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Eli Berman
John Bound
Stephen Machin

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ABSTRACT

Demand for less skilled workers decreased dramatically in the US and in other developed countries over the past two decades. We argue that pervasive skill-biased technological change rather than increased trade with the developing world is the principal culprit. The pervasiveness of this technological change is important for two reasons. First, it is an immediate and testable implication of technological change. Second, under standard assumptions, the more pervasive the skill-biased technological change the greater the increase in the embodied supply of less skilled workers and the greater the depressing effect on their relative wages through world goods prices. In contrast, in the Heckscher-Ohlin model with small open economies, the skill-bias of ***local*** technological changes does not affect wages. Thus, pervasiveness deals with a major criticism of skill-biased technological change as a cause. Testing the implications of pervasive, skill-biased technological change we find strong supporting evidence. First, ***across*** the OECD, most industries have ***increased*** the proportion of skilled workers employed ***despite*** rising or stable relative wages. Second, increases in demand for skills were concentrated in the ***same*** manufacturing industries in *different* developed countries.

Eli Berman
Department of Economics
Boston University
270 Bay State Road
Boston, MA 02215
and NBER
eli@bu.edu
http://econ.bu.edu/eli

John Bound
Department of Economics
University of Michigan
Ann Arbor, MI 48109
and NBER
jbound@umich.edu

Stephen Machin
Department of Economics
University College London
Gower Street
London WC1E 6BT
UNITED KINGDOM

I. Introduction'

Less skilled workers have suffered declines in relative wages, increased unemployment and sometimes both in the OECD economies over the 1980s. In the United States the real wages of young men with twelve or fewer years of education *fell* by 26 percent between 1979 and 1993, and have not recovered since.' Between 1979 and 1992 the average unemployment rate in European OECD countries increased from 5.4 percent to 9.9 percent[3] and has remained high, with most of the unemployment concentrated among unskilled workers, In the same period relative wages of less skilled workers declined slightly in several OECD countries and sharply in others. Over the last few years, several authors have documented the decline in the relative wages of less skilled workers in the US and the concurrent decline in their employment in manufacturing (e.g., Murphy and Welch, 1992, 1993; Bound and Johnson, 1992; Katz and Murphy. 1992; Blackbum, Bloom and Freeman, 1990), and a number have documented similar trends in wages, employment or unemployment in other OECD countries (e.g., Freeman, 1988; Freeman and Katz, 1994: Katz and Revenga, 1989; Katz, Loveman and Blanchflower, 1995; Davis, 1992; Machin, 1996a; Nickel1 and Bell, 1995). Over the past two decades despite the fact that rapid increases in the supply of skilled labor in the OECD have made the less skilled increasingly scarce: their labor market outcomes have clearly worsened.

The literature has proposed several reasons for this decline in the demand for unskilled labor, including both Stolper-Samuelson effects of increased exposure to trade from developing countries and skill biased (or unskilled labor saving) technological change (SBTC). While there is no consensus, labor economists generally believe that skill-biased technological change is the principal culprit. That belief is

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[1] We appreciate the helpful comments and suggestions of Jonathan Eaton, Christine Greenhalgh, Larry Katz, Kevin Lang, John Martyn, participants in the Bureau of Industry Economics conference at ANU, NBER Productivity, Labor Studies, International Trade and Growth sessions, an OECD conference in Paris, an IFS conference and in seminars at Amsterdam, Boston University, Florence, IUI (Stockholm), LIE, Manchester, Montreal, NYU. Oxford, Tel Aviv, Yale, Wisconsin and the New York Federal Reserve. The Sloan Foundation supported plant visits. We thank Thibaut Desjonqueres and Noah Greenhill for research assistance. We especially appreciate results provided by Ken Troske.

[2] Calculated for high school graduates with 5 years of labor market experience in Current Population Survey from Bound and Johnson (1995), table 1.

[3] Source: OECD (1992, 1993). For specific countries, the 1979-92 increases in unemployment were: 5.0 percent to 10.1 percent (U.K.); 3.2 percent to 7.7 percent (Germany); 7.6 percent to 10.7 percent (Italy); 5.9 percent to 10.2 percent (France). All are considerably larger than the American increase from 5.8 percent in 1979 to 7.4 percent in 1992.

based on a combination of three factors: a) employment shifts to skill-intensive sectors seem to be too small to be consistent with explanations based on product demand shifts, such as those induced by trade, or Hicks-neutral, sector biased technological change (Bound and Johnson, 1992; Katz and Murphy, 1992; Berman, Bound and Griliches, 1994 (BBG); Freeman and Katz, 1994); b) despite the increase in the relative cost of skilled labor, the majority of US industries have had within sector shifts in the composition of employment towards skilled labor (Bound and Johnson, 1992; Katz and Murphy, 1992; BBG), and c) there appear to be strong, within sector correlations between indicators of technological change and increased demand for skills (Bemdt, Morrison and Rosenblum, 1994; BBG; Autor, Katz and Krueger, 1997; Machin, 1996b; Machin, Ryan and Van Reenen, 1996).

In this paper we make the stronger claim that skill biased technological change was pervasive in the OECD over the past two decades, occurring simultaneously in most, if not all, developed countries. Pervasiveness is important for two reasons: First, at the current level of international communication and trade it is hard to imagine major productive technological changes occurring in one country without rapid adoption by the same industries in countries at the same technological level, Thus pervasive SBTC is an immediate implication of SBTC, which invites testing. If we didn't observe evidence of SBTC throughout the OECD, we would be forced to doubt if it occurred in any OECD country.

Second, the more pervasive the SBTC, the greater its potential to affect relative wages. To illustrate that point consider a Heckscher-Ohlin (H-O) model with small open economies and two factors of production. In that context skill-biased technological change cannot change the wage structure in an H-O model unless it is also sector-biased. On those grounds, Learner (1994, 1995, 1996) has objected to the notion that SBTC is the dominant factor explaining the decline in the demand for skilled labor. This critique is powerful, as the long run H-O model is widely considered to be the relevant model for analyzing the effect on wages of the increased exposure of developed economies to LDC manufacturing over the past few decades. (The long run is long enough for factors to detach themselves from industries, allowing wages to be set by perfectly elastic demand curves.[4]) However, as Krugman (1995) has pointed out, ***pervasive** skill-biased technological change* will affect relative wages, since an integrated world economy will respond to such technological change as a closed economy would. Under standard assumptions, including

[4] The H-O model has been criticized, as its property of perfectly elastic labor demand curves is inconsistent with evidence that labor supply affects wages (Freeman (1995)). One way to reconcile those two views is to recognize that the H-O model applies only in the long run, so that the short and long run effects of a local SBTC or of an increase in trade may differ. Since the trend increase in relative demand for skilled labor seems to have persisted for decades, long run models deserve consideration.

homothetic preferences, a sector-neutral skill-biased technological change would release less skilled workers from industries, depressing their relative wages, Pervasive skill-biased technological change in the developed world provides an explanation consistent with both increased wage premiums for skilled workers and within-industry substitution towards skilled workers. That conclusion generalizes to the large open economy H-O model as well.

Pervasive SBTC has two testable implications. 1) The within sector shifts away from unskilled labor observed in the US should occur throughout the developed world. 2) These shifts should have been concentrated in the same industries in different countries. Using data on the employment of production and nonproduction workers in manufacturing for 10 OECD countries, we find evidence consistent with both predictions. In all countries in our OECD sample we find large scale within-industry substitution away from unskilled labor despite rising or stable relative wages. Moreover, the cross country correlations of within-industry increases in employment of skilled workers are generally positive and often quite large.

The manufacturing industries which experience the greatest skill upgrading across our OECD sample are those we commonly associate with the spread of microprocessor technology. They are electrical machinery, machinery (including computers), and printing and publishing. Together, these three account for 40% of the within-industry increase in the relative demand for skills. Case study evidence reveals that all three of these industries underwent significant technological changes associated largely with the assimilation of microprocessors.[5] Casual empiricism suggests that the spread of microprocessors within these and other manufacturing industries was pervasive in the 1980s. This pattern, combined with the correlation of skill upgrading with measures of technological change cited above, provides further evidence that technological change is the driving force behind increased demand for skill.

The little evidence we have from the developing world is also consistent with the SBTC hypothesis. Several studies *have* found *increased* relative wages of skilled labor in LDCs undergoing trade liberalization, despite the Stolper-Samuelson prediction (Feliciano, 1995; Hanson and Harrison, 1995; Robbins, 1995). We examine a larger sample of developing countries and check for evidence that increased trade in the 1980s depressed the wages of skilled workers. We find, on average, constant relative wages, despite the fact that the proportion of skilled workers increased as fast in the rapidly growing manufacturing sectors of the LDCs as in the shrinking manufacturing sectors of developed countries.

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[5] U.S. Department of Labor, 1982a, 1982b, 1986.

The paper proceeds as follows. In Section II we embed skill-biased technological change in a H-O framework, examine possible explanations for the decrease in skill demand and derive their implications. In section III we test the implications of the model, presenting evidence on within-industry changes in the employment of skills in OECD countries. We also examine how well the nonproduction/production worker classification to education and occupation based measures of skill. Section IV presents further evidence of pervasive technological change, describing common technological changes across countries. In section V we discuss possible extensions to developing countries. Section VI concludes.

II. The Heckscher-Ohlin Framework

In this section we discuss a framework that allows both Stopler-Samuelson effects and skill-biased technological change to influence wages. Our purpose is to examine the roles of pervasiveness, factor bias and "smallness" in those mechanisms and to develop empirical implications that will allow us to distinguish between causes. We start with the two factor, small open economy version of Heckscher-Ohlin trade theory with local technological change and then move on to pervasive technological change and the model in which countries are large enough to affect goods prices.

