IMPLICATIONS OF SKILL-BIASED TECHNOLOGICAL CHANGE: INTERNATIONAL EVIDENCE*

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Demand for less-skilled workers plummeted in developed countries in the 1980s. In open economies, *pervasive* skill-biased technological change (SBTC) can explain this decline. SBTC tends to increase the domestic supply of unskill-intensive goods by releasing less-skilled labor. The more countries experiencing a SBTC, the greater its potential to decrease the relative wages of less-skilled labor by increasing the *world* supply of unskill-intensive goods. We find strong evidence for pervasive SBTC in developed countries. Most industries *increased* the proportion of skilled workers *despite* generally rising or stable relative wages. Moreover, the *same* manufacturing industries simultaneously increased demand for skills in *different* countries. Many developing countries also show increased skill premiums, a pattern consistent with SBTC.

I. INTRODUCTION

Less-skilled workers have suffered reduced relative wages, increased unemployment, and sometimes both in OECD economies over the 1980s. In the United States 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.[1] Between 1979 and 1992 the average unemployment rate in European OECD countries increased from 5.4 percent to 9.9 percent[2] 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. Several authors have documented the decline in the relative wages of less-skilled workers in the United States and the concurrent decline in their employment in manufacturing (e.g.,

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

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

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Murphy and Welch [1992, 1993]; Bound and Johnson [1992]; Katz and Murphy [1992]; and Blackburn, 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]; and Nickell and Bell [1995]). It is now well documented that labor market outcomes of less-skilled workers have worsened in the developed world in the past two decades, despite their increasing scarcity relative to the rapidly expanding supply of skilled labor.

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 based on a combination of four findings: (1) employment shifts to skill-intensive sectors seem 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]; (2) despite the increase in the relative cost of skilled labor, the majority of U. S. industries have increased their ratio of skilled to unskilled labor [Bound and Johnson 1992; Katz and Murphy 1992; Lawrence and Slaughter 1993; BBG], (3) there appear to be strong, within-sector correlations between indicators of technological change and increased demand for skills [Berndt, Morrison, and Rosenblum 1994; BBG; Autor, Katz, and Krueger 1998; Machin 1996b; Machin and Van Reenen 1998];[3] and (4) case studies conducted by the Bureau of Labor Statistics Office of Productivity and Technology that indicate the nature of innovations often mention innovations that lowered or are expected to lower production labor requirements [Mark 1987].

In this paper we claim that skill-biased technological change was pervasive over the past two decades, occurring simultaneously in most, if not all, developed countries. Thus, *it was not*

3. 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, although computer investment is. Siegel [1995] finds that technology adoption is correlated with increased proportions of high skill occupations.

only the major cause of decreased demand for less-skilled workers in the United States, but also shifted demand from less-skilled to skilled workers throughout the developed world. 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 did not observe evidence of SBTC throughout the developed world, we would be forced to doubt whether it occurred in any developed country, such as the United States.

Second, the more pervasive the SBTC, the greater its potential to affect relative wages. To illustrate that point, we consider a Heckscher-Ohlin (H-O) model with small open economies and two factors of production. In that context the skill-bias of local technological change is irrelevant to the wage structure in an H-O model unless it is also sector-biased. On those grounds, Leamer [1994] 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 H-O model is widely considered to be a relevant model for analyzing the long-run effect on wages of 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 homothetic preferences, skill-biased technological change releases less-skilled workers from industries, depressing their relative wages by depressing the world (relative) prices of goods intensive in less-skilled work. Thus, pervasive skill-biased technological change in the developed world provides an explanation consistent with both increased wage premiums for skilled workers and within-industry

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 increased exposure to trade may differ. Since the trend increase in relative demand for skilled labor seems to have persisted for decades, long-run models deserve consideration.

substitution toward skilled workers, even in small open economy models.

Pervasive SBTC has two testable implications. 1. The within-sector shifts away from unskilled labor observed in the United States should occur throughout the developed world. 2. These shifts should be concentrated in the same industries in different countries. Using data on the employment of production and nonproduction workers in manufacturing from twelve developed countries in the 1980s, we find evidence consistent with both predictions. In all those countries we find large-scale within-industry substitution away from unskilled labor despite rising or stable relative wages in the 1980s. Moreover, the cross-country correlations of within-industry increases in employment of skilled workers are generally positive and often quite large.

The manufacturing industries that experience the greatest skill upgrading in our sample are those associated with the spread of microprocessor technology. Electrical machinery, machinery (including computers), and printing and publishing together account for 46 percent of the within-industry increase in relative demand for skills in our 1980s sample. Case studies reveal that these three industries underwent significant technological changes associated largely with the assimilation of microprocessors [United States Department of Labor 1982a, 1982b]. Casual empiricism suggests a pervasive spread of microprocessors within these and other manufacturing industries in the 1980s. This pattern strongly suggests a common technology linking similar patterns of skill upgrading across countries.

Evidence 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 in the 1980s, despite the opposite Stolper-Samuelson prediction [Feliciano 1995; Hanson and Harrison 1995; Robbins 1995]. We examine a larger sample of developing countries, finding that relative wages also increased in many developing countries during a decade of trade liberalization in the 1980s.

The paper proceeds as follows. In Section II we discuss skill-biased technological change in an H-O framework, contrasting the effects of local and pervasive SBTC on wages. In Section III we test one implication of SBTC, presenting evidence on within-industry changes in the employment of skills in OECD countries. We also examine alternative explanations for within-industry skill upgrading. Section IV presents further evidence of pervasive technological change, describing common technological changes across countries. In Section V we examine evidence that SBTC is pervasive in developing countries as well as in developed. Section VI concludes.

II. Local versus Pervasive Technological Change in Open Economies

How does skill-biased technological change affect the relative wages of skilled labor in open economies? In this section we argue that the pervasiveness of an SBTC is key to establishing its long-run influence on relative wages. In open economies the effect of *local* SBTC on relative wages is muted by the high price elasticity of product demand. In contrast, *pervasive* SBTC, occurring in many countries, will drive up the relative price of skill-intensive goods under fairly general conditions. That change in goods prices will induce an increase in the skill premium.

To illustrate the role of pervasiveness, we start with the extreme example of a small open economy, in which local SBTC has no effect on relative wages [Leamer 1994], but pervasive SBTC has a large effect [Krugman 1995]. While small economies provide a clear example, the mechanism is fairly general: the more pervasive the SBTC, the greater the effect on world prices and thus on wages. We discuss generalizations below.

Consider the two-factor, two-good small open economy version of Heckscher-Ohlin theory with local technological change [Helpman and Krugman 1985]: labor is either skilled or unskilled; two goods are produced by constant returns to scale, quasi-concave production functions; competition is perfect; all goods are produced in equilibrium; preferences are homothetic; world prices are parameters. These assumptions imply that goods are priced according to marginal cost as free entry of firms in any country and constant returns to scale dictate zero profits. The resulting zero profit condition is

$$p_i = a_{Si}(w)w_S + a_{Ui}(w)w_U \qquad \text{for all } i, \tag{1}$$

where p_i is the world price of good i and a_{li} is the demand for factor l per unit of good i, which is a function of the wage vector, w. (For more detail see Berman, Bound, and Machin [1997].)

A. Stolper-Samuleson Effects and Sector-Biased Technological Change

The Lerner-Pierce diagram [Lerner 1952] in Figure I provides a clear illustration of the effects of trade and technological change on wages. Here the unit-value isoquants $C1$ and $C2$ trace out combinations of inputs that produce one dollar of goods 1 and 2, respectively. The line AB tangent to those curves describes zero profit combinations of inputs at equilibrium wages. Its slope is the wage ratio $-w_U/w_S$.

To illustrate the Stolper-Samuelson effect, consider a shift from autarky to trade for a skill-abundant country. The Heckscher-Ohlin-Vanek theorem implies an increase in the relative price of good 1, the skill-intensive good. In the diagram, that price change is reflected in the shift of $C1$ toward the origin, as fewer inputs are required to produce a dollar's worth of good 1. Preserving zero-profit, relative wages of skilled labor increase, a change reflected in the decrease in w_U/w_S as the line of tangencies shifts from AB to EF.

