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James D. Adams

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ABSTRACT

Considerable effort has been devoted in recent years to the *description* of wage structure. This research has documented a rising return to education, unobserved skill, and work experience. However, there appears to be little research into causes of the change in structure. This paper seeks to fill the gap by studying the impact of domestic technology, foreign technology, and trade on U.S. wages. A standard model of general equilibrium is presented that shows each effect tends to be opposite in sign for high and low skilled labor. We then modify the model to allow for accumulation of sector-specific skills and sectoral immobility. In this version shocks have the same direction of effect on high and low skilled workers.

In the empirical work we devise measures of foreign and domestic R&D *inputs* for six sectors of the private U.S. economy, and of R&D *outputs* for twenty-four manufacturing industries. Holding time and industry effects constant we find that: (i), in most cases technology has the same rather than opposite effect on wages at both skill levels; (ii), a rise in the foreign share in world innovation or U.S. patents decreases U.S. wages; (iii), an increase in the U.S. share in world innovation or U.S. patents raises U.S. wages, especially for the less skilled; and (iv), the stock of world innovation and U.S. patents decreases real wages, especially for the less skilled. Turning to the relative skilled wage, we find that (v), the stock of world innovation or U.S. patents increases the skill differential. Holding technology constant we find mixed results for trade. Effects of trade on real wages are generally insignificant once time effects are taken into consideration.

Together the findings suggest that sectoral labor immobility is an important part of the interaction between the U.S. labor market, technology, and trade. They also suggest that technology is a key explanatory element in the twists of the wage structure of recent years, and that, *in and of itself*, trade may not be an important determinant of real wages.

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I. Introduction

Considerable effort has been devoted in recent years to the *description* of the structure of wages. This research has documented rising returns to education, unobserved skill, and work experience in the United States during the 1980s despite a large increase in the number of skilled workers. In their work on wage structure Murphy and Welch (1992) uncover a wavelike pattern to schooling differentials since the 1960s. The premium to college rises until the early 1970s, falls until about 1980, and rises to record levels by the late 1980s. The decline of the college premium through the 1970s is largely attributable to cohort size effects linked to the entry of young, college-trained workers [Welch (1979)]. The remaining increase in the college premium arises from changes in labor demand [Katz and Murphy (1992)], especially the pattern during the 1980s and 1990s of simultaneous increases in the relative supply and the relative wage of the college trained. Juhn, Murphy, and Pierce (1993) further argue that rising wage inequality *within* schooling and experience groups is due to the rising price of unobserved skills.

Technology and trade are the likely cause of shifts that favor skilled workers. But to my knowledge there has been little research that constructs indicators of trade and technology and studies their implications for wages, presumably because of concerns about data availability and the effort required to bring the data to light. This paper seeks to fill the gap by subjecting the role of technology and trade in wage structure to empirical tests.

Section II offers a graphical overview of the evidence on technology, trade, and wages. Section III presents a standard model of general equilibrium based on the simplifying assumption of sectoral labor mobility. We explore the implications of this standard model for wages of skilled and unskilled wages, where the level of skill is indexed by discrete levels of education. We find a distinctive signature of this model: the comparative statics effects of technology and trade on wages are opposite in sign for skilled and unskilled labor. Next we develop an alternative view of the labor market in general equilibrium. According to this view sector-specific skills accumulate at every educational level, giving rise to short run sectoral immobility. With this modification we find that shocks have the same, not the opposite effect on wages of skilled and unskilled workers.

Sections IV and V confront these implications with data. Section IV documents sources of the data, describes the construction of the technology and trade variables, and explains the estimation procedures. We develop two complementary sets of data to test the effects of technology and trade. The first covers six broad, "one digit" sectors that span the private U.S. economy over the period 1973-1988. The second covers twenty-four industries within manufacturing from 1979-1993. Throughout the paper trade indicators are ratios of the value of net imports to the value of U.S. output. However, technology indicators differ in the two data sets because of data availability. In the first data set technology is based on foreign and domestic R&D *inputs*, the sectoral science resources in the U.S and abroad. In the second, technology is based on R&D *output*, the stocks of patents by foreign and domestic inventors *in the U.S.*

