical Implementation and Results

The seven-equation system is comprised of the six variable input demand equations for the four labour categories, energy, and materials, and an Euler equation for capital. To estimate this model, we append an additive disturbance term to each equation. The resulting disturbance vector is assumed to be identically and independently normally distributed with mean vector zero and variance-covariance matrix Ω. The model is estimated by iterative three stage least squares, using the following as instruments: t, the beginning-of-the-year value of the capital stock, and single-lagged values of Y, K, E, M, L_i, and ΔK. Thus, the endogenous variables are the variable input quantities E, M, and L_i ; investment quantity K , and the level of output Y.

Note that our approach is consistent with Generalized Methods of Moments (GMM) estimation, which assumes that the mean value of "errors" in expectations is zero and that these errors are uncorrelated with the equation residuals.[8] Standard errors for the parameter estimates were computed using the ANALYZ procedure in TSP. We use this approach because the elasticities are computed as combinations of first and second derivatives of the cost function in equation (4), evaluated at different points. Thus, each elasticity depends not only on the data, but also on a complex combination of parameter estimates, each with its own standard error. The ANALYZ procedure, by using a "delta" method, allows a combined standard error to be computed for these expressions.[9]

Consistent with our earlier discussion, the values of the T_n variables (T_1=import/output ratio, T_2=high-tech capital (computers), T_3=R&D, and T_4=outsourcing of services) are available at the 2-digit industry level. A data appendix summarising our variables is presented at the end of the paper. The conventional arguments of the cost function were available at the 4-digit industry level. Parameter estimates were then used to compute the elasticities for each 4-digit industry, which were then

[7] Morrison [1988a, 1988b] provides more details about the development of this type of long run elasticity in somewhat different contexts.
[8] See Pindyck and Rotemberg (1983),
[9] See Gallant and Jorgenson (1979) and Gallant and Holly (1980)

aggregated to the 2-digit level and in turn to the total manufacturing level (using output shares as weights for the averages). For parsimony, we present only the aggregate results.[10]

Before presenting our empirical results, it is useful to consider the expected signs of the elasiticity measures. The "new" growth theories discussed earlier imply that the ε_{CTn} variables will be negative. That is, technology or trade factors might be expected to generate positive spillovers, which would enable industries to reduce costs. Similarly, outsourcing should, in theory, lead to a decline in the demand for labour and, thus, enable firms to reduce variable costs.

The likely signs of the labour demand elasticities are similarly unambiguous for technological factors. The literature on skill-biased technological change suggests that increases in computers, R&D, and openness, especially in advanced industrial nations such as the U.S., are likely to lead to a reduction in the demand for less educated workers. The effects of outsourcing, on the other hand, are somewhat more difficult to predict. While it is true that many low skilled functions have been outsourced, business services now constitute most of outsourcing activity by manufacturing firms. Fixler and Siegel [1999] report that the cost share of purchased services in U.S. manufacturing has almost tripled over the past forty years, rising from 5% in 1949 to approximately 14% in 1988, and that business services now account for over 50% of these purchased services. This category includes accounting, legal, and computer services, which require higher levels of education.

Table 1 presents cost elasticity measures for the U.S. Manufacturing sector for 1959-1989. The ε_{CT1} - ε_{CT4} estimates imply that cost savings from trade, technology, and outsourcing occurred throughout the period. R&D and computers appear to have the largest potential cost-saving impact, while outsourcing has the smallest. There is some weak evidence of intensification of these effects over time, although only in the case of R&D are the differences over time statistically significant.

As discussed in Section III, the cross elasticity terms, such as ε_{C12}, represent interaction effects among technology, trade, and outsourcing. For example, given that ε_{CT1} is negative, a negative value of ε_{C12} indicates that computerisation augments cost declines associated with trade. This *indirect* impact underscores the importance of outlining a model that incorporates such effects. Note that almost all of the interaction terms are negative, implying that these external factors act in a synergistic fashion to reduce costs. The interaction terms are largest for trade, and almost uniformly statistically significant. However, the magnitudes of these cross elasticities are much smaller than their direct impacts on cost.

Table 2 contains estimates of the impact of trade, technology, and outsourcing on the demand for four types of workers (L_n), classified by level of education (L_1=no high school, L_2=high school, L_3=some college, and L_4=a college degree). The results presented in the top panel of Table 2 indicate that trade,

[10] Industry-specific parameter estimates are provided in Morrison and Siegel (2000).

technology, and outsourcing have all had a negative impact on workers without a high school diploma (L_1). Technological factors (computers and R&D) appear to have the largest direct impact. The interaction terms (ε_{L1nm}) are negative, indicating complementary indirect effects, although the magnitudes are quite small and generally statistically insignificant. While the magnitudes of these effects appear to be stronger over time, formal tests for differences across periods were uniformly insignificant.