Now consider the effect on wages of technological change in the skill-intensive sector. Figure I can also be used to illustrate Hicks-neutral technological progress occurring only for good 1. Assuming that these goods are traded, their prices are exogenously fixed (under the small country assumption). Technological progress in good 1 production reduces factor requirements, shifting the unit value isoquant toward the origin from $C1$ to $C1'$. This shift is Hicks-neutral since at the old relative wage the ratio of inputs S/U is unchanged, a condition reflected in the diagram by CD being parallel to AB. Profit opportunities in good 1 production will bid up the relative wage of skill, as in the Stolper-Samuelson case, a change reflected, as before, in the decrease in w_U/w_S as the line of tangencies shifts from AB to EF. Note that within both sectors, rays from the origin to points of tangency reflect lower ratios of S/U. That is to say, whether the change in relative wages is driven by changes in sector-specific prices or productivity, there is within-sector substitution away from skilled labor due to its new, higher, relative wage.

B. 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. Figure II illustrates the effects of a skill-biased technological change on wages.

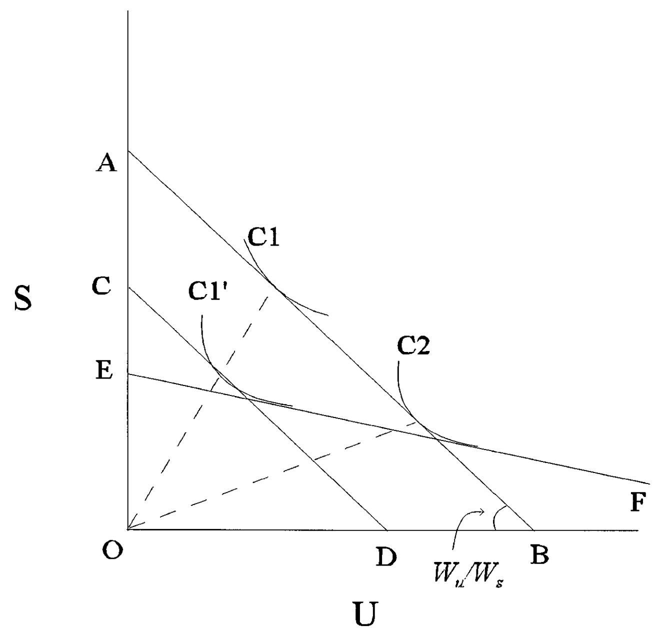

FIGURE I
The Stolper-Samuelson Effect or Sector-Biased Hicks-Neutral Technological Change

Skill-biased technological change is reflected in the shift of unit cost curves *C*1 and *C*2 to *C*1′ and *C*2′. This change is sector-neutral in the sense that both *C*1 and *C*2 shift to lower levels of inputs in a way that reduces costs by the same proportion in each sector. The line *CD*, tangent to *C*1′ and *C*2′ reflects the new zero-profit condition, and is parallel to *AB*, reflecting the same relative wage. These shifts are skill-biased as the new equilibrium ratios of skilled to unskilled workers are higher than the old. (Rays from the origin are steeper.) While a technological change that saves factors in the same proportion in each sector may seem artificial, it provides a useful contrast to the sector-biased technological change of Figure I. Note the testable implication: unlike Stolper-Samuelson effects, skill-biased technological change directly increases the proportion of skilled labor employed in each sector.

One feature of technological changes with fixed goods prices is that the skill bias of technological changes has no effect on

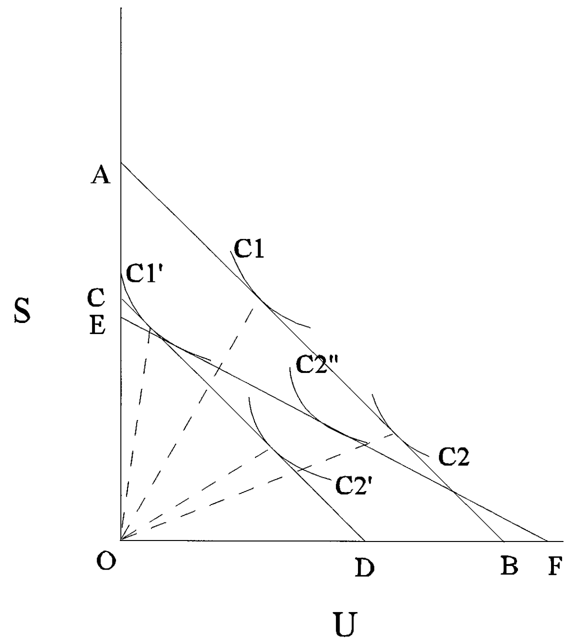

FIGURE II
Skill-Biased Technological Change

relative wages [Leamer 1994].[5] This appears particularly damning to the claim that skill-biased technological change increased the skill premium.

C. Pervasive Skill-Biased Technological Change

Now consider a *pervasive* skill-biased technological change occurring simultaneously in all economies in the production of some traded good. Imagine an integrated world economy consisting of many small open economies, each experiencing SBTC.[6] The response of prices and wages would be like that of a closed economy. SBTC would initially cause a disproportionate expan-

5. Imagine sliding the isovalue curve *C*1′ along the unit-cost line so that the point of tangency is at a different ratio of skilled to unskilled workers. Any of those locations represent the same unit cost of production. Although the skill-biases of those locations (technologies) differ, they all share the same solution for relative wages.

6. The integrated world economy is discussed in Helpman and Krugman [1985]. It behaves like the closed economy in Jones [1965]. Baldwin [1994] provides a clear graphical presentation.

sion of production of the good intensive in unskilled labor (good 2) as each industry reduces its proportion of unskilled labor. Under homothetic preferences that disproportionate expansion would induce a decrease in the relative price of good 2 and in the relative wages of unskilled labor.[7] 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 the 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 most alternative explanations of the increased skill premium, such as Stolper-Samuelson effects or factor-neutral sector-biased technological change, it implies within-industry increases in the proportion of skilled workers.

How general is the result that pervasive SBTC will affect relative wages more than local SBTC? It clearly generalizes to a number of models with product demand curves that are less than perfectly elastic, such as large open economies [Baldwin 1994], locally produced goods which are imperfect substitutes for traded goods [Johnson and Stafford, 1999] and models with barriers to trade, as long as perfectly elastic product demand is preserved.[8] In all these cases open economies behave more like the closed economies in the sense that SBTC can affect goods prices. While the contrast between the wage effects of a pervasive SBTC and those of a local SBTC is greatest in the small open economy model, it can also be large in more general models of trade, especially when product demand is elastic.

III. Testing the Implications of Alternative Explanations

Section II established that pervasive SBTC can affect relative wages regardless of the degree of openness of the economy. It also showed that among candidate causes of increased relative wages SBTC has a unique prediction: within-industry skill upgrading. If

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. With a little care, this result will also generalize to the $n > 2$ good case as in Ethier [1984]. Generalizations are much like those that allow the insensitivity of factor prices to changes in factor supplies [Leamer and Levinsohn 1995], which also relies critically on perfectly elastic product demand.

the dominant cause of increased skill premiums in the United States is indeed *pervasive* SBTC, then it must be evident in all developed countries. We begin this section by reporting evidence on plant-level skill upgrading despite increased relative wages in the United States and the United Kingdom. We then seek out the same pattern in a new, larger sample of OECD countries.