Section V presents estimates corresponding to the two data sets. Holding time and industry effects constant we find consistent patterns for real wages of high skilled (college) and low skilled (high school) workers: (i), technology has the same rather than opposite effect on wages at both skill levels; (ii), a rise in the foreign share in world innovation or U.S. patents usually decreases U.S. wages; (iii), an increase in the U.S. share in world innovation or U.S. patents tends to raise U.S. wages; and (iv), the stock of world innovation and of U.S. patents are associated with a decrease in real wages, especially for the less skilled. Turning to the relative skilled wage, we find that (v), the stock of world innovation or U.S. patents is linked to an increase in the skill differential. Holding technology constant we find mixed results for trade. Effects of trade on real wages are generally insignificant when time effects and technology are held constant. However, for the U.S. private economy, (vi) trade with the Western Hemisphere causes an increase in the skill differential. Within manufacturing we find that (vii), trade has a generally insignificant effect on the skill differential. Together these findings suggest that sectoral immobility is an important part of the interaction between the U.S. labor market, technology, and trade. They suggest that technology is an element in the twists of the wage structure of recent years, and that, *in and of itself*, trade may not be an important determinant of real wages. Section VI concludes with a summary of findings and an appraisal of the evidence.

II. Graphical Overview of the Data

Figures 1 through 7 present the graphical evidence. Figure 1 shows the path of weekly earnings for college and high school graduates in four major sectors of the U.S. economy during 1973-1988. The four sectors are high technology manufacturing ("HT Man"), low technology manufacturing ("LT Man"), agriculture ("Agric"), and services ("Serv"). In all sectors college and high school wages narrow until roughly 1980, and spread apart thereafter. But there are industry effects in Figure 1: the decline of high school wages, for example, differs by sector.

Figures 2 and 3 trace a measure of the inventive efficiency for the United States, Europe, and Asia. This measure is the ratio of patents issued to resident inventors divided by the number of scientists and engineers in a given region; it is a measure of the productivity of invention[1].

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[1] The source of the resident patent data is World Intellectual Property Organization, **Industrial Property Statistics**. Sources for numbers of resident scientists and engineers *at the*