Consider a version of the standard theory (Helpman and Krugman, 1985) based on the following assumptions:

1. There are two factors, skilled and unskilled labor, $l = S,U$.
2. N goods are produced by constant returns to scale, quasi-concave production functions with associated cost functions $c_i(w)$, where w is a vector of wages $[w_s, w_u]$ and $i = 1,2,......,N$.
3. Perfect competition.
4. All goods are produced in equilibrium.
5. There are $J \geq 2$ countries.
6. Factor endowments and technology allow factor price equalization.
7. Homothetic preferences.

Define the demand for factor l per unit of good i as $a_{li}(w)$. Under cost minimization, it can be expressed as the derivative of a unit cost function with respect to the wage of factor l

$$a_{li}(w) = \frac{\partial c_i(w)}{\partial w_l} \quad for \ i=1,2,..N; \quad l=S,U.$$

Now consider the "integrated equilibrium" for all countries. Using X^W_i to denote the world output level of good i and $V^W = [S^W, U^W]$ the world endowments of factors, the equilibrium conditions are:

1. $p_i = c_i(w)$ for all i,

2. $\sum_i a_{li}(w) X_i^W = V_l^W$ for all l,

3. $\alpha_i(P) = \dfrac{p_i X_i^W}{\sum p_i(w) X_i^W}$ for all i.

The conditions state that 1) goods are priced according to marginal cost as free entry of firms in any country and constant returns to scale dictate zero profits, 2) factor markets clear and 3) commodity markets clear.

The concept of an integrated equilibrium allows a convenient comparison of labor demand under trade and autarky. Consider the skill-abundant country with ($S/U > S^W/U^W$). In trade, the Heckscher-Ohlin-Vanek theorem states that it will export services of its abundant factor and import services of its scarce factor, thus the world price of the skill abundant good must exceed the price under autarky.

Implication for within-industry demandfor skills

The Stolper Samuelson Theorem states that an increase in the price of the exported good will increase the return to the abundant factor (w_S) and decrease the return to the scarce factor (w_U).[6] So an opening up to trade will increase w_S/w_U for a skill abundant country.

As a result, within each industry in the skill (unskill) abundant country, transition from autarky to trade will decrease (increase) the demand for skilled workers.

To see this, note that:

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[6] To see this fully in the N=2 case differentiate (1) to get dw= A^{-1} dp since dAw=0 by cost minimization. The result follows from A being positive semi-definite. For N>2, a positive definite 2x2 matrix exists by assumption 6, and its inverse is used.

$$\frac{S_i}{U_i} = \frac{a_{Si}X_i}{a_{Ui}X_i} = \frac{a_{Si}}{a_{Ui}}$$

$$\Rightarrow \quad \frac{\partial(S_i/U_i)}{\partial(w_S/w_U)} \leq 0$$

by cost minimization and the quasi-concavity of the underlying production function.

This is just an expression of the fact that for a single industry only substitution effects are at work. Note that within-industry substitution away from skilled workers will be compensated by a between-industry shift in employment toward skill intensive industries, which increase production for export.

Sector-Biased Technological Change

Consider the effect of a change in the technology of production so that a skill-intensive sector becomes more efficient in a single country. Learner (1994) reproduces the result that only the sector-bias of a technological change affects relative wages, That argument is most clearly demonstrated by a Lemer diagram (Figure I) which corresponds to the zero-profit conditions (equilibrium condition (1) above) for the two traded goods that allow factor price equalization. (Assumption 6 guarantees existence of two such goods.) In the diagram the curves C 1 and C2 are unit cost combinations of inputs in production of goods 1 and 2 respectively. Assuming that these goods are traded, their prices **are** taken as parameters under the small country assumption. The wage ratio w_u/w_s consistent with cost minimization at zero profit is the absolute value of the slope of the line AB tangent to unit cost curves C 1 and C2. Now consider a Hicks-neutral technological improvement in the production of good 1, the skill-intensive good, which shifts C 1 to lower levels of inputs at Cl'. This shift is Hicks-neutral since at the old wage ratio the ratio of inputs S/U is unchanged. In the diagram this is reflected by CD being parallel to AB. Because the technological improvement occurred in the skill-intensive sector, it implies an increase in output of good 1, and increased demand for skills. This is expressed as a decreased relative wage of unskilled labor or a shallower slope of the new line EF joining the points of tangency with C 1' and C2, the new equilibrium.

Note that, at the new equilibrium, *the ratio **of** skilled to unskilled labor is lower in each sector.* This is due to substitution away from skilled labor in each sector in response to an increase in the relative wage of skills, as above.

Skill-Biased Technological Change

A skill-biased technological change is an exogenous change in the production function that increases the unit demand ratio a_{Si} / a_{Ui} at the current wage level. A sector neutral, skill-biased technological change is illustrated in Figure II in the shift of unit cost curves C 1 and C2 to C 1' and C2'. This change is sector neutral in the sense that both Cl and C2 shift towards in to lower levels of inputs in a way reduces costs by the same proportion. The line CD, tangent to C 1' and C2' reflects the new zero profit condition, and is parallel to AB, reflecting the same relative wages. These shifts are skill-biased as the new equilibium ratios skilled to unskilled workers are higher than the old. (Rays from the origin are steeper.) While this sector neutral technological change may seem artificial it provides a useful point of comparison in the discussion below. Note that unlike sector biased technological change and Stolper-Samuelson effects, skill-biased technological change directly increases the proportion of skilled labor employed in each sector.

Learner Critique: Skill vs. Sector Bias

One feature of technological changes in this model with fixed goods prices is that only the sector bias of technological changes has any effect on relative wages (Learner, 1994). To see this, imagine sliding the isovalue curve C 1' along unit cost line so that the point of tangency moves to a different ratio of skilled to unskilled workers. Any of those locations represent the same level of costs for production of good 1, so that the sector bias of each of those technological changes is the same. Though the skill-biases of those locations differ, they all share the same solution for relative wages. Thus, in the small open economy model, a skill-biased technological improvement has no effect on relative wages except through the implied sectoral bias. This argument appears particularly damning for the widespread conclusion of the literature. Local skill-biased technological change, the champion explanation of increased wage inequality among most labor economists, cannot have any effect on wages in the two factor Heckscher-Ohlin model with small, open economies.

Now consider a *pervasive* skill-biased technological change occurring simultaneously in all economies in the production of some traded good. In the integrated world economy, the response to such a change would be like that of a closed economy. SBTC would cause a disproportionate expansion of production of the good intensive in unskilled labor (good 2) as each industry reduces its proportion of unskilled labor. Under homothetic preferences that would induce a decrease in the relative price of good 2 and in the relative wages of unskilled labor. That decrease in the relative price of the good intensive in unskilled labor is illustrated as a shift of the unit cost curve from C2' to C2" as more inputs are required to provide the same value of output, That shift implies a decrease in the relative wages of unskilled labor, reflected in the slope of line EF, which is shallower than that of CD. Thus pervasive, sector-neutral, skill-biased technological change is a possible explanation for the increased skill premium even in the small open economy model.' Note that unlike the two alternative explanations of the increased skill premium, Stolper-Samuelson effects and sector-biased technological change, it implies within-industry ***increases in the*** proportion of skilled workers.

How general is the result? Consider relaxing the small economy assumption in the integrated equilibrium. The more we allow local conditions to affect world prices, the greater the effect of a local SBTC in increasing the relative price of the skill-intensive good and the relative wages of skilled labor.' Analytically, pervasiveness and bigness work in the same direction, allowing SBTC to affect relative wages through their effect on world prices. By the same token, both pervasiveness and bigness reduce the importance of sector bias, as productivity gains which produce the sectoral increase in input demand are offset by reduced goods prices. Of course, barriers to free trade will also tend to work in the same direction? making local prices and wages more responsive to a local technological change and increasing the ability of a SBTC to increase the local skill premium. In any case, the effect of a pervasive SBTC *on* relative wages in the small open economy H-O model is robust to making the economy larger or more closed.

III. Testing the Implications of Alternative Explanations

Evidence-from the United States and the United Kingdom

The US and the UK experienced the greatest increase in the skill premium among developed countries in the 1980s.[9] The manufacturing sectors of both countries, in which most trade occurs, experienced large reductions in employment and a trend increase in the share of nonproduction workers in employment, as shown in Figure III. We treat nonproduction workers as skilled and production workers as unskilled, and justify that classification below.

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[7] Homothetic preferences are sufficient but not necessary for the increased skill premium. Krugman (1995) points out that a limit on the cross-elasticity of demand will do.

[8] For a clear graphical presentation of this argument see Baldwin (1994). The integrated equilibrium behaves like the closed economy analyzed in Jones (1965).

[9] The U.S. college/l-IS ratio for males increased by 14% in 1979-89. The U.K. nonmanual/manual wage ratio increased by 15% for men and 23% for women in 1979-91 (see Katz, Loveman and Blanchflower, 1995).