As shown in the second panel of Table 2, similar patterns emerge for workers with a high-school diploma (L_2). Based on an alternative method (wage equation estimation), Autor, Katz, and Krueger (1998) report comparable findings for high school graduates. Interestingly, our results imply that reductions in labour demand associated with trade, technology, and outsourcing are greater for workers with a high school degree than for those without one. Once again, technological factors, especially computers, have the largest impact on high-school graduates. The computer effects (ε_{L2T2}) are almost twice as large for this category of workers than for non-high school graduates (ε_{L1T2}). These impacts become even stronger when interaction effects are taken into account, although the interaction terms are again rather small and significant only for those involving trade.

The results for workers with at least some college education (bottom two panels of Table 2) provide a stark contrast to the elasticity estimates for non-college educated workers. Note that the impacts of computers and R&D on labour demand (ε_{L3T2}, ε_{L3T3}, ε_{L4T2} and ε_{L4T3}) are still larger than for trade and outsourcing, but are now *positive*. The largest positive impacts appear for the effect of computers on college educated workers. For workers with some college (L_3), the impacts of trade and outsourcing remain negative, although these effects are now *attenuated*, at least to some degree, by computerisation rather than augmented ($\varepsilon_{L312}>0$).

As shown in the bottom panel of Table 2, the direct impact of trade on labour demand (ε_{L4T1}) is positive for college-educated workers. The positive (and quite large) ε_{L412} measure indicates that computerisation further enhances the demand for these more educated workers. Thus, it is obvious that, in relative (bias) terms, trade is labour-saving for workers without a college education, yet labour-using for workers with at least some college. Finally, outsourcing appears to be labour saving for all labour categories, although these effects appear to be stronger for less educated workers (and in fact, are only statistically significant for these labour categories), despite the substantial increase in purchased services over this time frame noted earlier. While firms are increasingly likely to purchase accounting, technical, and legal services, the bulk of this activity still involves more menial tasks. Thus, it is usually more common to outsource low-skilled, rather than highly-skilled labour.

Although our discussion has focused exclusively on absolute cost and demand changes, these values can also be used to impute biases. The overall input composition effects are evident from a perusal of the relative cost and labour elasticities. Each trade and technology factor reduces overall variable costs by far more than any one labour category is affected, and thus, more than labour as a whole. This implies that increased cost effectiveness is derived largely from savings on materials inputs, which constitutes the largest cost share of any input. It also implies a greater increase in overall productivity than that attributable solely to labour.

The impacts on labour composition follow from our earlier discussion of the relative impacts of trade, technology, and outsourcing on different educational categories. An increase in each external factor leads to cost savings on less educated workers, which are greatest for workers with just a high school diploma. On the other hand, trade and technical change stimulate an increase in demand for workers at least some college. This finding is consistent with the observed dramatic shifts in employment away from lower skilled labour categories in U.S. manufacturing.

Not only the absolute levels of the impacts (as outlined above), but also the differences across the input categories point to the technological factors as the primary causes of changing employment patterns. The trade and outsourcing variables have less overall impact and impose less of a differential across inputs. In fact, the outsourcing impact is virtually neutral; little bias is observed across educational categories.

Recall that our framework allows us to distinguish short and long run effects of changes in labour demand that arise from technology, trade, and outsourcing. A comparison of the direct effects of these variables on cost and labour demand is presented in Table 3. The findings indicate that the elasticity values are almost uniformly larger in the long run. That is, declines in cost and labour demand declines are exacerbated in the long run, whereas positive values are attenuated in the long run. The impact of outsourcing on college educated workers is the only exception to this rule; where the long run and short run values are virtually identical.

The results imply that the cyclical tendency to reduce unskilled labour demand with changes in trade/technology variables has an even stronger secular tendency -- it will get worse. By contrast, the increases in skilled (more highly educated) labour in the short run are reduced somewhat in the long run when capital changes can occur and additional cost savings may be gained by either substitution of more capital for the skilled workers, or downsizing altogether.