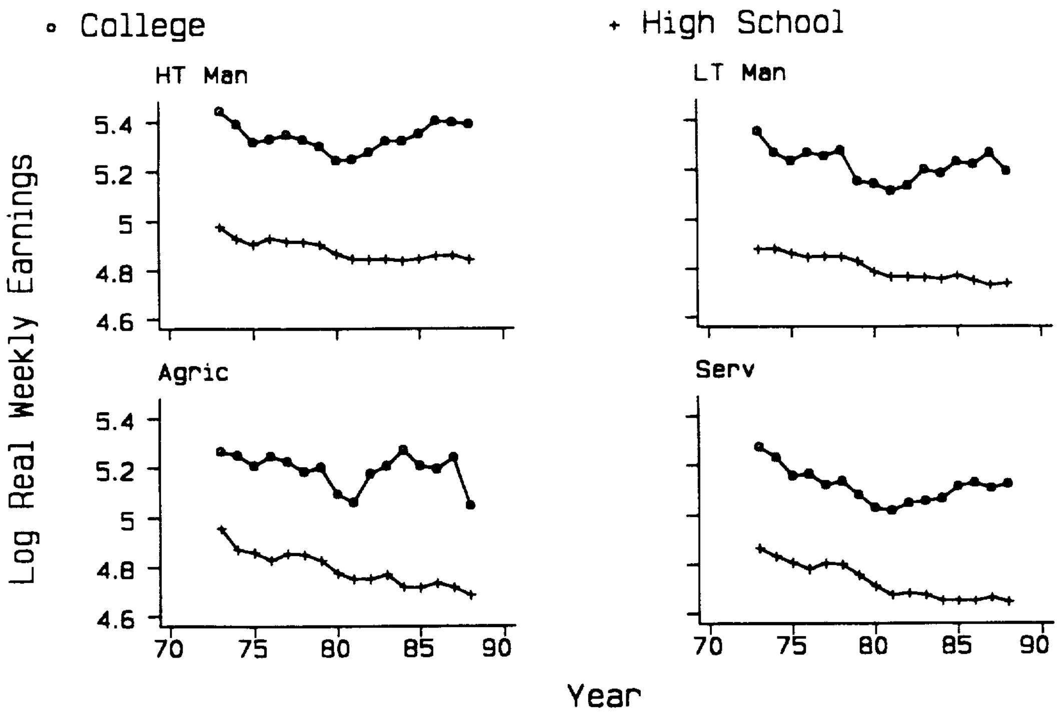

Fig.1-- Log Real Weekly Earnings by Sector

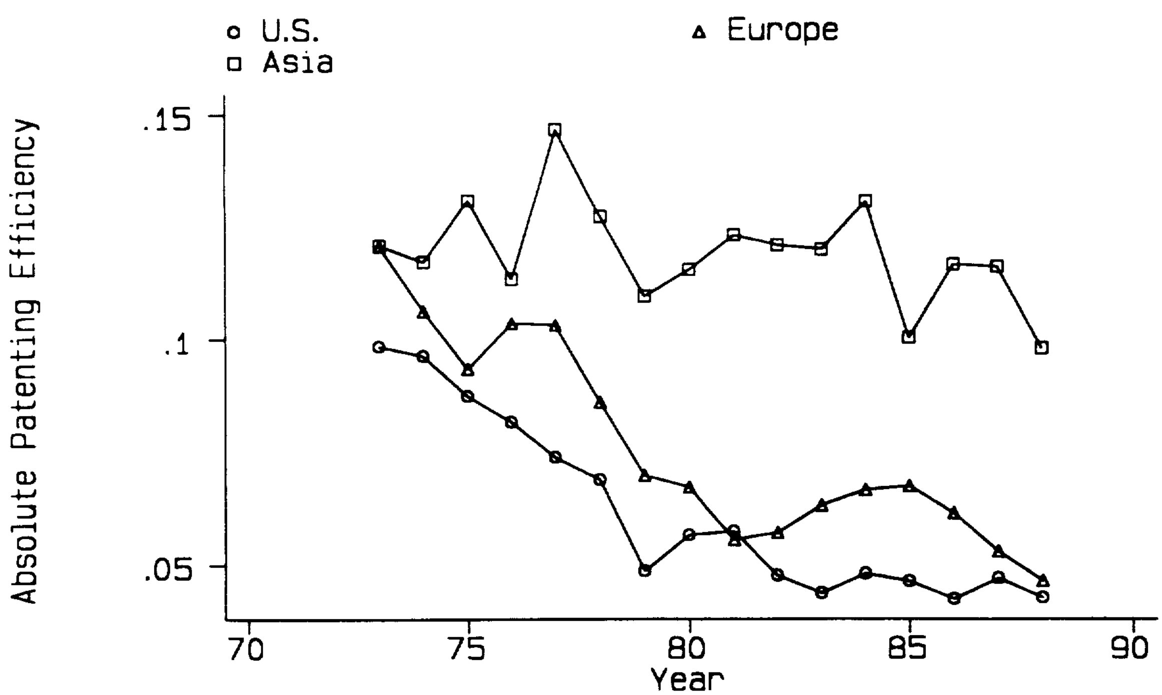

Fig.2-- Resident Patents/S&E by Region

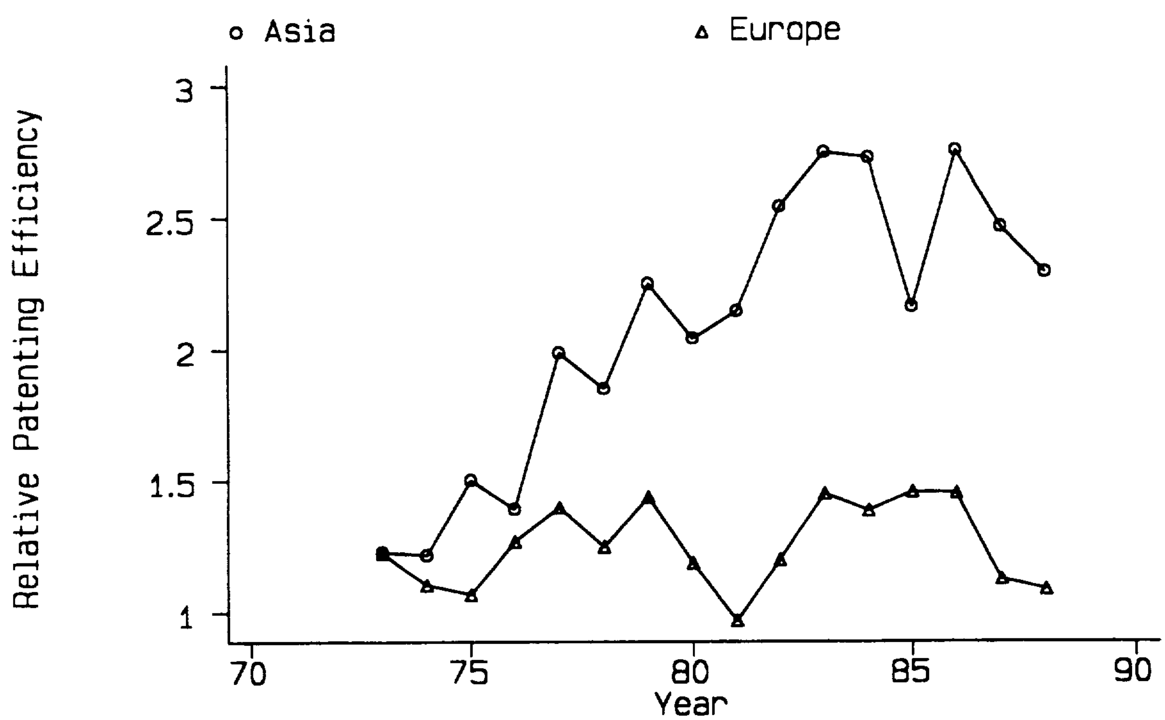

Fig.3-- Resident Patents/S&E Relative to the US

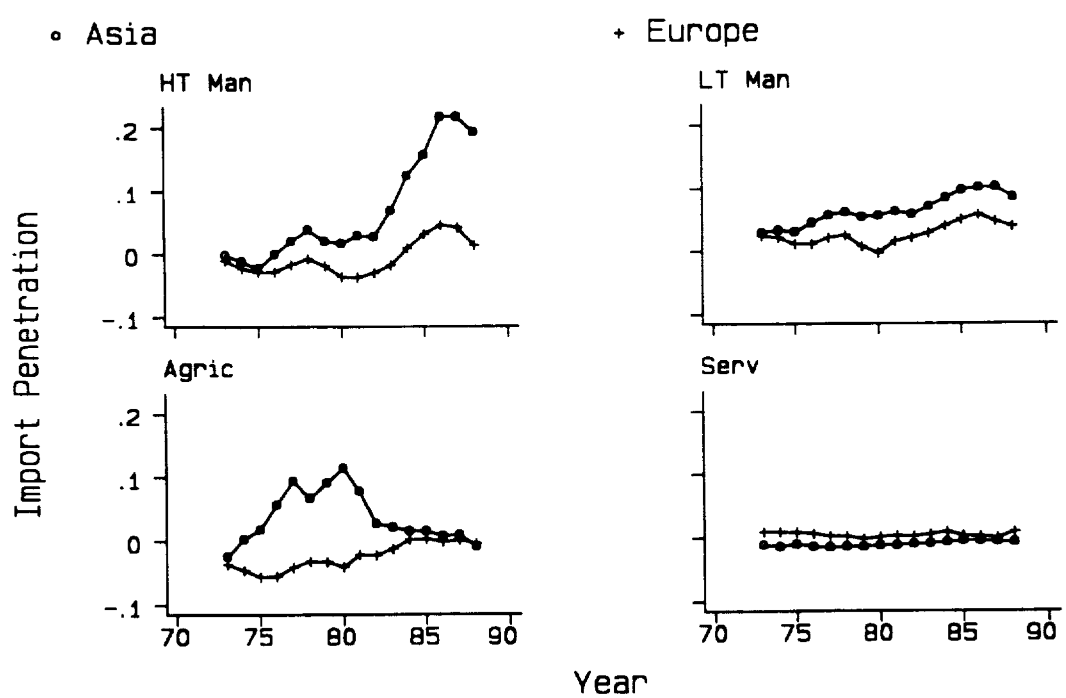

Fig.4-- Ratio of Net Imports to Output

Figure 2 shows a sharp decline in patenting per scientist and engineer (S&E) in the U.S. and in Europe, but not in Asia[2]. Figure 3 displays the difference in apparent patenting productivity more clearly by taking the ratio of patents per S&E in both Europe and Asia to the U.S. ratio. This "ratio of a ratio" is flat for Europe but rises abruptly for Asia. Figures 2 and 3 suggest that in recent years the relative efficiency of invention has risen in Asia.