Let Sn, be the share of nonproduction workers in manufacturing employment in industry i (Sn, = S, / (S, + U,). The analysis in Section II predicts that an increase the relative wages of nonproduction workers imply a decrease in Sn, if the cause is a Stolper-Samuelson effect or sector biased technological trade (biased toward the skilled sector), whereas an increase in Sn, accompanied by an increase in the relative wage is evidence of pervasive skill-biased technological change. Consider the average change in Sn,, weighted by employment,

$$\sum_{i} \Delta Sn_i \overline{S_i}$$

where S, is the employment share of industry i. Table I reports that for American manufacturing the average annual increase in Sn, (i.e., the within-industry increase) is 0.387 percentage points between 1979 and 1987. For the UK the comparable figure is 0.301 between 1979 and 1990. In both countries relative wages of nonproduction workers increased: in the US the nonproduction/production worker wage ratio rose from 1.53 in 1979 to 1.57 in 1987 and to 1.64 in 1990; in the UK the ratio rose from 1.31 in 1979 to 1.50 in 1990. Substitution of production for nonproduction workers despite the increase in their relative wages is evidence of skill-biased technological change in both countries.[10]

To put these magnitudes into context, consider how much of the aggregate increase in the proportion of nonproduction workers is due to substitution within industries. The change in aggregate proportion of nonproduction workers can be decomposed into two components, one due to reallocation of employment *between* industries with different proportions of skilled workers and another due to changes in the proportion of skilled workers *within* industries:

$$\Delta Sn = \sum_{i} \Delta S_i \overline{Sn_i} + \sum_{i} \Delta Sn_i \overline{S_i}$$

where an overstrike indicates a simple average over time. Table I reports that these within-industry components are not only positive, but quite large, accounting for 70 percent of the aggregate increase in the US share of nonproduction workers and 82 percent of the British. In the presence of increased relative

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[10] Lawrence and Slaughter (1993) present the same argument for the U.S. These results are from Berman, Bound and Griliches (1993,1994) and Machin (1996b), who make similar arguments.

in international prices with more skill-intensive goods substituted for less skill-intensive, creating apparent wages for skilled labor, the only explanation we have from the model for that within-industry skill upgrading is skill biased technological change.[11][12]

A weakness in these measurements is that they require the strong assumption that within observed industries a homogeneous good is produced with identical production functions so that the response to a relative wage change within an industry is a pure substitution effect. Alternatively, each industry "within" term could contain a number of dissaggregated "between" (between goods and production processes) terms in it, allowing a composition effect that could reverse the substitution effect. For example, *increased* skill intensity for the exported high-skill product could occur if the industry is a combination of high and low skill subindustries, so that opening up to trade caused the high skill subindustry to expand it's share of production within the industry.[13][14] The second and fourth columns of Table I address this concern by reproducing "within-between" decompositions at the *plant* level carried out by Dunne, Haltiwanger and Troske (1996) and Machin (1996b), respectively. Here the potential for composition effects is limited by looking at changes in employment within plants. (A definitive decomposition of this type is impossible as changes in goods prices could increase demand for skilled labor through substitution across goods within plants while SBTC may also imply a sector bias, reducing the prices of skill-intensive goods and increasing demand for skilled labor through shifts of production between goods across plants.) Within-plant substitution toward nonproduction labor accounts for 71% of the aggregate substitution toward nonproduction workers in the American LRD[15] and for 83% in the British WIRS. Following the implication

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[11] Capital skill complementarity is a possible explanation in a more general model of production. In previous work BBG found that it accounts for very little skill upgrading in U.S. manufacturing.

[12] Clearly SBTC could account for between industry skill upgrading as well.

[13] Wood (1991) and Bernard and Jensen (1993) raise this point and the symmetric argument for importing industries.

[14] A similar objection is that within industries (or plants) the product mix may respond to changes in international prices with more skill-intensive goods substituted for less skill-intensive, creating apparent within industry skill upgrading. BBG (1994) find only very small correlations between within industry upgrading and increased imports, indicating very little skill upgrading due to shifts in final product mix.

[15] Bernard and Jensen (forthcoming) perform a similar decomposition on a balanced panel of plants in the LRD rather than the Census sample and find a smaller within plant proportion of 54% for the 1979-87 period. Dunne et al (1996) attribute the difference in results to the use of sampling weights to impute values for unobserved plants in the LRD and to the choice of period.

of H-O theory we interpret this substitution toward skilled labor within plants despite an increase in relative wages as evidence for SBTC.

More concrete evidence that this within industry (and within plant) skill upgrading reflects technological change is available from three sources. Within industry increases in the proportion of nonproduction workers are correlated with indicators of technological changes such as investments in computers, investment in R&D and significant innovations (Bemdt, Morrison and Rosenblum, 1994; BBG; Autor, Katz and Krueger, 1997; Machin, 1996b; Machin, Ryan and Van Reenen, 1996).[16] Case studies such as those conducted by the BLS Office of Productivity and Technology can give use some sense of the nature of the actual innovations involved (Mark, 1987). These often mention innovations that lowered or are expected to lower production labor requirements. Along similar lines, as part of the NBER - Sloan Plant Visit program, we saw evidence that microprocessor technologies played a key role in allowing production processes to be programed, monitored and centrally controlled, replacing tasks formerly performed for the most part by production workers.

Examples from two plant visits can help illustrate skill biased technological change. We visited a metal fabrication plant where metal was stretched and thinned to precise specifications by a large number of machines working in parallel. The old technology involved one operator per machine who monitored by eye, stopping and adjusting the process when necessary. The new system allowed three machines to be monitored and controlled by a single operator at a console, and run three times as fast, resulting in a ninefold increase in labor productivity. In a modernized steel mill we saw a steel rolling line controlled by tens of operators and technicians at consoles in a cavernous building that formerly housed thousands of production workers. The new line ran faster and produced more output than the old. In visits to several manufacturing plants in these and *other* industries we saw evidence that microprocessor technologies played a key role in allowing processes to be programmed, monitored and centrally controlled, replacing tasks formerly performed for the most part by production workers.

Outsourcing

A potential problem with the evidence cited above on within-industry substitution toward skilled labor is that firms may "outsource" low-skill parts of the production process abroad, replacing in house

[16] Plant level studies using finer measures of technology adoption, such as use of computer aided manufacturing, yield mixed results. Doms, Dunne and Troske (1997) find that technology adoption is not correlated with changes in the proportion of nonproduction workers, though computer investment is. Siegel (1995) finds that technology adoption is correlated with increased proportions of high skill occupations in employment.

production with imported materials. Imagine a production process made up of high-skill and low-skill subprocesses. The H-O effect would be to increase imports of the low-skill and exports of the high skill, increasing the ratio of skilled to unskilled labor in the aggregated production process. This apparent contradiction of Stolper-Samuelson is empty, since unskilled labor is replaced with imported materials.

While it is hard to measure such outsourcing, let alone its impact on US employment, we have done some simple calculations which suggest that outsourcing cannot be responsible for the bulk of the changes we observe. The 1987 Census of Manufacturing included a direct question regarding the purchase by establishments of foreign materials. These data show that in 1987 the total cost of material purchased by establishments from foreign sources was 104 billion dollars, or 8 percent of all materials purchased and 30 percent of all imported manufactured goods. Foreign materials purchased include substitutes for domestically produced materials as well as substitutes for products that would have been produced within the purchasing establishment's own industry. While we know of no reliable way to distinguish uses for the material purchased from foreign sources, we note that census data show that only a small fraction (<10 percent) of purchased materials come from an establishment's own industry.”[17] This fact suggests that only a small fraction of foreign materials purchased represent outsourcmg (as they do not replace domestic production in the same industry).

In our calculation we assume that imported materials displace production but not non-production labor. In particular we assume that imported materials embody the same amount of production labor as do domestically produced goods in the same industry, but no non-production labor. Thus, for each industry, we calculate that the number of production workers displaced by outsourcing as of 1987 as (imported materials/total shipments) × production employment. These calculations suggest that the employment of production workers would have been 2.8 percent higher in 1987 had there been no outsourcing. This translates into a 0.76 percentage point increase in production workers' share in total employment, Within industry, production workers' share had dropped 4.22 percentage points between 1973 and 1987. Thus, this calculation would suggest that outsourcing could directly account for 16 percent of the decline in the production worker share of employment that occurred over this time period.

While we expect that only a fraction of the materials that an establishment purchases from foreign sources will represent outsourcing, the Census category misses one dimension of outsourcing. The census

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[17] Data drawn from the materials files of the 1987 Census of manufacturing shows that 2 percent of materials purchased originate in the same four-digit industry as purchased the material. 7 percent originate in the same three-digit industry.

instructions state that "items partially fabricated abroad which reenter the country" should not be included as "foreign materials." Such items would normally enter the country under items 806 and 807, schedule 8 of the Tariff Schedule of the United States. In 1987 the value of such items totaled a not insignificant 68.6 billion dollars. However, the automobile industry that accounted for only 3 percent of total skill upgrading accounted for roughly two-thirds of such imports. Eliminating both the auto industry and domestic content of such items reduces the 68.6 billion to 14.0 billion or roughly 0.5 percent of the value of manufacturing shipments that year---too small a quantity to matter very much (U.S. International Trade Commission, 1988).

Outsourcing may be important in some industries. For example, as of 1987,806 and 807 imports represented 57 percent of imports in the auto industry and 44 percent of imports of semiconductors. A calculation similar to the one done above suggests that these imports are sufficient to account for more than 100 percent of the shift away from production workers that occurred in the auto industry and one-third of the shift that occurred in semiconductors." However, the point is that foreign outsourcing is concentrated enough in specific industries that it is hard to imagine that it can account for anything more than a small fraction of the total, within-industry shift away from production labor.

Our estimates are crude, but they err on the side of overestimating the effects of outsourcing on demand for production workers: Not all foreign materials represent outsourcing. For those that do, some nonproduction labor is certainly. embodied in the domestic production replaced by outsourcing. Still, these calculations suggest that while outsourcing might be important for some industries it cannot account for the bulk of the skill upgrading that occurred within manufacturing over the last two decades, [19]

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[18] Figures on the overseas production of semiconductors (U.S. International Trade Commission, 1982) are consistent with these calculations.