Table I reproduces evidence of skill upgrading in the presence of increasing relative wages in both U. S. and U. K. manufacturing, collecting estimates from several sources. The manufacturing sectors of both countries experienced large reductions in employ-

TABLE I
WITHIN-INDUSTRY SKILL UPGRADING: U. S. AND U. K. MANUFACTURING IN THE 1980S

	United States		United Kingdom	
Period	1979–1987	1977–1987	1979–1990	1984–1990
Number of industries/ plants	450	360,000	100	402
Level of aggregation	4-digit SIC	plants	3-digit SIC	plants
Source	Annual Survey of Manufactures	Census of Manufactures	Census of Production	Workplace Industrial Relations Survey
Annual change in non-production employment share (percentage points)	.552	.483	.367	.41
Within-industry/plant component (percent)	.387 (70)	.341* (71)	.301 (82)	.34 (83)
Between-industry/plant component (percent)	.165 (30)	.077* (16)	.066 (18)	.07 (17)
Annual change in non-production wage bill share (percentage points)	.774	—	.668	—
Within-industry component (percent)	.468 (60)	—	.554 (83)	—
Between-industry component (percent)	.306 (40)	—	.114 (17)	—

Sources. U. S. industries—Berman, Bound, and Griliches [1994], Table IV, Using the Annual Survey of Manufactures [Bartelsman and Gray 1994]. U. S. plants—Dunne, Haltiwanger, and Troske [1997], Table 1, United Kingdom—Machin [1996b], Tables 7.2 and 7.3.

* This decomposition also includes a small negative cross-product term and a positive net entry term for the effect of entering and exiting plants. These terms are the sum of within and between components in 1977–1982 and 1982–1987 decompositions.

ment of less-skilled (production) workers in the 1980s and a trend increase in the share of skilled (nonproduction) workers in employment. In that work and in this paper nonproduction workers are treated as skilled and production workers as unskilled. That mapping is supported by comparisons of skill classifications of the same individuals in plant and household surveys reported in Berman, Bound, and Machin [1997], BBG, and Machin, Ryan, and Van Reenen [1996].[9] The table reports a decomposition of the increase in the aggregate employment share of nonproduction workers into between-industry and within-industry components using the following decomposition:

$$\Delta Sn = \sum_i \Delta W_i \overline{Sn_i} + \sum_i \Delta Sn_i \overline{W_i}, \tag{2}$$

where

$$Sn \equiv \frac{S}{S+U}, \qquad W_i \equiv \frac{E_i}{\Sigma_i E_i}.$$

Here S are skilled workers, U are unskilled, E is employment, and an overstrike indicates a simple average over time. The weights are the industry employment shares in manufacturing employment. The first column reports that between 1979 and 1987 the aggregate proportion of nonproduction workers in U. S. manufacturing increased by 0.55 percentage points per year. Of that increase 70 percent occurred within the 450 four-digit industries. Dunne, Haltiwanger, and Troske [1997] replicate this result at the plant level using the entire Census of Manufactures, showing that 71 percent of the aggregate increase in Sn was due to within-plant shifts in demand. Machin [1996b] reports similar results from the United Kingdom. There as well, most of the sizable decrease in unskilled labor's share of manufacturing employment is due to

9. Berman, Bound, and Machin [1997] use the Worker Establishment Characteristics Database [Troske 1994], which matches the 1990 Census of Population to the Census of Manufactures. Standard occupational and educational measures correspond closely with the production/nonproduction classifications of skill in manufacturing plants. Seventy-five percent of nonproduction workers are in white-collar occupations; while 81 percent of production workers are in blue-collar occupations. Seventy-six percent of nonproduction workers have at least some college education, while 61 percent of production workers have a high school education or less. BBG also 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. Machin, Ryan, and Van Reenen [1996] match manufacturing data and labor force surveys at the two-digit industry level, and find that the correlation of nonproduction/production categories with educational categories in the United Kingdom is similar to that in the United States.

within-industry (and apparently within-plant) decreases in demand for unskilled labor, despite its falling relative price.

If SBTC is pervasive, as in Section II, we should see the same pattern in all developed countries. The United Nations General Industrial Statistics Database [United Nations 1992] contains manufacturing employment and wage bill data for a large number of countries categorized into 28 consistently defined industries. We choose the most productive 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 serious 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 1 reports the countries in order of rank. The Data Appendix describes these data and our selection criteria in more detail.

In most of these developed countries manufacturing employment declined substantially (Appendix 1). The decline of 9 percent in the United States was typical. That employment decline was particularly severe for the (less-skilled) production workers who lost employment share to nonproduction workers in all sampled countries.

Table II reports changes in nonproduction/production wage ratios (in column 6).[10] Relative wages of nonproduction workers rose by an average of 4 percent in these developed countries in the 1980s.[11] The U. S. increase of 7 percent was above average. Production workers lost employment share in all of these countries while suffering relative wage declines in seven of the ten. This pattern is roughly consistent with a common description of European labor markets in the 1980s: they share the same phenomenon of decreased demand for less-skilled workers but differ in how it is expressed. In the United States and United Kingdom where wages are more flexible, the relative wages of the

10. Variation in relative wage changes across countries need not be inconsistent with the framework of Section II. In the short run, local supply or institutional changes may affect relative wages even if small open economy assumptions apply in a longer run.

11. The wage ratio of nonproduction to production workers is a noisy measure of the preferable skill premium based on educational levels. In the 1980s the increased skill premiums in Table II are consistent with those reported in Davis [1992], Freeman and Katz [1994], and Gottschalk and Joyce [1998] for the United States, Australia, Japan, and the United Kingdom. The decreased skill premium we report for Sweden is inconsistent with those sources. In the 1970s the decreased skill premiums in Table II are consistent with those sources for the United States, Australia, and the United Kingdom, while the increased premiums are inconsistent for Sweden and Germany.

TABLE II
PROPORTION OF INCREASED USE OF SKILLS "WITHIN" INDUSTRIES

Country	1970–1980 Change in % non-production (annualized)	1970–1980 % within	1970–1980 Change in wage ratio (%)	1980–1990 Change in % nonproduction (annualized)	1980–1990 % within	1980–1990 Change in wage ratio (%)	Note
U. S.	0.20	81	−2	0.30	73	7	
Norway	0.34	81	−3	—	—	—	1970,80,n/a
Luxembourg	0.57	90	6	0.30	144	12	
Sweden	0.26	70	3	0.12	60	−3	
Australia	0.40	89	−17	0.36	92	2	1970,80,87
Japan	—	—	—	0.06	123	3	n/a*,81,90
Denmark	0.44	86	−11	0.41	87	7	1973,80,89
Finland	0.42	83	−11	0.64	79	−2	
W. Germany	0.48	93	5	—	—	—	1970,79,n/a
Austria	0.46	89	7	0.16	68	7	1970,81,90
U. K.	0.41	91	−3	0.29	93	14	
Belgium	0.45	74	6	0.16	96	−5	1973,80,85
Average	0.40	84.3	−1.8	0.28	91.5	4.2	

a. The change in aggregate proportion of nonproduction workers can be decomposed into a component 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. The percentage within is calculated by dividing the second term of equation (2) in the text by the sum of both terms.

b. *Source:* United Nations General Industrial Statistics Database.

c. There are 28 industries in this classification for all countries except Belgium (20), W. Germany (22), Japan (27), Luxembourg (9 in 1970–1980, 6 in 1980–1990), and Norway (26). For these countries aggregate changes and "within" calculations are based upon the reduced set of industries. Appendix 2 includes an industry list. See the Data Appendix for details.

* The sampling frame changed for Japanese data between 1970 and 1981.

less-skilled declined sharply, while in European countries with less flexible wages, reduced demand was expressed as unemployment [Freeman and Katz 1995; Krugman 1995].

A. Pervasive within-Industry Skill Upgrading

Table II reports the increased percentage 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) The increased use of nonproduction workers in manufacturing is a universal phenomenon. The first and fourth column report that their proportion increased by an average of four percentage points in the 1970s and three percentage points in the 1980s. (2) In all these countries the vast majority of the aggregate substitution toward nonproduction workers was due to substitution toward nonproduction workers *within* industries in both decades.