Figure 4 surveys the trade indicators. The graph shows the ratio of net imports to U.S. output originating in Asia and Europe in each of the four sectors of Figure 1. Except for services, trade penetration has been rising over time. However, regional patterns of import penetration differ by sector. Asian trade penetration is greater and rises more rapidly in high technology manufacturing than in other sectors. When we compare Asia with Europe, it is clear that Asian trade penetration of U.S. markets is again the more recent of the two.

Figures 5 and 6 furnish an overview of the technology indicators. Figure 5 shows S&Es employed in each of our four sectors in the U.S., Japan, and Europe[3]. S&Es have risen over time in all three regions but with some notable differences. Japanese S&Es are fewer but increase more

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country level are the **United Nations Statistical Yearbook** and the **OECD Main Science and Technology Indicators**. Coverage at the national level is broader than we were able to achieve at the sectoral level, yet it is still dominated by the top five R&D countries. The data for Europe include all European countries in the OECD, while the data for Asia cover Hong Kong, India, Indonesia, Korea, Japan, Malaysia, and Singapore.

[2] For interpretations of the decline of patenting in the U.S., see Griliches (1990, 1994).

[3] See Section IV for sources of the science resources and patenting data appearing in Figures 5-7. Sectoral data on industrial scientists and engineers in Europe are not consistently available over time except in France, Germany, and the U.K. Similarly, sectoral data on science resources in Asian are not available except for Japan. From the data on Asia that we have, it is clear that Japanese science resources are the bulk of Asian science resources in the 1970s and 1980s.