Finally, to obtain a general idea of the extent of explanatory power these numbers provide, we can examine summary measures of actual changes in these variables. Using some overall measures for changes in the L and T variables, our evidence that the largest impacts result from automation/computerisation becomes even stronger. For example, the direct impact of trade on L_1 explains only 1.4% of the total drop in employment of labourers without a high-school degree evaluated over the time frame of the sample. High tech capital, however, explains 8% of the variation, with R&D and outsourcing contributing less than 1% of the total explanation.

This wide variation in explanatory power stems from the great differences in the degree of change of the variables themselves over the time period -- the proportion of high-tech capital increased nearly 450% over the sample period. In addition, the explanation provided for the L_2 and L_3 labour categories is even larger than for L_1 (at least partly since less variation has been experienced). For example, high-tech capital accounts for nearly 50% of the decline in employment of labourers with a high school diploma, 30% of the increase for workers with some college, and 9% of the expanding employment of college graduates. The corresponding numbers for trade are 6%, 1.5% and 1.3%, respectively.

It should be recognised that these numbers are quite significant, given the scope of the "explanation" provided for in this model. The model already has incorporated any responses to relative price changes (substitution) among inputs that occurred. Labour supply changes are also taken into account implicitly, as are migrations between industries (or even out of manufacturing into services), since these are exogenous to the model. All these factors together therefore account for the rest of the variation in labour unexplained by our trade/tech/outsourcing factors.

It is also worth commenting on the extent that these numbers change over time. In the 1973-89 time period, for example, automation/computerisation appears to explain 78% of the employment changes for high-school graduates, and 65% for those with some college (compared to 2.7% and 1% for trade, and 8% and 4% for high-tech capital in the earlier [1959-73] period). Also, the explanation provided by the long run numbers is quite a bit larger. Over the entire time period, the increase in trade accounts for 2.5% of the decrease in employment of workers without a high school diploma, nearly 8% of the change for high school graduates, and 3.7% of the change for workers with some college (less than 1% for college graduates). High tech capital, by contrast, explains 10.5%, 55.1%, 22.4% and 7.1%, respectively. Finally, the interaction terms provide little explanatory power, as evidenced by their small percentage magnitudes. Adding the high-tech capital impact to the trade explanation for L_1, for example, changes the explanatory power of the direct trade variable by only 1.35% (for L_2, L_3 and L_4 the numbers are 2.25%, 2.7% and 3.15%, respectively), and the rest of the interaction terms never exceed 1%.

5 Conclusions

Robert Hall, in commenting on Sachs and Shatz [1994] (p. 75), stated that "both the strength and the weakness of the hypothesis of biased technical change is that it can explain any pattern of change in relative wages". The spirit of Hall's comment is that it is difficult, based on existing empirical methodologies, to discriminate among alternative theories regarding shifts in the wage and employment structure. We believe that one way to address Hall's concern is to explore interactions among the various potential causes and consequences of changes in labour demand. This is a critical issue in assessing the impact of technology and trade on employment and labour composition.

In this study, we outline a rich production theory model that allows us to distinguish between absolute/relative, input/labour, demand/composition and short run/long run responses to trade, technology, and outsourcing, while controlling for interaction effects. Based on this dynamic cost function framework, and more detailed data, we provide comprehensive estimates of the impacts of these factors on employment and labour composition.

We find that technology has a stronger impact on shifts in labour composition in favour of highly educated workers than trade or outsourcing. An increase in investment in computers and R&D simultaneously reduces the demand for workers without a college degree and increases the demand for workers with at least some college. These results are consistent with several recent studies of skill-biased technological change, which attribute a greater role to technology than trade in explaining changes in the wage and employment structure. The effects of computers and R&D, our proxies for technology, do not appear to differ substantially. Trade also has a negative impact on the demand for less educated workers, but it is not associated with an increase in demand for more educated workers. Outsourcing appears to have a relatively small negative impact on demand across all education levels, with the strongest effects for workers with less than a college degree.

Perhaps our most interesting result concerns the interaction between trade and computers. Specifically, we find that trade stimulates computerisation, which exacerbates the negative impact that each factor has on the demand for workers without a college degree, and augments the positive effects that each factor has on the demand for workers with a college degree. Thus, models that ignore these indirect effects may underestimate the overall impact of trade on labour composition.