The table shows strong evidence for pervasive skill-biased technological change in the 1980s. *In seven of the ten countries, positive "within" industry terms indicate that industries substituted nonproduction for production workers despite increasing relative wages.* Referring back to the discussion in Section II, increases in relative wages due (only) to Stolper-Samuelson effects imply negative "within" terms as firms substitute away from the input with an increasing relative wage. More generally, any increase in relative wages not due to a shift in the relative demand for skills at the industry level implies negative within terms. But a shift in relative demand for skills at the industry level (i.e., increased relative demand for skills, at fixed wages and prices) is by definition a skill-biased technological change.

Wage bill shares of nonproduction workers provide an additional way of looking at increased demand for skilled workers. If the elasticity of substitution between nonproduction and production workers is close to one, these shares provide a measure of demand robust to changes in relative wages. Table III reports increases in nonproduction wage bill shares in all countries in the 1970s and 1980s. Although the United States and United Kingdom show acceleration, the average rate of increase is constant. As in Table II, aggregate increases were mainly due to increases in within-industry skill upgrading.

It is not possible to tell from Tables II and III whether the rate of SBTC accelerated, remained constant, or decelerated during the 1980s [Bound and Johnson 1992; Katz and Murphy 1992; BBG]. In most of these countries within-industry skill upgrading occurred less in the 1980s than in the 1970s. However, the relative wage of nonproduction workers typically declined in the 1970s and increased in the 1980s, so that substitution effects alone could account for that decrease.[12] Without netting out those substitution effects, something that would be hard to do, it is impossible to tell whether the rate of SBTC accelerated, remained constant, or

12. These effects, in turn, are likely to be a symptom of decelerating skill supply, which can affect wages in the short run in small open economies or in an integrated equilibrium. All these countries show a trend increase in the proportion of college educated in the labor force in the 1970s, which decelerated in most of them in the 1980s [Organization for Economic Co-operation and Development (OECD) 1995; Barro and Lee 1997].

TABLE III
PROPORTION OF INCREASED WAGE BILL SHARE OF SKILL "WITHIN" INDUSTRIES

Country	1970–1980 Change in % nonproduction (annualized)	1970–1980 % within	1970–1980 Change in wage ratio (%)	1980–1990 Change in % nonproduction (annualized)	1980–1990 % within	1980–1990 Change in wage ratio (%)	Note
U. S.	0.19	86	−2	0.51	76	7	
Norway	0.33	76	−3	—	—	—	1970,80,n/a
Luxembourg	0.90	95	6	0.73	123	12	
Sweden	0.38	81	3	0.07	25	−3	
Australia	0.07	51	−17	0.42	92	2	1970,80,87
Japan	—	—	—	0.14	84	3	n/a*,81,90
Denmark	0.12	42	−11	0.64	89	7	1973,80,89
Finland	0.27	82	−11	0.70	83	−2	
W. Germany	0.67	95	5	—	—	—	1970,79,n/a
Austria	0.69	93	7	0.36	76	7	1970,81,90
U. K.	0.39	91	−3	0.62	92	14	
Belgium	0.77	86	6	−0.06	92	−5	1973,80,85
Average	0.43	79.8	−1.8	0.41	83.2	4.2	

a. The change in aggregate wage bill share of nonproduction workers can be decomposed into a component due to reallocation of wage bill *between* industries with different shares of skilled workers and another due to changes in the shares of skilled workers *within* industries. The percentage within is calculated by dividing the second term of the following decomposition by the sum,

$$\Delta S_n^w = \sum_i \Delta W_i^w \overline{S_{n_i}^w} + \sum_i \Delta S_{ni}^w \overline{W_i^w},$$

where

$$S_n^w \equiv \frac{w_S S}{w_S S + w_U U}, \qquad W_i^w \equiv \frac{WB_i}{\Sigma_i WB_i},$$

and an overstrike indicates a simple average over time.

b. *Source:* United Nations General Industrial Statistics Database.

c. There are 28 industries in this classification for all countries except Belgium (20), W. Germany (22), Japan (27), Luxembourg (9 in 1970–1980, 6 in 1980–1990), and Norway (26). For these countries aggregate changes and "within" calculations are based upon the reduced set of industries. Appendix 2 includes an industry list. See the Data Appendix for details.

* The sampling frame changed for Japanese data between 1970 and 1981.

decelerated during the 1980s. Similarly, we are reluctant to interpret differences across countries in the rate of within-industry skill upgrading as evidence of cross-country patterns in the rate of technological change. Rather, these patterns could plausibly reflect cross-country differences in other factors that affect 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 (not shown),[13] a pattern consistent with the findings of Gottschalk and Joyce [1998] for several developed countries. Anticipating the discussion of an integrated equilibrium for developed countries below, the pattern of wages and employment in Table II 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 on average, while local changes in supply affected relative wages as well.

In summary, in the developed countries for which we have manufacturing data in the 1970–1990 period, we find widespread within-industry substitution toward skilled labor, often despite increased relative wages. Applying the predictions of the analysis in the last section, that pattern indicates *skill-biased technological change in all of these countries.*

B. Alternative Explanations for within-Industry Skill Upgrading

To interpret positive within-industry upgrading despite increased relative wages as evidence for SBTC, one must assume homogeneous products within industries, which we did implicitly in Section II. Otherwise, an industry might reallocate employment from low-skill intensive products to high-skill intensive, perhaps in reaction to a change in product prices. That within-industry skill upgrading need not be due to SBTC. This problem of aggregation in measurement is more severe for the coarse 28-industry classification of Table II than for the finer plant-level data of Table I, allowing more room for composition effects to masquerade as within-unit effects. Yet, note that the "within" figures reported for the United States and the United Kingdom in Table II are not much higher than the comparable plant-level figures reported in Table I. Thus, a 28-industry decomposition seems to provide a good approximation of the plant-level substitution and composition effects that we report in Table I.

Within-plant skill upgrading could occur for a number of reasons besides SBTC. One possibility is capital investment combined with capital-skill complementarity. Previous work [BBG, Table VI] has found that capital accumulation in U. S. manufacturing was not large enough to generate the observed increase in relative wages using cross-sectional estimates of the elasticity of substitution.[14] Another possible explanation is intraplant demand

13. The OECD Employment Outlook provides figures [OECD 1993].

14. For a dissenting view see Krusell et al. [1997]. They find, using aggregate data, that if capital equipment, particularly computers, is evaluated using a

shifts toward skill-intensive goods. Considering the size of interplant shifts, it seems unlikely that this effect can be large. Also, the increased relative price of skills should induce intraplant shifts in the opposite direction. Wood [1991] and Bernard and Jensen [1997] have argued that an increase in the relative price of skill-intensive goods, due to increased exposure to unskill-intensive developing countries, would induce intraplant substitution toward skill-intensive goods. BBG [Table IV] test that hypothesis, finding that only a tiny fraction of within-industry increase in the proportion of nonproduction workers can be explained by net imports using a fixed factor model, so that trade-induced within-plant composition effects are probably negligible. A third possibility is skill-biased product innovations, which can be thought of as SBTC for our purposes. A fourth possible explanation is intraplant skill upgrading induced by trade through an H-O effect whereby firms "outsource" low-skill parts of the production process abroad, replacing in-house production with imported materials [Feenstra and Hanson 1996a, 1996b, 1997].

While it is hard to measure outsourcing, let alone its effect on U. S. employment, two calculations suggest that outsourcing is responsible for at most a fraction of skill upgrading. First, BBG report that skill-upgrading occurred no more rapidly in import-intensive industries than in the rest of U. S. manufacturing in the 1980s [BBG, Table IV]. Second, the 1987 Census of Manufacturing reports that the total cost of imported material was 104 billion dollars, or 8 percent of materials purchased and 30 percent of imported manufactures. Imported materials substitute for domestically produced materials, but they only constitute outsourcing if they substitute for materials produced within the purchasing establishment. While we know of no reliable way to distinguish uses for imported materials, at most 7 percent of purchased materials (imported and domestic) come from an establishment's own industry.[15] This suggests that only a small fraction of imported materials represent outsourcing (as they do not replace domestic production in the same industry). Extending that calculation, assume that imported materials displace production but not nonproduction labor and that imported materials embody the

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Gordon [1990] measure, its increase in value is fast enough to explain the increased demand for skills using a constant elasticity of substitution between capital and skill.