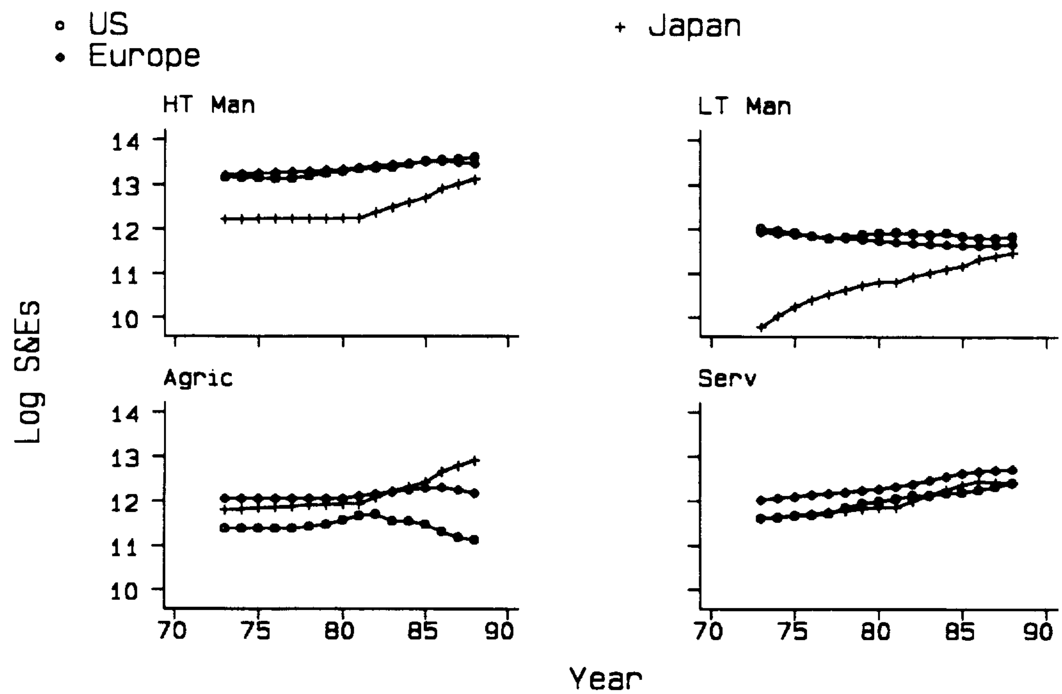

Fig.5-- Log Foreign and US S&Es by Sector

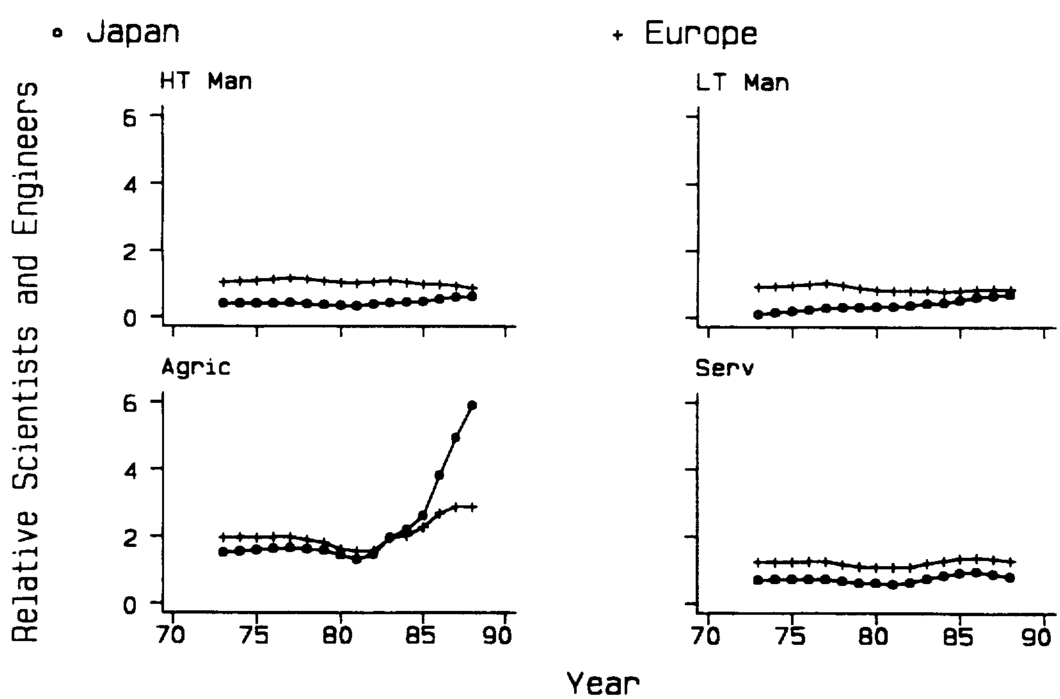

Fig. 6-- Ratio of Foreign to US S&Es

rapidly than S&Es in the U.S. and Europe. Still, the increase of Japanese S&Es does not explain the sharp upward trend of mostly Japanese resident patents implied by Figures 2 and 3. To make this point more clearly, Figure 6 reports ratios of foreign to U.S. S&Es by sector. The increase in Japanese S&Es is not dramatically larger than the increase in the West.

The graphical presentation concludes with an exploration of somewhat different patent data, patents *in the U.S.* by U.S., European, and Japanese inventors. Figure 7 reports findings for our four sectors. Since the U.S. is the world's largest technology market, it might be expected that minor or imitative patents would be eliminated from Figure 7. Consistent with this, Japanese patents *in the U.S.* rise only slightly more rapidly than those of the U.S. or Europe. This view is different from the graphs of Asian patents in Figures 2 and 3, which are dominated by Japan. It suggests that many of Japan's *resident* patents are of a minor or imitative nature[4].

Overall Figures 1 to 7 imply that technology and trade effects differ by region of the world and by sector of the U.S. economy. Furthermore, the time paths of U.S. wages, while exhibiting common trend, also vary by sector and skill. The industry dimension of the data contains information that is independent of trend.

III. Analytical Framework

In this section we present a general equilibrium model of wages that encompasses several leading approaches to technology, trade, and growth. Afterwards we use this "canonical" model to derive the effects of technology and trade on wages. Given the strong implications of the model as conditioned on the assumption of factor mobility, we then introduce short run sectoral

[4] For more on this point, see Robert E. Evenson (1984).