One useful extension of our analysis would be to examine the mechanism by which trade stimulates computerisation. It would be illuminating to determine whether this trend merely reflects the purchase of computer-intensive capital goods, or a more complex knowledge or technology transfer, as implied by recent new growth theories. Exploring the relative importance of intra-industry vs. inter-industry evidence on the determinants of changes in labour composition is another potentially interesting extension. This could generate additional insights into Haskel and Slaughter's (1998) provocative finding that the *sector bias* of skill-biased technological change provides most of the explanatory power with regard to skill upgrading in various countries. Finally, we would also like to estimate our model with data from several countries, to determine whether our findings generalise to other nations.

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DATA APPENDIX

Our primary source of data is the National Bureau of Economic Research's (NBER) Productivity File, which contains annual measures of output and inputs in current and constant dollars for 450 manufacturing industries (4-digit SIC level) for 1958-1989. The price and quantities of the following five inputs are provided or can be estimated from this file: capital, production labour, non-production labour, energy, and materials (or intermediate goods purchased from other firms). Conventional cost or production functions can be estimated based on these data. This file is an updated version of the Penn-SRI Database created at the U.S. Census Bureau in the late 1970's. An earlier version of this file was analysed in Siegel [1997].

MEASURES OF EXTERNAL FACTORS (elements of T_n)

TRADE:

Our measure of "openness" is the ratio of imports to output. The data for these variables were obtained from Feenstra [1996]. An alternative measure, the ratio of imports to exports, yielded very similar results.

HIGH TECH CAPITAL (COMPUTERS):

Our measures of investment in computers are based on data on the price and quantity of "high-tech" office equipment reported at the 2-digit SIC level in manufacturing by the Bureau of Economic Analysis. This is the same file examined by Berndt and Morrison (1995). According to the BEA, "high-tech" office equipment is an aggregate of four classes of assets: office, computing, and accounting machinery, communications equipment, scientific and engineering instruments, and photocopy and related equipment.

R&D INVESTMENT:

The major source of R&D data at the industrial level (primarily at the 2-digit SIC level) is the series entitled Research and Development in Industry, published by the National Science Foundation.

OUTSOURCING:

Our outsourcing data is derived from the Bureau of Labor Statistics's 2-digit SIC KLEMS file (see Gullickson and Harper (1987)) on purchased services by manufacturing industries. Nine types of purchased services are reported for the years 1949-1990: communications, finance and insurance, real estate and rental, personal and repair services, excluding autos, business services, auto repair and services, amusements, medical and educational services, government enterprises.

EDUCATION OF THE LABOUR FORCE:

Our measure of labour composition is based on the education levels of industrial workers, derived from the Current Population Survey (CPS). Data on the characteristics of workers in 21 (mainly 2-digit SIC) manufacturing industries were provided to us by Larry Rosenblum of the BLS's Productivity Division. The four education classifications for workers are: a) without a high school diploma; b) with exactly a high school diploma; c) with some college; d) with a college degree.

Table 1

Estimates of the Impact of External Technological and Trade Factors (T_n) on Cost (ε_{CTn})

for the U.S. Manufacturing Sector: 1959-1989, Including Interaction Effects

(T_1=Trade, T_2=High-Tech Capital (Computers), T_3=R&D Investment, T_4=Outsourcing)

Period	ε_{CT1}	ε_{CT2}	ε_{CT3}	ε_{CT4}	ε_{C12}	ε_{C13}	ε_{C14}	ε_{C23}	ε_{C34}	ε_{C24}
1959-1973	-.043*	-.074*	-.063*	-.014**	-.006**	-.008**	-.004**	-.004	-.002	-.001
	(.018)	(.035)	(.026)	(.007)	(.003)	(.004)	(.002)	(.003)	(.003)	(.001)
1973-1979	-.049*	-.079*	-.075*	-.015**	-.007**	-.008*	-.004	-.006**	-.001	-.003
	(.022)	(.038)	(.036)	(.007)	(.002)	(.004)	(.003)	(.003)	(.002)	(.002)
1979-1989	-.052*	-.074*	-.082*	-.015**	-.009**	-.010**	-.006**	-.005	-.001	-.002
	(.024)	(.033)	(.039)	(.008)	(.004)	(.005)	(.003)	(.003)	(.002)	(.001)

Note: asymptotic standard errors in parentheses
* significant at .01 level
** significant at .05 level

Table 2

Estimates of the Impact of External Technological and Trade Factors (T_n)
on the Demand for Four Classes of Workers (L_i)
for the U.S. Manufacturing Sector, 1959-1989, Including Interaction Effects
(T_1=Trade, T_2=High-Tech Capital (Computers), T_3=R&D Investment, T_4=Outsourcing,
L_1=No High School, L_2=High School, L_3=Some College, L_4=College)