[19] Feenstra and Hanson (1996b) use a somewhat different method to estimate the magnitude of foreign "outsourcing". Using census of manufactures data, they multiply materials purchased by the proportion of imports in their source industry. Their estimate is that 11.5% of materials could represent outsourcing, rather than the 8% reported by BBG. Feenstra and Hanson emphasize that contract work could explain the difference between these estimates, since it is included in imports, but not in imported materials. Nevertheless, both figures are likely to be substantial overestimates, as most imported materials probably do not replace in house production. Using regression techniques, Feenstra and Hanson estimate that outsourcing can account for as much as 5 1% of the within industry shift away from production labor. However, given the calculation reported in the text, this estimate seems improbably large. What is more, in unpublished work Baru (1995) uses regression techniques and measures similar to those used by Feenestra and Hanson, but when calculating her measure of oursourcing, Baru uses only purchases within the same three digit industry. She finds no association between her more narrowly defined measure and skill

A correspondence between measures of skill

All of the work we discuss in this paper is based on manufacturing data in which the only available measure of skill is the proportion of nonproduction workers in employment. This measure is viewed with skepticism by Learner (1994), who points out that skilled jobs such as line-supervisor, product development and record keeping are classified as production worker jobs while jobs such as sales delivery, clerical, cafeteria and construction are classified as nonproduction. BBG defend the production/nonproduction classification, showing that the proportion of nonproduction workers follows the same trend increase as the proportion of skilled workers in U.S. manufacturing.[20]

A powerful new data set offers a way of examining how the production / nonproduction classification compares to educational and occupational measures of skill. The Worker Establishment Characteristics Database (Troske, 1994), matches individuals from the Census of Population in 1990 to plants in the Census of Manufactures in 1989. Combining the educational and occupational information we find a close correspondence between the different classifications of skill: 75% of nonproduction workers are in white collar occupations, while 8 1% of production workers are in blue collar occupations. Details are given in the appendix and in Table A 1.

While there seems to be lots of scope for the nonproduction/production categories not to correspond with other measures of skill, these are the exceptions rather than the rule. For the educational and occupational categories in the Appendix Table Al, they correspond quite well. This one cross section does not conclusively demonstrate a correspondence between *changes* in the proportion of nonproduction workers and changes in other measures of skills, but we find it convincing enough to adopt the nonproduction / production classification as our measure of skill.

Evidence from Manufacturing Sectors of the Developed World

If the dominant cause of increased relative wages of skilled workers *in the* US and *UK* is *pervasive* SBTC, then it must be occurring in other developed countries. The United Nations General Industrial Statistics Database (United Nations, 1992)contains manufacturing employment data for a large number of countries categorized into 28 consistently defined industries. We are interested in the most productive

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upgrading

[20] Sachs and Shatz (1994) also discuss the suitability of a production/nonproduction classification as a measure of skill in their appendix.

economies under the assumption that they are most likely to use the same production technologies as the United States, From the set of countries without data problems we define our developed sample as the top twelve countries, ranked by GNP/capita in 1985. They range from the United States ($16,910) to Belgium ($8290). Appendix Table A2 gives the rankings. The table also reports employment shares of nonproduction workers in manufacturing in the 1970s and 1980s. The nonproduction employment share has generally increased in both the 1970s and 1980s in our developed sample. In eight of the twelve countries total manufacturing employment fell through the 1980s.

Among the developed countries we study, the employment share of skilled labor increased in all twelve in the 1970s and 1980s. Relative wages of skilled labor either increased or remained constant in most.” A common description of European labor markets in the 1980s is that they share the same phenomenon of decreased demand for less-skilled workers but differ in how it is expressed. In the US and UK where wages are flexible, the relative wages of the less-skilled declined sharply, while in other countries collective bargaining and minimum wages moderated the decline in relative wages but caused high levels of unemployment.*’

Table II reports the increased proportion of nonproduction workers in manufacturing employment and the percentage of that increase due to within-industry components in the 1970s and 1980s. Across countries with very diverse labor market institutions, two common features stand out:

1) an increased proportion of nonproduction labor in manufacturing,
2) substitution toward nonproduction workers within industries in the 1980s, despite increased or flat relative wages of nonproduction workers.

Not only was within-industry substitution positive, it was quite large, accounting for most of the increase in the aggregate in all countries (except Belgium where it accounts for 49%). Large within-industry skill upgrading despite rising or constant relative wages is evidence of skill biased technological change in each of these countries. Taken together, they provide evidence for pervasive skill-biased technological change in the developed world.

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[21] The US, UK, Austria and Denmark experienced large increases in the skill premium. Australia, Japan and Sweden had modest increases. Germany and Italy had no change. Finland had a modest decrease and Belgium had a large decrease. We lack information about Norway and Luxemburg. (Freeman and Katz (1994) supplemented by calculations for manufacturing from UN data for countries not covered in the former.)

[22] Freeman and Katz (1995) and Krugman (1995) offer this interpretation of inequality in OECD labor markets.

A limitation of this data is this 28 industry classification much more aggregated than those reported in Table I, allowing more room for composition effects to masquerade as within plant effects. But, note that the 28 industry "within" figure for the US in Table II is only 3% higher (as a proportion of the aggregate change) than the comparable 450 industry figure in Table I, so a 28 industry decomposition may provide a good approximation of the substitution and composition effects at the finer levels of disaggregation that we report in Table I.

In many of these countries within-industry skill upgrading increased more in the 1970s than in the 1980s. However, this should probably not be interpreted as evidence of an overall slow down in the rate of SBTC. In most of these OECD countries the relative wages of nonproduction workers decreased during the 1970s, but increased or remained stable during the 1980s[23]. These changes in relative wages would tend to induce within industry skill upgrading during the 1970s and downgrading during the 1980s through substitution effects. Without netting out these substitution effects, something that would be hard to do, it is impossible to tell whether the rate of SBTC accelerated , remained constant or decelerated during the 1980s. (Bound and Johnson, 1992; Katz and Murphy, 1992). Similarly, we are reluctant to interpret differences across countries in terms of the rate of within industry skill upgrading as evidence of cross country patterns in the rate of technological change. Bather, these patterns could plausibly reflect cross country differences in other factors that effect wage setting. Some of the cross-country variation in changes in the relative wages of nonproduction workers seems to be due to cross-country variation in the supply of college educated workers. The overall pattern is consistent with a trend increase in both supply and demand of skills, with either accelerated demand or decelerated supply in the 1980s increasing the skill premium, while local changes in supply affects relative wages as well.

In summary, in the ten developed countries for which we have manufacturing data in the 1970-90 period, we find widespread within-industry substitution towards skilled labor despite either constant or increased relative wages in the 1980s. Applying the predictions of the analysis in the last section, this pattern indicates *skill-biased technological change in all of these countries.*

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[23] These effects, in turn, are likely to be a symptom of decelerating skill supply. While all these countries show a trend increase in the proportion of college educated in the labor force in the 1970s, that proportion decelerated almost uniformly in the 1980s (OECD, 1995; Barro and Lee, 1997). In the short run or in an integrated equilibrium, supply can affect relative wages even if the small open economy assumptions of section II apply in a longer run.

IV. Cross-Country Correlations: A Further Test of Pervasive Skill-Biased Technological Change

In this section we test implications of the *pervasiveness* of skill-biased technological change. In section II we argued that the more pervasive the SBTC, the greater its potential to affect relative wages. Casual empiricism suggest that microprocessors, the most likely source of this technological change, have indeed become ubiquitous throughout the OECD. The empirical literature has tied indicators of technological change with substitution towards skilled workers such as investment in R&D, significant innovations, increased investment in computers and in other "high tech" capital.[24] In the previous section we showed evidence for SBTC in our sample of OECD countries, Still, if SBTC is pervasive, there is another testable implication that we can check. We should find the same industries increasing their proportion of skilled workers in different countries.

Cross Country Correlations

Pervasive skill-biased technological change implies that within-industry changes in the use of skills be positively correlated across countries producing that good. So we test for pervasive SBTC by examining cross-country correlations of changes in the use of skills (ΔSn).

Table III presents a correlation matrix of $corr(\Delta Sn_{ci} S_{ci}, \Delta Sn_{c'i} S_{c'i})$, the cross-country within-industry changes in the share of nonproduction workers for nine developed countries." Stars denote a significant correlation at the 5 percent level. Note that the correlations are nearly all positive (34 of 36) and some are quite high. Indeed, 13 of the 36 are significant at the 5 percent level. The shift toward increased use of nonproduction workers has for the most part occurred within the same industries in different countries .[26]

The cross-country correlations suggest that technological change in several of the countries is quite similar. The strongest positive correlation is between the UK and the US, but a group of countries (especially Denmark, Finland, Sweden, the UK and the US) have very similar within-industry changes in the proportion of nonproduction employment. Consider the US on the one hand and Sweden, Denmark and

[24] Bemdt, Morrison and Rosenblum (1994), BBG, Machin (1996b).

[25] Luxembourg has been dropped as it has only 6 observed industries in this period. Norway and Germany was dropped for lack of employment share figures in 1980-90.

[26] Other authors have found similarities between manufacturing sectors in different countries. Both Katz and Summers (1989) and Krueger and Summers (1987) have found that the wages of workers in the same manufacturing industry have high positive correlations across countries.

Finland on the other. These are economies with very different labor market institutions and very different trade and macroeconomic experiences in the 1980s. The similarity in the pattern of decreased use of production workers despite their different experiences is compelling evidence for common technological changes as an underlying cause of decreased demand for unskilled labor.

Industries with Large Skill-Biased Technological Change

The industries that drive the correlations in Table III indicate what the nature of these technological changes may be. Figure IV displays the scatterplot of US within-industry terms against those of the UK. The US-UK correlation is mainly due to the large common increases in the share of nonproduction employment in four industries: Machinery (& computers), Electrical Machinery, Printing and Publishing and Transportation.

A more systematic way of looking for industries with large effects is to estimate industry effects in a country-industry panel. In a regression of "within" industry terms on country and industry indicators,

$$wit_{ci} = \Delta Sn_{ci}\overline{S_{ci}} = \sum_{i=1}^{I} \alpha_i + \sum_{c=1}^{C} \beta_c + \varepsilon_{ci}$$

the *a,* are the average industry terms once country means have been removed. A well estimated industry effect will reflect a within term common to many countries, while a large industry effect is evidence of increased use of skills in at least one country-industry.