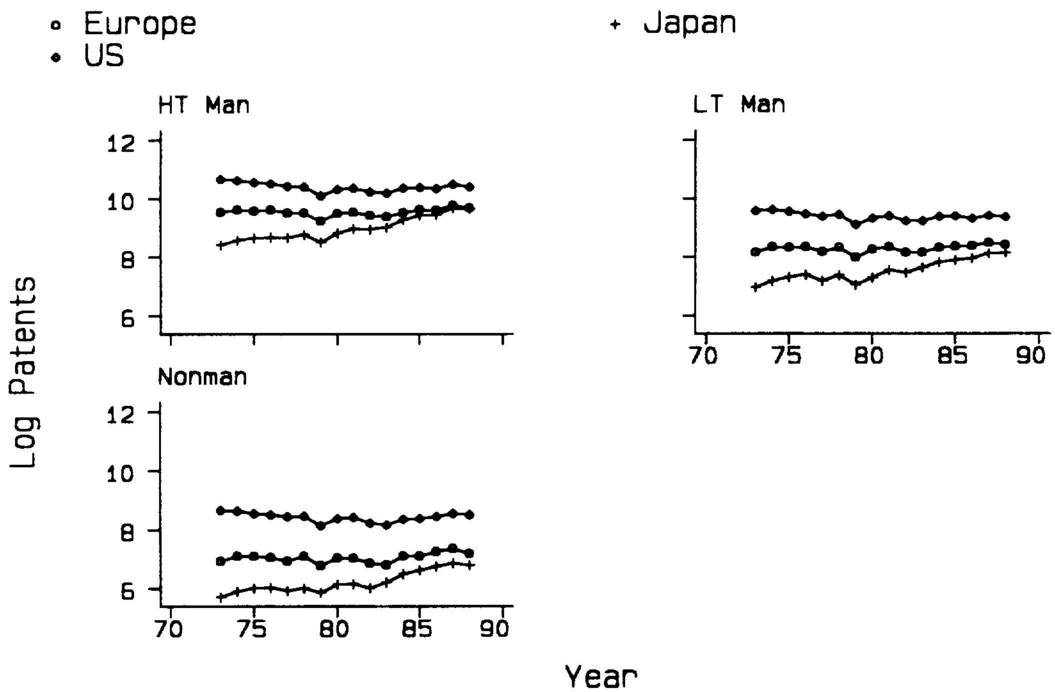

Fig.7-- Log of US Patents by Region of Origin

immobility, which permits more general effects of technology and trade on wages.

A. Labor Perfectly Mobile between Sectors

Consider an economy comprised of two sectors X and Y. Goods are produced using unskilled labor ℓ, skilled labor h, and stocks of domestic and foreign R&D capital. Let X be the high technology good and assume that R&D uses the same production function as X, so that output of X and research in the X sector can be treated as a single good. X uses skilled labor intensively, whereas Y is intensive in the use of unskilled labor. Wages of skilled and unskilled labor are w_h and w_ℓ. Production in both sectors is a constant returns to scale process so unit cost is independent of output. Unit costs, which are Cobb-Douglas in form, increase in the wage rates w_ℓ and w_h. Unit costs of X, the lone sector undergoing technological change, are decreasing in the stocks of domestic and foreign R&D capital k_X and K_X [5]. It follows that

$$
\begin{aligned}
c_X &= A_X k_X^{\beta_X} K_X^{\gamma_X} w_\ell^{\alpha_X} w_h^{1-\alpha_X} \equiv b_X w_\ell^{\alpha_X} w_h^{1-\alpha_X} \\
c_Y &= A_Y w_\ell^{\alpha_Y} w_h^{1-\alpha_Y},
\end{aligned}
\tag{1}
$$

where $0<\alpha_j<1$, $\beta_j<0$, and $\gamma_j<0$, and we impound cost-saving effects of technology in the term

$$
b_X \equiv A_X k_X^{\beta_X} K_X^{\gamma_X} \tag{2}
$$

By the factor intensity assumptions $\alpha_Y>\alpha_X$. Domestic and foreign technology have different effects on c_X since $\beta_X \neq \gamma_X$, yet both reduce c_X: $\beta_X<0$, $\gamma_X<0$. For later use define the absolute value of the cost reduction as

[5] The assumption that X is the lone sector to undergo technical change is a simple way to represent the fact that industries differ in their rate of technical change.

$$b*_X = -\beta_X k*_X - \gamma_X K*_X. \quad \textbf{(3)}$$

The term $b*_X$ is positive since β_X and γ_X are negative and the stocks of R&D are growing: $k*_X$, $K*_X$ are both positive.

By Shephard's lemma, factor demands per unit of output are given by derivatives of the unit cost functions with respect to factor price, $c_{\ell j} = \partial c_j/\partial w_\ell$, $c_{hj} = \partial cj/\partial w_h$, j=X,Y. Building on this result we see that labor market clearing requires that factor demands equal the endowments of labor:

$$\begin{aligned} c_{hY} Y + c_{hX} X &= H \\ c_{\ell Y} Y + c_{\ell X} X &= L, \end{aligned} \quad \textbf{(4)}$$

in which L and H are the endowments of skilled and unskilled labor.