Period	ε_{L1T1}	ε_{L1T2}	ε_{L1T3}	ε_{L1T4}	ε_{L112}	ε_{L113}	ε_{L114}	ε_{L123}	ε_{L134}	ε_{L124}
1959-1973	-.006**	-.010**	-.013**	-.006	-.004**	-.001	-.002	-.002	-.000	-.002
	(.003)	(.005)	(.006)	(.004)	(.002)	(.002)	(.002)	(.002)	(.002)	(.001)
1973-1979	-.008**	-.013**	-.014**	-.007**	-.003**	-.002	-.001	-.002	-.000	-.002
	(.004)	(.006)	(.007)	(.003)	(.001)	(.002)	(.001)	(.001)	(.002)	(.002)
1979-1989	-.011*	-.015*	-.017*	-.009**	-.002	-.002	-.001	-.003**	-.001	-.001
	(.005)	(.007)	(.006)	(.004)	(.002)	(.001)	(.001)	(.001)	(.002)	(.002)

Period	ε_{L2T1}	ε_{L2T2}	ε_{L2T3}	ε_{L2T4}	ε_{L212}	ε_{L213}	ε_{L214}	ε_{L223}	ε_{L234}	ε_{L224}
1959-1973	-.007**	-.021*	-.018*	-.005	-.005**	-.004**	-.006**	-.003	-.001	-.002
	(.003)	(.010)	(.008)	(.003)	(.002)	(.002)	(.003)	(.002)	(.002)	(.002)
1973-1979	-.009**	-.023*	-.019*	-.006**	-.004**	-.003**	-.004**	.000	-.001	.001
	(.004)	(.011)	(.009)	(.003)	(.002)	(.001)	(.002)	(.001)	(.002)	(.001)
1979-1989	-.012*	-.025*	-.022*	-.009**	-.003	-.002	-.005**	-.000	-.002	-.001
	(.005)	(.012)	(.010)	(.004)	(.002)	(.002)	(.002)	(.002)	(.001)	(.002)

Period	ε_{L3T1}	ε_{L3T2}	ε_{L3T3}	ε_{L3T4}	ε_{L312}	ε_{L313}	ε_{L314}	ε_{L323}	ε_{L334}	ε_{L324}
1959-1973	-.003	.010**	.015*	-.003	.004	.002	-.003	.001	.006**	-.002
	(.002)	(.005)	(.006)	(.002)	(.003)	(.002)	(.002)	(.001)	(.003)	(.001)
1973-1979	-.002	.012**	.010**	-.005	.005	-.000	.002	.001	.004	-.002
	(.002)	(.006)	(.005)	(.003)	(.003)	(.002)	(.001)	(.002)	(.003)	(.003)
1979-1989	-.001	.015*	.012**	-.007**	.005**	.001	-.003	.002	.002	-.001
	(.001)	(.007)	(.006)	(.003)	(.002)	(.002)	(.003)	(.002)	(.001)	(.002)

Period	ε_{L4T1}	ε_{L4T2}	ε_{L4T3}	ε_{L4T4}	ε_{L412}	ε_{L413}	ε_{L414}	ε_{L423}	ε_{L434}	ε_{L424}
1959-1973	.008**	.013**	.011**	-.004	.005**	-.001	.000	.002	.003	.001
	(.004)	(.006)	(.005)	(.003)	(.002)	(.001)	(.001)	(.001)	(.001)	(.001)
1973-1979	.005	.016*	.013**	-.003	.005**	.002	-.001	.003	.002	-.002
	(.002)	(.007)	(.006)	(.003)	(.002)	(.001)	(.001)	(.001)	(.001)	(.001)
1979-1989	.009**	.018*	.016*	-.002	.007**	.001	-.002	.002	.004**	.001
	(.004)	(.008)	(.007)	(.003)	(.002)	(.001)	(.001)	(.001)	(.001)	(.001)

Note: asymptotic standard errors in parentheses
* significant at .01 level
** significant at .05 level

Table 3

Estimates of Short-Run and Long-Run Impacts of External Technological and Trade Factors
On Cost and Labor Demand (ε_{CTn}, ε^{L}_{CTn}, ε_{LnTn}, ε^{L}_{LnTn}) for the U.S. Manufacturing Sector
(T_1=Trade, T_2=High-Tech Capital (Computers), T_3=R&D Investment, T_4=Outsourcing)
(L_1= No High School, L_2=High School, L_3=Some College, L_4=College Graduate)