15. Materials files of the 1987 Census of Manufactures shows that 2 percent of materials purchased originate in the four-digit industry of the purchaser, and 7 percent originate in the same three-digit industry.

same amount of production labor as do domestically produced goods in the same industry (but no nonproduction labor). Thus, for each industry we calculate the number of production workers displaced by outsourcing as of 1987 as (imported materials/total shipments) $\times$ production employment. These calculations suggest that the employment of production workers would have been at most 2.8 percent higher in 1987 if there had 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 indicates that outsourcing could directly account for at most 16 percent of the decline in the production worker share of employment over this time period, making the generous assumption of no outsourcing in 1973.[16]

While we expect that only a fraction of the materials that an establishment purchases from foreign sources represent outsourcing, the Census measure understates outsourcing in one respect. Census 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, which 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

16. Feenstra and Hanson [1996b, 1997] use different methods to estimate the magnitude of foreign "outsourcing." First, they multiply materials purchased by the proportion of imports in their source industry. Their estimate is that, as of 1990, 11.6 percent of materials could represent outsourcing, rather than 8 percent. (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. When Feenstra and Hanson redo their calculation restricting attention to purchases with an establishment's two-digit industry, their 11.6 percent estimate drops to 5.6 percent. Second, using regression techniques, Feenstra and Hanson [1997] estimate that outsourcing can account for as much as 15 percent of the within-industry shift away from production labor during the 1980s. Baru [1995] uses similar measures, but calculates outsourcing using only purchases within the same *three*-digit industry. She estimates a translog variable cost function using data on 51 three- and four-digit importing and exporting industries, and finds no association between changes in the price of imported materials and skill upgrading. Given the potential for measurement error in the variables and the apparent lack of robustness of the results, we put more stock in the back-of-the-envelope calculations, which are likely to exaggerate effects.

manufacturing shipments that year—too small a quantity to matter very much [United States International Trade Commission 1988].[17]

Our estimates are crude, but they err on the side of overestimating the effects of outsourcing on skill upgrading: not all foreign materials represent outsourcing. For those that do, some nonproduction labor is certainly embodied in 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 1970s and 1980s. Calculations based on U. S. data also overstate the potential share of outsourcing in within-industry skill upgrading in the OECD as a whole, since the United States had a much greater increase in trade with the developing world than did the average developed country in the 1980s. We conclude that the majority of within-industry upgrading reported in Table II is due not to outsourcing, but to skill-biased technological change, implying pervasive SBTC among developed countries in the 1980s.

IV. Cross-Country Correlations: An Additional Test of Pervasiveness

A. Cross-Country Correlations

The variation in rates of skill-upgrading across industries provides another testable implication of SBTC. We should find the same industries increasing their proportion of skilled workers at similar rates in different countries. Figure III displays a scatterplot of changes in the proportion of nonproduction workers (ΔSn) in U. S. manufacturing industries against changes in that proportion in their U. K. counterparts. Observations are weighted by industry employment shares in manufacturing employment (averaged over all countries in the developed sample), which is

17. 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 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. (Figures on the overseas production of semiconductors are consistent with these calculations [United States International Trade Commission, 1982]. However, foreign outsourcing is concentrated enough in specific industries that it is hard to imagine it accounting for more than a small fraction of the total within-industry shift away from production labor.

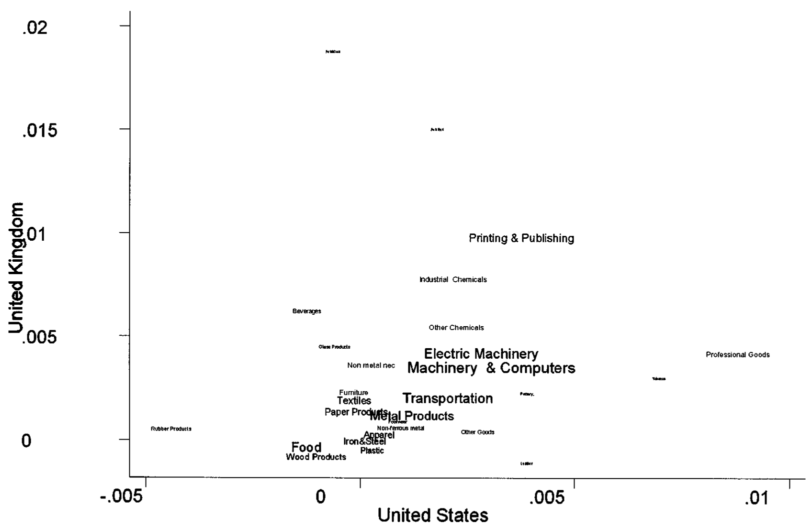

FIGURE III
Changes in Nonproduction Employment Shares:
United States and United Kingdom

Note: Each observation is a pair of "within"-industry increases in the proportion of nonproduction workers between 1980 and 1990. Text size is proportional to the industry share in manufacturing employment.

Source: United Nations General Industrial Statistics Database.

reflected in the size of the text. Among large industries there is certainly a positive correlation in rates of skill upgrading across countries. Printing and Publishing, Machinery and Electronics, Electrical Equipment, and Transportation all have high rates of skill upgrading in both countries, while Metal Products and Food industries have relatively low rates of skill upgrading in both. The weighted correlation coefficient corresponding to this scatterplot is 0.46.

Pervasive skill-biased technological change implies that (holding relative wages constant) within-industry changes in the use of skills will be positively correlated across all countries producing that good. So we test for pervasiveness by examining cross-country correlations of changes in the use of skills (ΔSn) for our entire developed sample.

Table IV presents a matrix of weighted correlations of ΔSn_{ci} with $\Delta Sn_{c'i}$, the cross-country, within-industry changes in the proportion of nonproduction workers for nine developed countries

TABLE IV

CROSS-COUNTRY CORRELATIONS OF WITHIN-INDUSTRY CHANGES IN PROPORTION NONPRODUCTION: 1980–1990

	U. S.	Sweden	Australia	Japan	Denmark	Finland	Austria	U. K.
Sweden	.55*							
	(.00)							
Australia	.25	.18						
	(.20)	(.35)						
Japan	.25	.19	−.09					
	(.21)	(.35)	(.65)					
Denmark	.43*	.17	.19	.25				
	(.02)	(.40)	(.33)	(.21)				
Finland	.45*	.41*	.11	.42*	.31			
	(.02)	(.03)	(.57)	(.03)	(.11)			
Austria	.09	−.21	.33	−.08	.24	.40*		
	(.65)	(.27)	(.09)	(.70)	(.23)	(.04)		
U. K.	.48*	.09	.20	.14	.31	.41*	.64*	
	(.01)	(.65)	(.30)	(.48)	(.11)	(.03)	(.00)	
Belgium	.48*	.58*	.14	.29	.16	.42	.13	.03
	(.03)	(.01)	(.57)	(.23)	(.50)	(.06)	(.60)	(.91)

a. These are cross-country correlations of ΔSn_{ci} and $\Delta Sn_{c'i}$ for countries c and c'. Observations are weighted by industry employment shares averaged over time and across all countries.

b. The number in brackets is the significance level of a two-tailed test that the correlation is zero. An asterisk denotes a significant correlation at the 5 percent level.

c. The sample was restricted to countries with GNP/capita of over $8000 US in 1985 and twenty or more consistently defined industries observed in 1980–1990.

d. The 28 industries in this classification are listed fully in Appendix 2.

e. All correlation coefficients are calculated using a full set of 28 industries, except those involving Japan (27), Belgium (20), and Japan and Belgium (19).

f. *Source*: United Nations General Industrial Statistics Database.

in the 1980s.[18] For example, the first column reports that skill upgrading (ΔSn) in U. S. industries is positively and highly correlated with skill upgrading in Sweden, Denmark, Finland, the United Kingdom, and Belgium and positively correlated with skill upgrading in the other three countries. Asterisks denote a significant correlation at the 5 percent level. Note that the correlations are nearly all positive (33 of 36) and some are quite high. Indeed, 11 of the 36 are significantly positive at the 5 percent level (which is much more than the expected 2.5 percent). These results are robust to changes in the choice of weights and to using wage bill

18. Luxembourg has been dropped, as it has only six observed industries in this period. Norway and Germany were dropped for lack of employment share figures in 1980–1990.