Table IV reports the three largest of the statistically significant estimated industry effects. Three industries: Electrical Machinery, Machinery (& computers) and Printing & Publishing, together account for 40 percent of the average within-component across countries. A full set of estimated industry effects is reported in Appendix Table A3. Case studies indicate that these industries introduced significant skill-biased technologies during this period, especially in the automation of control and monitoring of production lines." For example, a principal source of SBTC in the printing and publishing industry was automated rather than manual sorting and folding of newspapers.

[27] U.S. Department of Labor, (1982a, 1982b).

V. Global Skill-Biased Technological Change?

What about the developing world? According to the H-O approach, in a country that is abundant in unskilled labor the opening up to trade that occurred in 1980s should have a negative Stolper-Samuelson effect on the relative wages of skilled workers. Thus H-O and SBTC hypotheses have opposite predictions for relative wages in LDCs. The literature reports that relative wages of skilled labor have *risen in* some, though not all, LDCs undergoing trade liberalizations in the 1980s (e.g., Feliciano, 1995; Hanson and Harrison, 1995; Robbins, 1996; Feenstra and Hanson, 1996a). Appendix Figure A 1 reproduces that result using the UN data, showing that a number of developing countries experienced an increase in the relative wages of nonproduction workers in manufacturing between 1980 and 1990.

Stable and rising relative wages are particularly interesting, considering that almost all of these countries experienced considerable increases in the proportion of skilled labor in manufacturing over the 1980s, as illustrated in Appendix Figure A2.[28] For the developing world, that increase in the proportion of skilled labor was generally accompanied by rapid growth in manufacturing employment (see Appendix Table A2 and Wood, 1994). While H-O logic implies that increased trade should reduce relative demand for skilled workers in LDCs, their manufacturing sectors are expanding rapidly and upgrading skills at the same time. Besides the effects of trade, some other effect must have more than compensated to keep wages of nonproduction workers stable especially as their proportion increased quickly in the 1980s. Skill-biased technological change is one possible explanation. Other causes could be increased investment and technology transfer combined with capital-skill complementarity, or decreased protection of industries intensive in unskilled workers. Nevertheless, these findings raise the intriguing possibility that SBTC is at work in the developing world as well as the developed.

VI. Concluding Remarks

In this paper we have presented evidence that the kind of skill biased technological change which occurred in the US has been pervasive across the OECD. Our data show that : a) substitution towards skilled labor within industries occurred in all ten developed countries that we studied in the 1970-90 period, despite constant or increasing relative wages of skilled labor, and b) the same manufacturing industries that substituted towards skilled labor in the US did so in other developed countries as well. The industries with common large within-industry contributions to skill upgrading are machinery (& computers), electrical

[28] Widespread skill upgrading in the developing world is also reported in a literature survey by Davidson (1995).

machinery and printing & publishing. Together, these three account for 40% of the within-industry increase in the relative demand for skills. Case studies reveal that all three of these industries underwent significant technological changes associated largely with the assimilation of microprocessors.

Based on this evidence alone, it would be hard to distinguish the effects of SBTC from those of capital-skill complementarity. Previous work (BBG) has found that capital accumulation in US manufacturing was not large enough to generate the observed increase in relative wages using cross-sectional estimates of the elasticity of substitution. Similarly, it would be hard to distinguish the effects of SBTC from those of a general increase in the quality of skilled labor, due to improved sorting or improved human capital production. We feel that pervasive improvements in the quality of skilled labor are unlikely unless they are caused by some pervasive technological effect.

The debate in the literature over the effects of SBTC on relative wages has often turned on the relevance of the small, open economy assumptions (Freeman (1995), Leamer (1996)). Pervasiveness allows SBTC to reduce the relative wages of the unskilled even in a model that assumes small, open economies because its occurrence in a large number of countries allows analysis of the integrated equilibrium as if the OECD were a closed economy. In the context of that model, to calculate the size of the effect of different factors, we must gauge their relative effects on world goods prices. The relative price of skill-intensive to low-skill-intensive goods is in turn set by the factor content embodied in increased supplies of goods to the OECD. Using the American experience as a guide we see that the factor content of SBTC in manufacturing alone implies a decrease in the proportion of less skilled (production) workers about eight times that attributable to increased trade. Referring back to Table I, in the 1979-87 period, during which demand for less-skilled workers dropped sharply in the U.S., the factor content of SBTC accounts for at least 70% of the displacement of unskilled workers (i.e. the increase in the proportion of skilled workers) in U.S. manufacturing. The factor content of trade accounts for about 9% (BBG, Table IV) in the U.S.[29] For the OECD as a whole, 70% would be a typical figure for SBTC, but 9% would be generous for the effects of trade as the U. S experienced a much greater increase in trade with the developing world than OECD as a whole. Assuming that demand elasticities are approximately the same for imports and domestic production, that calculation implies that the effects of SBTC on relative wages are an order of magnitude larger than those of increased trade with the developing world.

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[29] For a justification of the use of factor content calculations in approximating the effects of trade flows on relative wages, see Krugman (1995) or Deardorff and Staiger (1988).

Even if pervasive SBTC is a principal explanation, there is no reason to believe that it is the sole explanation for increased relative demand for skills. Stolper-Samuelson effects and institutional changes such as decreased unionization and decreased minimum wages all occurred during this period and' undoubtedly contributed to increased relative demand for skills, though the evidence weighs against any of these causes as a principal explanation. Deviations of the supply of skill from a long run trend increase also play a role in deter-mining relative wages, European OECD countries do show considerable variation in the rate of growth of skill supply which appears to be negatively correlated with changes in their skill premia in the 1980s, suggesting that the H-O short run can last for long enough for supply effects to be observed. In an integrated equilibrium long term fluctuations in supply of skilled labor in the entire OECD will affect relative wages. That is an interesting topic for future research.

Though the evidence we present is only from manufacturing, where measurement is easiest, the effects of SBTC on wages may be just as important in the service sectors. In retail and financial services, for example, microprocessor based information processing technologies have dramatically changed accounting and secretarial work (Levy and Murnane, 1996). At a more aggregate level, Bound and Johnson (1992): Murphy and Welch (1992) and Katz and Murphy (1992) all present evidence of within-industry skill upgrading in other sectors. despite increased relative wages of skilled workers. This within industry skill upgrading outside of manufacturing also occurred in the same industries in the US and the UK. The correlation of within 'industry terms between the US and UK across the 15 industries outside of manufacturing is 0.93.[30] That high correlation is largely due to very rapid skill upgrading in financial services in the two countries. Skill-biased technological change outside of manufacturing may have also been pervasive and is an additional likely cause of decreased demand for less skilled workers.

Pervasive skill-biased technological change suggests several avenues for interesting research. The source of SBTC, its rate of flow across borders, the identification of the technologies involved and especially the likely implications for labor demand in the receiving country are all interesting and relevant. This is especially true for developing countries in which technological changes could exacerbate current high levels of income inequality.

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[30] The measure of skill is postsecondary education in this calculation. Authors calculation from the U.S. Current Population Survey and the U.K. Labour Force Survey, 198 l-9 1.

Appendix: A Correspondence Between Measures of Skill

The Worker Establishment Characteristics Database, constructed at the Center for Economic Studies (Troske, 1994), matches individuals from the Census of Population in 1990 to plants in the Census of Manufactures in 1989. For 2490 large manufacturing plants we have information from the Census of Population about the demographics of a sample of employees. Using the educational and occupational information we construct estimates of the number of employees in each education or occupation category in a plant. A regression of these estimates on the number of production and nonproduction workers in a plant allows estimation of the distribution of nonproduction (production) workers across educational and occupational categories.

Let the probability that a worker is in educational category j conditional on being a nonproduction (production) worker be β_{jn} (β_{jp}). The expected number of type j workers in a plant is $E_j = \beta_{jn}E_n + \beta_{jp}E_p$, where E_n and E_p are the number of production and nonproduction workers, respectively. We have X_j, a noisy measure of E_j (the true 1989 employment figure). A regression of X_j on E_n and E_p estimates β_{jn} and β_{jp}.

Table Al reports estimates for education and occupation groups.[31] The restriction that the sum over categories j of β_{jn}(β_{jp})s one has been imposed. Looking at the educational distribution, the median nonproduction worker has some college, with 66% having some college or more education. The median production worker has a high school education, with 6 1% having high school or less. Occupational categories show an even closer correspondence to the production / nonproduction classification. 75% of nonproduction workers are in white collar occupations (48% are managers and professionals, 25% are technicians, in sales or in administrative support and 2% are in services). 8 1% of production workers are in blue collar occupations.[32]

A possible explanation for this close correspondence is that Census of Manufactures respondents ignore the definitions and classify hourly workers as production and salaried workers as nonproduction, which corresponds more tightly with the other measures of skill than do the definitions. If that's the case, the correspondence may hold between *changes* in the proportion of nonproduction workers and changes in other measures of skills as well.[33]

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[31] We thank Ken Troske for performing this analysis.

[32] The intercept terms in this regression should be zero. Their significant difference from zero may be due to a correlation between the proportions (p's) and plant size. Note that the intercept is an out of sample prediction for large plants so light effects of size on β's may cause large shifts in the intercept.

[33] Unfortunately, we could not check the plant level correspondence of measures of skill in other countries. A similar exercise at the 2 digit industry level using manufacturing and labor force surveys indicates that the correlation of nonproduction/production categories with educational categories is similar in the UK to that in the US (Machin, Ryan and Van Reenen, 1996).