Period	ε_{CT1}	ε^{L}_{CT1}	ε_{CT2}	ε^{L}_{CT2}	ε_{CT3}	ε^{L}_{CT3}	ε_{CT4}	ε^{L}_{CT4}
1959-1973	-.043*	-.048*	-.074*	-.079*	-.063*	-.066*	-.014**	-.017**
	(.018)	(.022)	(.035)	(.038)	(.026)	(.030)	(.007)	(.008)
1973-1979	-.049*	-.050*	-.079*	-.082*	-.075*	-.080*	-.015**	-.018**
	(.022)	(.021)	(.038)	(.039)	(.036)	(.039)	(.007)	(.009)
1979-1989	-.052*	-.055*	-.074*	-.087*	-.082*	-.086*	-.015**	-.022**
	(.024)	(.026)	(.033)	(.041)	(.039)	(.042)	(.008)	(.011)

Period	ε_{L1T1}	ε^{L}_{L1T1}	ε_{L1T2}	ε^{L}_{L1T2}	ε_{L1T3}	ε^{L}_{L1T3}	ε_{L1T4}	ε^{L}_{L1T4}
1959-1973	-.006**	-.008**	-.010*	-.012*	-.013*	-.016*	-.006	-.009**
	(.003)	(.004)	(.005)	(.004)	(.006)	(.001)	(.004)	(.004)
1973-1979	-.008**	-.010**	-.013*	-.016*	-.014*	-.017*	-.007**	-.010**
	(.004)	(.005)	(.006)	(.007)	(.007)	(.001)	(.003)	(.005)
1979-1989	-.011*	-.012**	-.015*	-.019*	-.017*	-.018*	-.009**	-.009**
	(.005)	(.006)	(.007)	(.009)	(.006)	(.008)	(.004)	(.004)

Period	ε_{L2T1}	ε^{L}_{L2T1}	ε_{L2T2}	ε^{L}_{L2T2}	ε_{L2T3}	ε^{L}_{L2T3}	ε_{L2T4}	ε^{L}_{L2T4}
1959-1973	-.007**	-.008**	-.021*	-.024*	-.018*	-.022*	-.005**	-.006**
	(.003)	(.004)	(.010)	(.011)	(.007)	(.009)	(.003)	(.003)
1973-1979	-.009**	-.014*	-.023*	-.026*	-.019*	-.025*	-.006**	-.011**
	(.004)	(.006)	(.011)	(.012)	(.009)	(.011)	(.003)	(.005)
1979-1989	-.012*	-.013*	-.025*	-.028*	-.022*	-.023*	-.009**	-.007**
	(.005)	(.006)	(.012)	(.013)	(.010)	(.010)	(.004)	(.003)

Period	ε_{L3T1}	ε^{L}_{L3T1}	ε_{L3T2}	ε^{L}_{L3T2}	ε_{L3T3}	ε^{L}_{L3T3}	ε_{L3T4}	ε^{L}_{L3T4}
1959-1973	-.003	-.005	.010*	.006**	.015*	.012**	-.003	-.006**
	(.002)	(.003)	(.004)	(.003)	(.006)	(.006)	(.002)	(.003)
1973-1979	-.002	-.004	.012*	.016*	.010**	.014*	-.005	-.007**
	(.002)	(.003)	(.006)	(.007)	(.005)	(.006)	(.003)	(.003)
1979-1989	-.001	-.003	.015*	.016*	.012*	.015*	-.007**	-.006
	(.001)	(.002)	(.007)	(.006)	(.006)	(.007)	(.003)	(.004)

Period	ε_{L4T1}	ε^{L}_{L4T1}	ε_{L4T2}	ε^{L}_{L4T2}	ε_{L4T3}	ε^{L}_{L4T3}	ε_{L4T4}	ε^{L}_{L4T4}
1959-1973	.008**	.005	.013**	.008**	.011**	.009**	-.004	-.007**
	(.004)	(.003)	(.006)	(.004)	(.005)	(.004)	(.003)	(.003)
1973-1979	.005	.006**	.016*	.018*	.013**	.016*	-.003	-.008**
	(.002)	(.003)	(.007)	(.008)	(.006)	(.007)	(.003)	(.004)
1979-1989	.009**	.005	.018*	.022*	.016*	.015*	-.002	-.007**
	(.004)	(.003)	(.008)	(.010)	(.007)	(.007)	(.003)	(.003)

Note: asymptotic standard errors in parentheses
* significant at .01 level
** significant at .05 level