TABLE V
CROSS-COUNTRY CORRELATIONS OF WITHIN-INDUSTRY CHANGES IN PROPORTION NONPRODUCTION: 1970–1980

	U. S.	Norway	Sweden	Australia	Denmark	Finland	W. Germany	Austria	U. K.
Norway	.59*								
	(.00)								
Sweden	.29	.53*							
	(.13)	(.01)							
Australia	−.09	−.26	.20						
	(.66)	(.20)	(.31)						
Denmark	.13	.44*	.46*	.07					
	(.51)	(.03)	(.01)	(.73)					
Finland	−.20	.14	−.07	−.07	.27				
	(.31)	(.48)	(.70)	(.72)	(.17)				
W. Germany	.34	.64*	.69*	−.08	.75*	.31			
	(.12)	(.00)	(.00)	(.72)	(.00)	(.15)			
Austria	.36	.60*	.45*	−.08	.37	.42*	.56*		
	(.06)	(.00)	(.02)	(.70)	(.05)	(.03)	(.01)		
U. K.	.46*	.46*	.52*	.01	.37	.19	.59*	.56*	
	(.01)	(.02)	(.00)	(.96)	(.05)	(.34)	(.00)	(.00)	
Belgium	−.12	−.11	.00	.10	.16	.23	.02	.22	.32
	(.61)	(.67)	(.99)	(.68)	(.50)	(.32)	(.93)	(.36)	(.16)

a. These are cross-country correlations of ΔSn_{ci} and $\Delta Sn_{c'i}$ for countries c and c'. Observations are weighted by industry employment shares averaged over time and across all countries.

b. The number in brackets is the significance level of a two-tailed test that the correlation is zero. An asterisk denotes a significant correlation at the 5 percent level.

c. The sample was restricted to countries with GNP/capita of over $8000 US in 1985 and over twenty consistently defined industries observed in 1980–1990.

d. The 28 industries in this classification are listed fully in Appendix 2.

e. All correlation coefficients are calculated using a full set of 28 industries, except those involving Belgium (20), W. Germany (22), and Norway (26). The cross-country correlations between these three countries are based on the following number of observations: Belgium and W. Germany (18), Belgium and Norway (18), and W. Germany and Norway (22).

f. *Source*: United Nations General Industrial Statistics Database.

rather than employment shares.[19] The high number of precisely estimated large positive correlations is remarkable considering the potential for measurement error. These data are collected from separate national institutions with heterogeneous methods and sampling techniques (see the Appendix). Moreover, the fairly aggregated industry classifications imply that the same (2.5-digit) industry may contain very different four-digit industries in different countries.

Table V replicates that result for a similar sample of ten developed countries the 1970s. It reports similarly high rates of

19. Correlations of wage bill shares show 12 of 36 to be significantly positive. All results are essentially unaffected by using employment weights averaged only over the two paired countries.

correlated skill upgrading. In that earlier decade 36 of 45 correlation coefficients are positive, with 16 significantly so.

Is this convincing evidence of pervasive SBTC? An alternative interpretation of the positive correlations in Tables IV and V is that they reflect similarity within industries in their reaction to similar changes in relative wages.[20] Suppose that industries have elasticities of substitution between skilled and unskilled labor which are similar across countries. Industries faced with similar changes in relative wages in different countries would then respond with similar adjustments to their skill mix of employment, generating positive correlations in ΔSn.

To test that explanation, we compared correlations in country pairs with changes in relative wages in the same direction to correlations in country pairs with changes in wages in opposite directions. This alternative explanation implies that correlations only be positive for countries experiencing changes in relative wages with the same sign. Yet reexamination of Tables IV and V reveals that correlations of skill upgrading are just as high in pairs of countries with wage changes in opposite directions. In the 1980s, six of eighteen country pairs with wage changes in opposite directions have statistically significant positive correlations of ΔSn (at the 5 percent level). For comparison, five of the eighteen pairs with wage changes in the same direction have significantly positive correlations. In the 1970s the result is similar: 9 of 21 country pairs with wage changes in opposite directions have significantly correlated skill upgrading, while 7 of the other 24 have significant correlations. Not only are correlations not negative for country pairs with wage changes in opposite directions, they seem to be significantly positive. We conclude that correlated within-industry upgrading is not caused by changes in wages.

The cross-country correlations suggest that technological change in several of the countries is quite similar. A group of countries (Denmark, Finland, Sweden, the United Kingdom, and the United States) have very similar within-industry changes in the proportion of nonproduction employment. Consider the United States, on the one hand, and Sweden, Denmark, and 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 compel-

20. We thank the editors for this insight.

ling evidence for common technological changes as an underlying cause of decreased demand for unskilled labor.

B. Industries with Large Skill-Biased Technological Change

The industries that drive the correlations in Tables IV and V may indicate what the nature of these technological changes may be. Referring to Figure III, the United States-United Kingdom correlation in the 1980s is mainly due to the large common increases in the share of nonproduction employment in four industries: Machinery (and computers), Electrical Machinery, Printing and Publishing, and Transportation.

Rather than examine all 36 scatterplots, a more systematic way of looking for industries with large effects is to estimate industry effects in a country-industry panel. We estimate the following regression of "within"-industry terms on country and industry indicators:

$$y_{ci} = \sum_{i=1}^{I} \alpha_i + \sum_{c=1}^{C} \beta_c + \epsilon_{ci}, \tag{3}$$

where

$$y_{ci} \equiv \Delta Sn_{ci}\overline{W}_{ci},$$

$$Sn \equiv \frac{S}{E},\ W_{ci} \equiv \frac{E_{ci}}{\Sigma_i\ E_{ci}}.$$

Here an overstrike indicates a simple average over time. The α_i are the average industry terms once country means have been removed. A precisely estimated industry effect reflects a "within" term common to many countries, while a large industry effect is evidence of a high average increase in Sn across countries.

Table VI reports the three largest of the statistically significant estimated industry effects. The third column reports that three industries: Electrical Machinery, Machinery (and computers), and Printing and Publishing, together account for 46 percent of the within-industry component (averaged across countries) in the 1980s. A full set of estimated industry effects is reported in Appendix 2. 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 [United States Department of Labor 1982a, 1982b]. For example, a principal source of SBTC in the printing and publishing industry was automated rather than manual typesetting.

TABLE VI

SELECTED INDUSTRY EFFECTS IN WITHIN-INDUSTRY TERMS: 1970–1980 AND 1980–1990

Industry	Industry effect/ within component		Average share of industry in employment	
	1970–1980	1980–1990	1970–1980	1980–1990
Printing & publishing	.078	.111	.056	.061
	(.021)	(.048)		
Machinery (incl. computers)	.128	.173	.114	.116
	(.025)	(.047)		
Electrical machinery	.131	.173	.090	.096
	(.029)	(.044)		
Sum (3 industries)	.337	.457	.260	.273
Number of observations	264	243		
Root MSE	.0392	.0676		

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

$$y_{ci} \equiv \Delta S n_{ci} \overline{W}_{ci} = \sum_{i=1}^{I} \alpha_i + \sum_{c=1}^{C} \beta_c + \epsilon_{ci},$$

the table reports the three largest estimated industry effects α_i. y_{ci} is the change in the proportion of nonproduction workers in employment multiplied by the industry's weight in manufacturing employment.

b. A full set of industry effects is reported in Appendix 2.

c. Data are scaled so that the estimated coefficient represents the ratio of the industry effect to the cross-country average "within" component.

d. The root mean squared error of the left-hand side variable is .0670 for 1970–1980 and .0894 for 1980–1990.

e. Standard errors are calculated using the White heteroskedasticity robust formula.

f. *Source*: United Nations General Industrial Statistics Database.