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CTable I: h a n g e s nd the US in the 1980s

	United States		United Kingdom	
Time Period	1979-87	1977-87	1979-90	1984-90
Jumber of Industries/ Plants	450	360,000	100	402
ˍevel of aggregation	4-digit SIC	plants	3-digit SIC	plants
Data Source	Annual Survey of Manu- factures	Census of Manu- factures	Census of Produc- tion	Workplace Industrial Relations Survev
Annual Change in Nonproduction Employment Share in percentage points)	0.552	0.483	0.367	0.41
Vithin-industry/plant :omponent (percent)	.387 (70)	.341[1] (71)	.301 (82)	0.34 (83)
etween-industry/plant :omponent (percent)	.165 (30)	.077 (16)	.066 (18)	0.07 (17)
Annual Change in Jonproduction Wage Bill Share	0.774		0.668	
Vithin-industry/plant :omponent (percent)	.468 (60)	-	.554 (83)	-
Between-industry/plant component (percent)	.306 (40)	-	.114 (17)	-

Sources: UK - Machin (1996b), Tables 7.2, 7.3; US industries - Berman, Bound and Griliches (1994), Table IV, US plants - Dunne, Haltiwanger and Troske (1996) Table 1.

[1] The Dunne et al (1996) decomposition also includes a small negative cross-product term and a positive net entry term for the effect of entering and exiting plants.

Table II: Proportion of Increased Use of Skills "Within" Industries

Country	Change in % non production 1970-80 (annualized)	% within 1970-80	Cbange in % non production 1980-90 (annualized)	% within 1980-90	Note
u s	0.20	81	0.30	73	
Norway	0.34	82			1970,80,n/a
Luxembourg	0.46	112	0.30	143	
Sweden	0.26	70	0.12	59	
Australia	0.40	87	0.36	99	1970.80.87
Japan			0.06	121	n/a*,81,90
Denmark	0.36	83	0.41	87	1970,80,89
Finland	0.42	83	0.64	79	
W. Germany	0.48	89			1970,79,n/a
Austria	0.46	89	0.19	73	
UK	0.41	91	0.29	94	
Belgium	0.46	59	0.32	49	1970 80,85

Notes: 1. The proportion within is the sum over 28 industries of (dn,, * S_i)/dPn_t in period t where S, is $[(Emp_{it}/Emp_t)+(Emp_{it-1}/Emp_{t-1})]/2$, the share of manufacturing employment in industry i, averaged over time.

2. Source: United Nations General Industrial Statistics Database.

* The sampling frame changed for Japanese data between 1970 and 198 1.

Table III: Cross-Country Correlations of Within-Industry Changes in Proportion Nonproduction: 1980-90

	US	Sweden	Australia	Japan	Denmark	Finland	Austria	UK
Sweden	.43* (.02)							
Australia	.28 (.14)	.19 (.34)						
Japan	.32 (.11)	.02 (.94)	-.22 (.26)					
Denmark	.73* (.OO)	.36 (.06)	.37 (.05)	.33 (.09)				
Finland	.59* (.00)	.39* (.04)	.51* (.01)	.14 (.47)	.80* (.00)			
Austria	.22 (.26)	-.17 (.37)	.52* (.01)	.12 (.54)	.51* (.OO)	.46* (.01)		
UK	.76* (.00)	.18 (.36)	.51* (.01)	.19 (.32)	.76* (.OO)	.64* (.OO)	.61 (.OO)	
Belgium	.18 (.44)	.oo (.99)	.01 (.97)	.22 (.37)	.11 (.63)	.09 (.71)	.37 (.10)	.15 (.53)

Notes.

1. These are cross-country correlation coefficients of within-industry changes in nonproduction employment shares,

$$wit_{ci} = \Delta Pn_{ci}\overline{S_{ci}}$$

   where i is an industry index and c is a country index.
2. The number in brackets is the significance level of a test that the correlation is zero. Standard errors in parentheses. A * denotes a significant correlation at the 5 percent level.
3. The sample was restricted to countries with GNP/capita of over $8000 US in 1985 (the top 12 in Table A2) and over twenty consistently defined industries observed in 1980-l 990.
4. The 28 industries in this classification are listed fully in Appendix table A3.
5. All correlation coefficients are calculated using a full set of 28 industries, except those involving Japan (27 observations), Belgium (20 observations) and Japan & Belgium (19 observations).
6. Source: United Nations General Industrial Statistics Database.

Table IV: Selected Industrv Effects in Within-Industrv Terms: 1980-90

In a regression of "within" industry terms on country and industry indicators,

$$wit_{ci} = \Delta Pn_{ci}\overline{S_{ci}} = \sum_{i=1}^{I} a, + \sum_{c=1}^{C} \beta_c + \varepsilon_{ci}$$

the following industry effects are statistically significant and represent more than 10% of the within component of the increase in the proportion of nonproduction workers in employment. A full set of industry effects are reported in Table A3.

Industry	Industry Effect /within Component	Avg share of industry in employment
Printing & publishing	,100 (.041)	,061
Machinery (incl. computers)	146 (.045)	,117
Electrical Machinery	,156 (.037)	.096
Sum (3 industries)	,402	,273
Number of observations Root MSE	249 .116284	

Notes:

1. Data are scaled so that the estimated coefficient represents the ratio of the industry effect to the cross country average "within" component.
2. The root mean squared error of the left-hand side variable is .126295.
3. Standard errors are calculated using the White heteroskedasticity robust formula.
4. Source: United Nations General Industrial Statistics Database.

Table A1: What is a Nonproduction Worker in US Manufacturing?

Education group (highest level achieved)	constant	non-production	production	R-square
<HS	9.82 (1.05)	.01 (0.01)	.03 (.001)	.28
HS	35.52 (5.33)	.23 (004)	.58 (.005)	.91
Some College	-20.96 (2.71)	.30 (.003)	.30 (.004)	.93
College- 4 year dg.	15.06 (3.58)	.31 (.004)	.07 (.005)	.81
>College (>4 yr dg.)	-9.3 1 (2.13)	.15 (002)	.01 (.003)	.68

Note: Calculated from the Worker-Establishment Characteristics Database for 2490 large plants. The left-hand side variable in each row is the estimated number of workers of that type in the firm. The right-hand side variables are the number of production and nonproduction workers. Coefficients are interpreted as the proportion of nonproduction (production) workers of each type. Each column of coefficients is restricted to sum to one. We thank Ken Troske for performing this calculation.

Table Al (cont) : What is a Nonmoduction Worker in US Manufacturing?

Occupation groups: (occ codes)	constant	nonprodu ction	producti on
Mgr & Prof	-20.72	.48	.08
(<= 199)	(5.27)	(.005)	(.006)
Tech, Sales & Admin. support	18.74	.25	.08
(203-3 89)	(2.17)	(.002)	(.003)
Service	-0.76	.02	.03
(403-469)	(0.54)	(.001)	(.001)
Farm-Forest & Fish	0.15	,001	.ooo
(473-499)	(.06)	(.0001)	(.0001)
Precision Prod	-21.64	.11	.33
(503-699)	(2.86)	(.003)	(.004)
Operators & Fabricators	11.42	.10	.38
(703-79 1)	(3.99)	(.003)	(.005)
Laborers	12.82	.03	.10
	(1.95)	(.002)	(.003)

Note: Calculated from the Worker-Establishment Characteristics Database for 2490 large firms. The left-hand side variable in each row is the estimated number of workers of that type in the firm. The right-hand side variables are the number of production and nonproduction workers. Coefficients are interpreted as the proportion of nonproduction (production) workers of each type. Each column of coefficients is restricted to sum to one. We thank Ken Troske for performing this calculation.

Table A2: Levels and Changes in the Proportion of Nonproduction Workers

	% non production 1970	% non production 1980	% non production 1990	changes in % non-production 1970-80	changes in % non-production 1980-90	% employment growth 1970-80	% employment growth 1980-90	GNP per capita 1985 (US$)	Note
US	26.1	28.1	31.1	0.20	0.30	5.2	-9.8	16910	
Norway	22.2	25.6	.	0.34	.	0.6	.	14560	
Luxembourg	16.3	20.9	23.9	0.46	0.30	-6.0	-5.7	14070	
Sweden	26.9	29.4	30.7	0.26	0.12	-6.4	-18.6	12040	
Australia	21.7	25.7	28.2	0.40	0.36	-12.1	-12.4	11760	1970,80,87
Japan *	levels not reliable			.	0.06	-6.0	6.1	11430	1970,81,90
Denmark	24.6	28.2	31.8	0.36	0.41	-10.0	2.4	11380	1970.80.89
Finland	19.8	24.0	30.5	0.42	0.64	12.9	-22.9	11000	
W. Germany	24.7	29.0	.	0.48	.	-14.9	.	10980	1970,79,n/a
Austria	24.6	29.1	31.0	0.46	0.19	5.0	-8.9	9100	
UK	25.9	30.0	32.9	0.41	0.29	-23.0	-35.0	8520	
Belgium	19.9	24.4	26.0	0.46	0.32	-31.1	-15.3	8290	1970,80,85
Hong Kong	12.1	12.0	19.2	-0.00	0.80	34.7	-35.8	6120	. ,
Greece	21.4	27.2	37.5	0.58	1.03	33.5	-8.6	5883	
Ireland	18.4	19.8	23.5	0.14	0.40	12.4	-18.9	4940	1970,80,89
Barbados	.	20.9	23.9	.	0.30	.	-21.5	4670	
Cyprus	.	15.8	16.5	.	0.07	.	21.4	4500	
Spain	15.9	21.6	24.5	0.57	0.29	19.2	-24.3	4370	
Venezuela	19.6	25.2	31.2	0.51	0.67	48.7	11.7	3910	1970,81,90
Iran	11.1	13.2	13.4	0.21	0.03	47.8	19.8	3770	1970,80,86
Malta	14.3	15.4	18.8	0.11	0.42	37.8	-5.8	3410	1970,80,88
Czechoslovak	25.3	26.6	28.7	0.14	0.21	5.2	-2.9	2560	
Puerto Rico**	16.4	19.4	19.5	0.30	0.00	11.6	2.4	.	
Panama	20.4	21.2	23.5	0.09	0.23	26.3	4.0	2380	1970,79,89
Korea	19.8	17.4	23.8	-0.22	0.71	58.9	32.0	2340	1970,81,90
Poland	23.0	26.1	22.3	0.31	-0.38	16.2	-36.9	2100	
Yugoslavia	28.5	28.0	27.3	-0.05	-0.08	38.7	20.8	2060	1970,80,89
Bulgaria	20.1	17.7	20.6	-0.25	0.29	17.1	7.8	2060	
Portugal	12.6	14.3	15.4	0.19	0.15	29.5	-9.3	1980	1971,80,87
Hungary	26.6	21.2	22.5	-0.55	0.13	-12.0	-23.9	1940	
Fiji	13.9	14.1	6.7	0.02	-0.74	34.1	38.5	1650	1972,80,90
Uruguay	21.9	21.7	22.8	-0.02	0.13	-22.7	-26.2	1550	1972,80,88
Chile	.	26.8	27.0	.	0.02	.	30.7	1430	n/a,1980,90
Colombia	20.6	26.7	32.7	0.61	0.60	33.4	-4.0	1290	1973,80,88
Guatemala	18.9	22.1	29.2	0.45	0.88	28.6	12.4	1200	1973.1988
Ecuador	21.2	23.7	28.7	0.26	0.49	57.7	-0.0	1180	
Papua New Guinea	9.2	11.9	14.8	0.27	0.58	30.1	7.4	750	1970,80,85
Indonesia	18.8	16.5	.	-0.22		9.8	.	550	1970,80,n/a
Bolivia	15.1	29.9	32.6	1.48	0.30	51.5	-64.5	430	1970,80,89
Pakistan	.	22.8	22.5	.	-0.04	.	12.2	370	n/a,1980,88
India	.	20.4	21.3	.	0.10	.	-1.0	290	n/a,1980,88
Bangladesh	14.8	20.0	17.1	0.52	-0.33	49.9	-314.7	170	1970,80,89
Ethiopia	.	22.3	28.2	.	0.75	.	22.4	110	n/a,1980,88

Sources: United Nations General Industrial Statistics. GNP/capita from World Bank (1994) "World Tables", country tables.
* Levels are not reliable for Japanese data as operatives are counted only for a subsample of large firms, while employment is counted for all firms. Differences should be accurate over the 1981-90 period, during which the definition of large firms remained constant. **Rank guessed.

Table A3: Industry Effects in Within-Industry Terms: 1980-90

Code and Industry	Coefficient	t-statistic	Coefficient	t-statistic
3110 Food	-.018	-0.652	-.045	-1.034
3 130 Beverages	.032	2.070	.028	1.587
3 140 Tobacco	.009	2.141	.002	0.193
32 10 Textiles	.042	2.827	.038	2.327
3220 Apparel	.006	0.379	.002	0.132
3230 Leather Products	.018	1.379	.014	0.845
3240 Footwear	,013	2.065	.009	0.801
3310 Wood Products	.038	1.785	,033	1.795
3320 Furniture	,018	1.916	,014	1.071
3410 Paper Products	.031	2.888	.027	2.388
3420 P&t & Publishing	.104	2.327	.100	2.433
35 10 Ind Chemicals	.049	5.243	.044	3.942
3520 Othr Chemicals	,036	2.766	,006	0.156
3530 Petr Refineries	,026	1.470	.022	1.107
3540 Pet&Coal	-.008	-0.746	-.012	-0.818
3550 Rubber Prod	.010	1.381	.006	0.505
3560 Plastic Prod	.001	0.196	-.003	-0.274
3610 Potterv. China	,012	2.006	.008	0.680
3620 Glass Products	-.004	-0.896	-.009	-0.703
3690 Non metal nec	,034	3.863	,029	2.078
37 10 Iron&Steel	.195	1.154	.165	1.322
3720 Non-ferrous metal	.008	1.448	-.021	-0.634
38 10 Metal Products	,042	2.058	,016	0.413
3820 Machinery, computers	.173	4.157	,146	3.275
3830 Electric Machinery	.160	4.156	.156	4.249
3840 Transport Equip	,002	0.046	-.002	-0.064
3850 Professional Goods	.056	2.399	,052	1.978
3900 Other Goods ;	,018	2.693	,013	1.212
Country Effects	No		Yes	
Observations	249		249	
Root MSE	0.1209		0.1163	

Notes: Estimating equation is given in Table IV. Coefficients are scaled so that the reported coefficient represents the ratio of the industry effect to the cross country average "within" component. The root mean squared error of the LHS var is .126295. t-statistics are calculated using heteroskedasticity robust standard errors. Countries included are all those included in Table III and Luxembourg (6 industries observed).

Source: United Nations General Industrial Statistics Database.

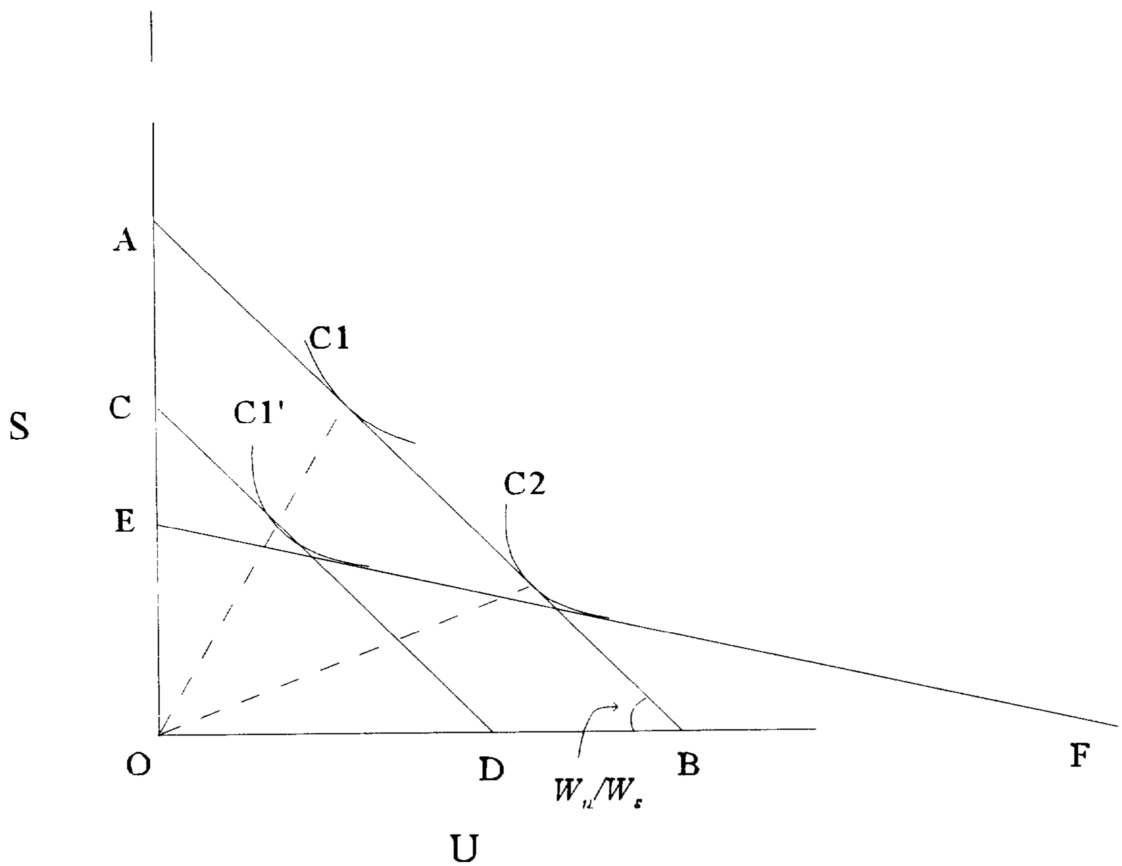

Figure I: The Sector Bias of a Hicks-Neutral Technological Change

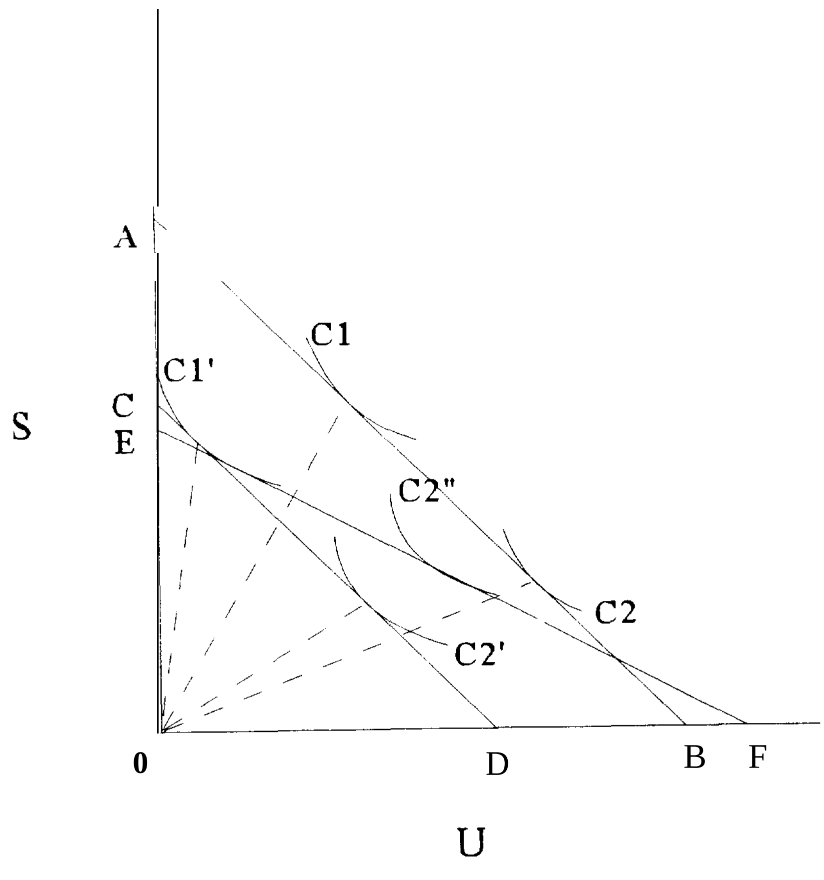

Figure II: Skill-Biased, Sector-Neutral Technological Change

Figure III: Nonproduction Employment Shares in UK And US Manufacturing, 1970-90

Sources: Bartelsman and Gray (1994) for US; Machin (1996b) for UK.