These three industries had the highest rates of investment in computers in the United States in the 1980s, if we exclude defense and space-related investment [Berman, Bound, and Griliches 1993, Table 9]. Taken together, the evidence implicates microprocessors as a principal cause of SBTC throughout the developed world in the 1980s. That technological change may not have been unique to the 1980s. The same three industries account for only a slightly smaller share (34 percent) of within-industry upgrading in the 1970s.

V. GLOBAL SKILL-BIASED TECHNOLOGICAL CHANGE?

How pervasive is skill-biased technological change? So far, we have discussed SBTC in developed countries. Looking for evidence of SBTC in developing countries is interesting for two reasons. First, it provides another source of evidence. Second, the implications for income inequality may be greater in countries where less-skilled workers are already extremely poor.

In an H-O framework, for a country that is abundant in unskilled labor, the opening up to trade that occurred in the 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], and Feenstra and Hanson [1996a]. Figure IV reproduces that result using the United Nations data, showing that many low-income countries experienced an increase in the relative wages of nonproduction workers in manufacturing during the decade of trade liberalization between 1980 and 1990. The correlation of wage changes and per capita GNP across countries in the figure is (a precisely estimated) zero, a pattern inconsistent with the Stolper-Samuelson prediction but consistent with SBTC.

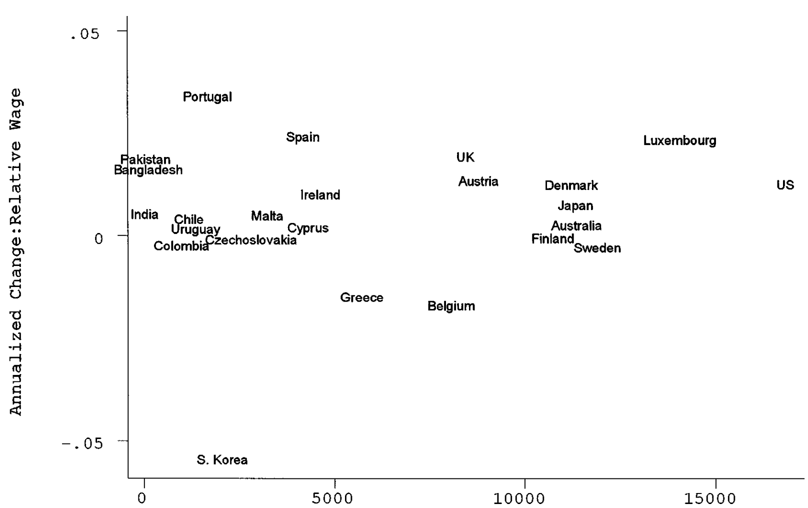

FIGURE IV
Change in Relative Wages in 1980s by GNP

The figure reports relative wages information for 24 countries judged to have reliable information over the 1980s. The annualized change in wage ratio of nonproduction to production workers is recorded between 1980 and 1990 where possible. Other endpoints are used when necessary.

Source: United Nations General Industrial Statistics Database.

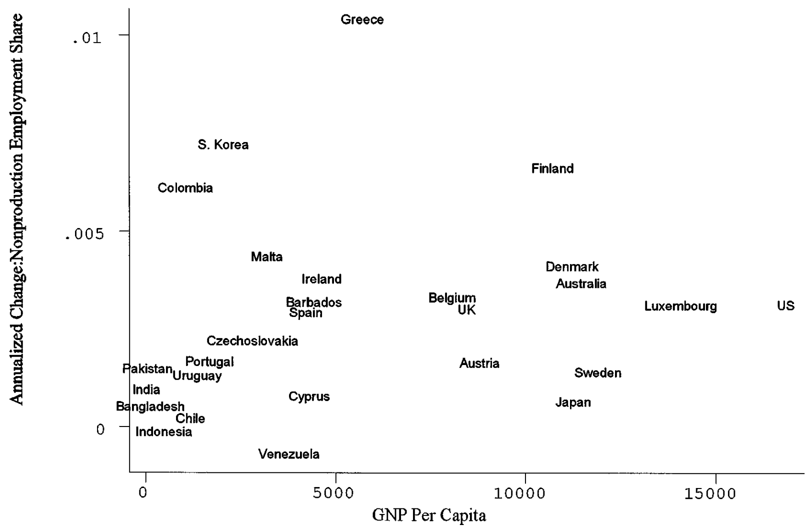

FIGURE V

Skill Accumulation in the 1980s by GNP

The figure reports changes in the proportion of nonproduction workers in manufacturing employment for 27 countries judged to have reliable information over the 1980s. The annualized change in the proportion of nonproduction workers is recorded between 1980 and 1990 where possible. Other endpoints are used when necessary.

Source: United Nations General Industrial Statistics Database.

Stable and rising relative wages are particularly interesting, considering that almost all of these developing countries experienced considerable increases in the proportion of skilled labor in manufacturing over the 1980s, as illustrated in Figure V.[21] For the developing world, that increase in the proportion of skilled labor was generally accompanied by rapid growth in manufacturing employment [Wood 1994]. While H-O logic suggests that increased exposure to trade should reduce relative demand for skilled workers in LDCs, their manufacturing sectors expanded rapidly and upgraded skills at the same time in the 1980s. 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

21. Richardson's [1995] literature survey also reports widespread skill upgrading in the developing world.

transfer combined with capital-skill complementarity, or decreased protection of industries intensive in unskilled workers. Nevertheless, the combination of these findings and the evidence presented above that SBTC was pervasive in the developed world raise the intriguing possibility that SBTC is at work in the developing world as well.

VI. Concluding Remarks

In this paper we have presented strong evidence that the kind of skill-biased technological change which occurred in the United States in the 1980s was pervasive throughout the developed world. Our data show that (a) substitution toward skilled labor within industries occurred in all ten developed countries that we studied, despite generally constant or increasing relative wages of skilled labor; and (b) the same manufacturing industries that substituted toward skilled labor in the United States in the 1980s did so in the other developed countries as well. The three industries with the largest within-industry contributions to skill upgrading are machinery (and computers), electrical machinery, and printing and publishing. All three carried out significant microprocessor-based technological innovation, suggesting microprocessors as the technological link between common patterns of skill-upgrading across countries.

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 countries 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 countries. Using the U. S. 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.* That calculation goes like this: referring back to Table I, in the 1979–1987 period, during which demand for less-skilled workers dropped sharply in the United States, the factor content of SBTC accounts for at least 70 percent 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 percent [BBG, Table IV].[22] For the OECD countries as a whole, 70 percent is a typical figure for SBTC, but 9 percent is a generous estimate of the effects of trade as the United States experienced a much greater increase in trade with the developing world than did the other developed countries. 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.

Although 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. Within-industry skill upgrading outside of manufacturing also occurred in the same industries in the United States as it did in the United Kingdom.[23] Skill-biased technological change outside of manufacturing may also have been pervasive and is an additional likely cause of decreased demand for less-skilled workers.

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. Heckscher-Ohlin trade and sector-biased technical change[24] have presumably both played a role in shifting employment toward sectors of the economy that are intensive in skilled labor. Particular groups, such as very low-

22. 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].

23. Calculations based on the U. S. Current Population Survey and the U. K. Labor Force Survey show a high cross-country correlation of increases in employment shares of people with postsecondary education in fifteen manufacturing industries in the 1980s. Much of the high correlation is driven by rapid skill upgrading in financial services.

24. Haskel and Slaughter [1998] and Jones [1965] analyze the possibility that technological change is both skill and sector biased.

skilled workers, may be disproportionately affected by increased imports. These effects may have increased in the 1990s with increased trade with LDCs. However, the observed between-industry employment shifts in the 1980s do not appear to be nearly large enough to explain the bulk of the shift in demand toward skilled labor.[25]

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 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.

DATA APPENDIX

The data are from the United Nations General Industrial Statistics Database. They cover 28 manufacturing industries at (broadly) the two- to three-digit level, consistently defined across countries and years. Data are collected by the United Nations directly from the appropriate statistical agencies in each country. The main purpose is to facilitate international comparisons relating to the manufacturing sector. Concepts and definitions are drawn from the International Recommendations for Industrial Statistics [Statistical Papers, Series M, No 48/Rev 1, United Nations Publication] and the classification by industry is taken from the International Standard Industrial Classification (ISIC) of All Economic Activities [Statistical Papers, Series M, No 4/Rev 2, United Nations].

For our analysis the key data included are the employment and wage bills of all employees and operatives. "Employees" is usually the average number of employees during the year (other than working proprietors, active business partners, and unpaid family workers). "Operatives" usually refers to employees directly engaged in production or related activities of the establishment, including clerks or working supervisors whose function is to record or expedite any step in the production process. Employees

25. Institutional factors such as the decline in the real value of the minimum wage and in unionization may have also played a role in explaining the rise in the relative wages of skilled workers in some countries. However, such factors have probably not contributed to within- and between-sectors shifts in employment, which have both favored skilled workers.

of a similar type engaged in activities ancillary to the main activity of the establishment and those engaged in truck driving, repair and maintenance, and so on, are also considered to be operatives. Wages and salaries includes all payments in cash or in kind made to employees or operatives during the reference year (these include direct wages and salaries, remuneration for time not worked, bonuses and gratuities, housing allowances and family allowances paid directly by the employer and payments in kind).

The sample of countries selected was dictated by the availability of consistently defined data on employment and wage bills for all employees and operatives over time. The resulting developed country sample includes the twelve highest ranked countries (in 1985 GNP per capita) that meet our selection criteria. For the wider sample of countries used in Figures IV and V we required consistent data over the 1980–1990 period (or as close to those years as possible). This produced the 24 countries judged to have reliable wage data and the 27 judged to have reliable employment data used in the figures.

APPENDIX 1: NONPRODUCTION EMPLOYMENT, WAGE BILL SHARES, AND EMPLOYMENT GROWTH IN MANUFACTURING, 1970–1990

	Nonproduction employment shares			Nonproduction wage bill shares			Employment growth (%)		GNP per capita (US$)	
	1970	1980	1990	1970	1980	1990	1970–80	1980–90	1985	Notes
U. S.	.261	.281	.311	.355	.375	.425	5.5	−8.9	16910	
Norway	.222	.256	—	.291	.323	—	0.6	—	14560	1970,80,n/a
Luxembourg	.163	.209	.239	.253	.328	.394	−5.7	−5.4	14070	
Sweden	.269	.294	.307	.355	.393	.400	−6.0	−15.7	12040	
Australia	.217	.257	.282	.284	.290	.320	−10.8	−11.1	11760	1970,80,87
Japan	see note below						—	6.5	11430	n/a,81,90
Denmark	.251	.282	.318	.336	.344	.402	−10.7	2.5	11380	1973,80,89
Finland	.198	.240	.305	.296	.323	.393	14.9	−18.6	11000	
W. Germany	.247	.290	—	.327	.388	—	−12.9	—	10980	1970,79,n/a
Austria	.246	.296	.310	.335	.411	.443	2.3	−5.4	9100	1970,81,90
U. K.	.259	.300	.329	.320	.359	.421	−18.7	−25.9	8520	
Belgium	.211	.244	.260	.327	.383	.392	−20.3	−13.2	8290	1973,80,85

Sources: United Nations General Industrial Statistics Database (numbers for ISIC 3000, total manufacturing). GNP per capita data are from World Bank [1994], Table 1. Conversion to U. S. dollars is according to the World Bank *Atlas Method*, which averages exchange rates for that year and the preceding two years, and adjusts for differences in U. S. and domestic inflation rates.

The levels are not reliable for Japan as the number of operatives is only counted for a subsample of large firms, while employment is counted for all firms. The changes considered should be more reliable over the 1981–1990 period when the definition of large firms remained the same.

APPENDIX 2: INDUSTRY EFFECTS IN WITHIN-INDUSTRY TERMS

Code and industry	1970–1980 Coefficient (*t*-statistic)	1970–1980 Coefficient (*t*-statistic)	1980–1990 Coefficient (*t*-statistic)	1980–1990 Coefficient (*t*-statistic)
3110 Food	.039 (1.745)	.019 (.842)	−.004 (−.145)	−.008 (−.295)
3130 Beverages	.026 (2.602)	.005 (.513)	.035 (1.947)	.032 (1.580)
3140 Tobacco	.008 (1.960)	−.012 (−1.489)	.011 (2.149)	.004 (.339)
3210 Textiles	.037 (2.511)	.017 (1.169)	.047 (2.662)	.043 (2.363)
3220 Apparel	.022 (2.450)	.002 (.188)	.000 (0.017)	−.003 (−.174)
3230 Leather products	−.002 (−.300)	−.021 (−2.327)	.020 (1.310)	.017 (.871)
3240 Footwear	−.001 (−.367)	−.021 (−2.688)	.015 (2.030)	.011 (.991)
3310 Wood products	.054 (4.740)	.037 (2.680)	.041 (1.677)	.037 (1.775)
3320 Furniture	.028 (3.537)	.012 (1.351)	.019 (1.704)	.015 (1.088)
3410 Paper products	.044 (4.385)	.024 (1.835)	.034 (2.725)	.031 (2.606)
3420 Print & publishing	.099 (5.049)	.078 (3.771)	.114 (2.183)	.111 (2.291)
3510 Ind chemicals	.027 (2.233)	.011 (.760)	.053 (4.809)	.049 (4.219)
3520 Other chemicals	.035 (3.008)	.018 (1.569)	.051 (5.041)	.047 (3.651)
3530 Petr refineries	.000 (.143)	−.018 (−2.161)	.029 (1.429)	.026 (1.125)
3540 Petr & coal	.007 (2.166)	−.012 (−1.542)	−.009 (−.700)	−.012 (−.766)
3550 Rubber prod	.013 (3.061)	−.001 (−1.062)	.011 (1.288)	.008 (.594)
3560 Plastic prod	.027 (4.398)	.007 (.872)	−.000 (−.004)	−.003 (−.321)
3610 Pottery, china	−.004 (−1.458)	−.023 (−2.788)	.014 (2.041)	.010 (.833)
3620 Glass products	.014 (3.512)	−.006 (−.850)	−.005 (−.889)	−.009 (−.672)
3690 Nonmetal nec	.046 (3.794)	.027 (2.145)	.034 (3.364)	.030 (2.005)
3710 Iron & steel	.052 (4.479)	.033 (2.761)	.016 (1.070)	.012 (.842)
3720 Nonferrous metal	.009 (2.756)	−.010 (−1.399)	.007 (.943)	.003 (.198)
3810 Metal products	.074 (5.740)	.054 (4.296)	.050 (1.989)	.046 (2.192)
3820 Machinery, computers	.148 (5.747)	.128 (5.162)	.177 (3.265)	.173 (3.658)
3830 Electric machinery	.151 (4.887)	.131 (4.501)	.177 (3.914)	.173 (3.943)
3840 Transport equip	.061 (3.379)	.041 (2.240)	−.001 (−.013)	−.004 (−.089)
3850 Professional goods	.011 (1.129)	−.009 (−.722)	.072 (3.842)	.069 (2.876)
3900 Other goods	.014 (4.512)	−.006 (−.741)	.019 (2.404)	.015 (1.332)
Country effects	No	Yes	No	Yes
Observations	264	264	243	243
Root MSE	.0403	.0392	.0702	.0676

The estimating equation is equation (3) in the text. 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 left-hand side variable is .0670 for 1970–1980 and .0894 for 1980–1990. *t*-statistics are calculated using heteroskedasticity robust standard errors. Countries included are all those in Tables IV and V.

Source: United Nations General Industrial Statistics Database.

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