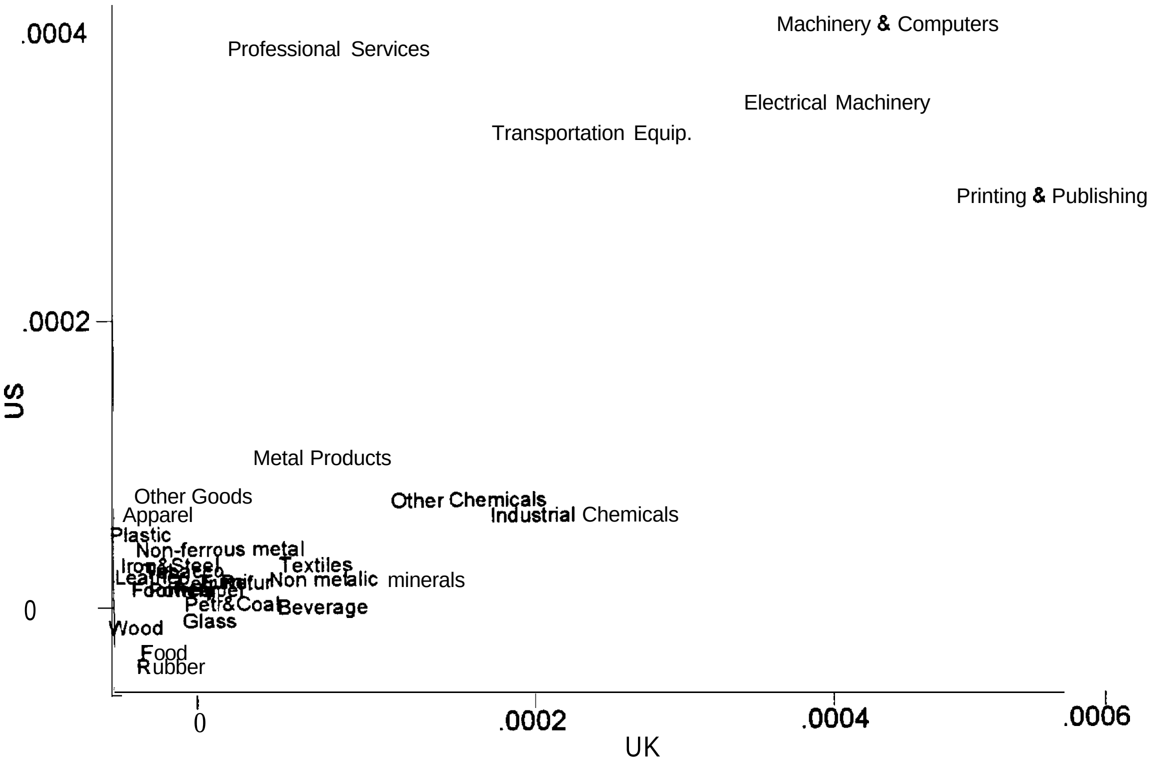

Figure IV: Within Industry Changes in Nonproduction Employment Share: US and UK

Notes: Each observation is a pair of “within” industry increases in the proportion of nonproduction workers between 1980 and 1990, defined as the change in proportion weighted by the industry share in manufacturing employment,

$$wit_{ci} = \Delta Pn_{ci}\overline{S_{ci}}$$

where i is an industry index and c is a country index. The 28 industries in this classification are listed fully in Appendix table A3.

Source: United Nations General Industrial Statistics Database.

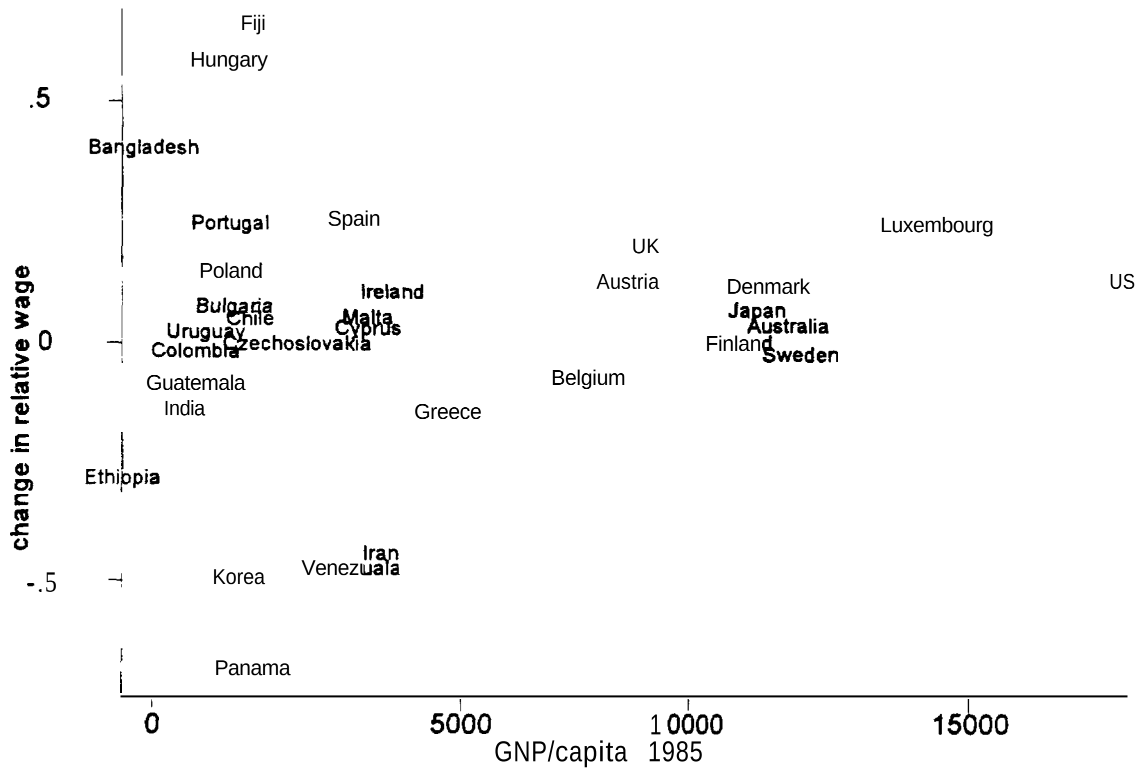

Figure Al: Change in Relative Wages in 1980s by GNP

Notes: The figure reports relative wage information for 33 countries judged to have reliable information over the 1980s (of the 43 listed in Table A2). The change in wage ratio of nonproduction to production workers is recorded between 1980 and 1990 where possible. Other endpoints are used when necessary, as indicated in Table A2.

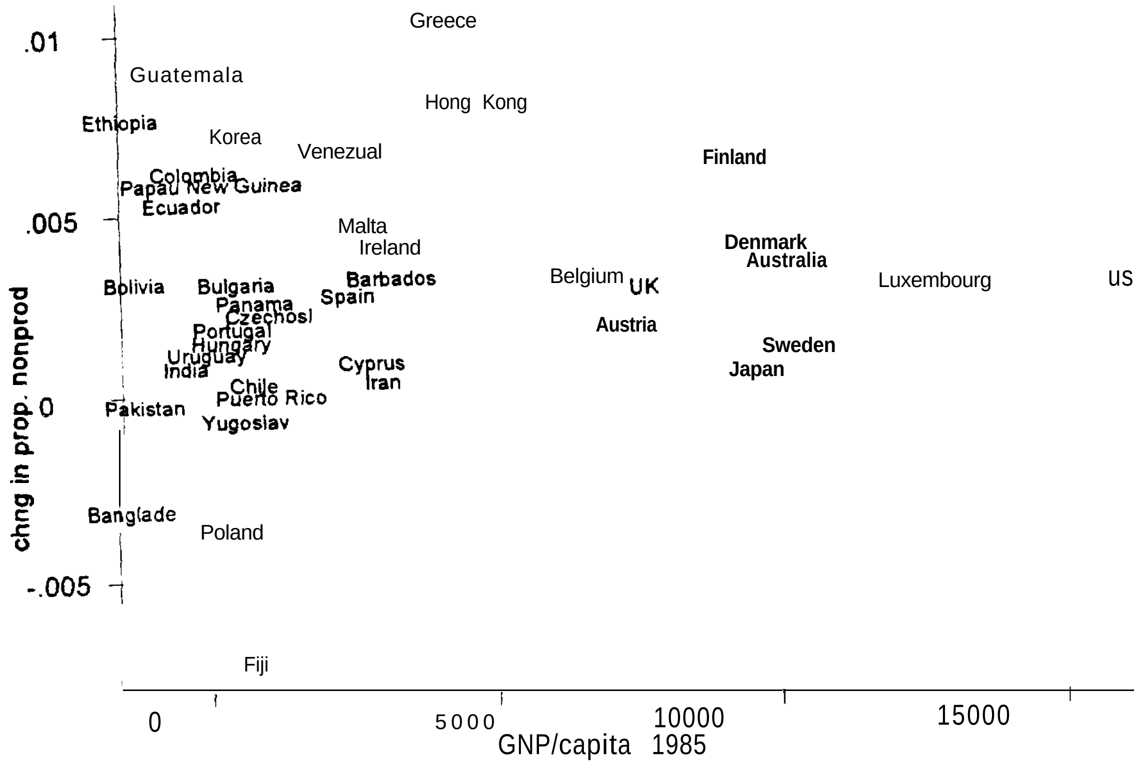

Figure A2: Skill Accumulation in the 1980s by GNP

Notes: See Table A2.