Pricing and demand conditions are required to complete (1)-(4)[6]. These are troublesome in that no one model of pricing and demand has been accepted by the economics profession. For this reason we summarize the implications of *several* models in one formulation without committing to any one. Models of intra-industry trade [Krugman and Helpman (1986)] complete (1)-(4) by assuming monopolistic competition of differentiated products in sector X. Y is a homogeneous good produced under competitive conditions. Markup pricing of each variety of X is symmetric and of the form $p_X=\theta \bullet c_X$, where θ is the markup factor, $\theta>1$. The price of Y equals average and marginal cost c_Y. Thus the pricing conditions are

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[6] See Jones (1965) for an algebraic treatment of the two sector model under conditions of competition. See Krugman and Helpman (1986) for extensions of the framework to imperfect competition. We employ Jones' notation in this paper in view of its familiarity to readers.

$$p_X = \theta \bullet c_X$$
$$p_Y = c_Y. \tag{5}$$

P_Y is exogenously determined on world markets. From (5) the price of X depends on determinants of the markup θ as well as domestic unit cost c_X. Clearly the markup is lower when unit costs of X are lower overseas; thus technology diffusion *decreases* θ by opening production elsewhere. In view of this, hereafter we treat variations in θ as exogenous.

Recent models of endogenous growth allow for an R&D sector that supports product development in X[7]. The "expanding varieties" approach assumes that R&D creates new types of goods. Since equilibrium requires that the present value of profits from a new good be less than or equal to development costs, firms do not infringe on existing varieties. Thus countries as well as firms specialize in different varieties, and Rivera-Batiz and Romer (1991) use this to show that globalization raises income and growth by expanding the range of capital goods. The second or "quality ladders" model assumes that firms seek to produce the latest versions of a given set of varieties. Thus the stock of foreign R&D lowers the volume of domestic high technology goods X by raising the fraction of the latest generation goods invented and produced abroad[8]. In contrast the stock of domestic R&D raises the domestic fraction of the latest varieties of X and the size of the domestic X sector.

Now consider the demand conditions. For Y the conditions are that the price of Y is fixed

[7] See Paul Romer (1986, 1990), Grossman and Helpman (1991), and Rivera-Batiz and Romer (1991) for examples.

[8] Krugman (1979) obtains similar results in a model of imitation by follower countries.

by the international market. This cannot hold for X because R&D requires market power to sustain product development; consistent with this we assume that demand for X has a constant price elasticity η, $\eta \geq 1$. Aggregate demand for domestically produced X is therefore,

$$X = f_X E \bullet p_X^{-\eta} \equiv d_X p_X^{-\eta}, \qquad \textbf{(6)}$$

where f_X is the share of X that is domestically produced, E is world expenditure, and we impound the effects of technology-driven demand shift in the term d_X[9].

Development of new products forces us to consider the effects of technology on product creation. Domestic and foreign R&D (k_X and K_X) have opposite effects on the domestic share f_X; and yet both could raise expenditures E through spillovers. Reflecting the two channels of demand shift for domestic and foreign R&D we write d^*_X, the percent change in expenditures on domestic X, as a constant elasticity function of the R&D stocks,

$$d^*_X = \mu_X k^*_X + \nu_X K^*_X, \qquad \textbf{(7)}$$

where $\mu_X > 0$ and the signs of ν_X and d^*_X are uncertain.

The model consists of (1)-(7). We now turn to the comparative statics of changes in wages brought about by changes in technology and trade. Let Z^* represent the log differential dZ/Z of Z and log differentiate (1)-(7). After some algebra, which is contained in the Appendix,

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[9] In the expanding varieties approach, as in quality ladders preferences are homothetic and goods X and Y consume constant shares of the budget. The two approaches differ in their interpretation of the domestic share f_X. In the expanding varieties model, if we approximate so that prices of high technology goods are the same regardless of location, we find that $f_X = n_d/n$, where n_d is the number of domestically produced varieties. In the quality ladders approach, f_X is the fraction of all latest generation commodities produced at home.

we reach the solutions for percentage changes in unskilled and skilled wages,

$$w*_{\ell} = \frac{1}{D} \times \left\{ -(1-\alpha_Y)\bullet d*_X - (1-\alpha_Y)(\eta - 1)\bullet b*_X + \left[(1-\alpha_X)\eta + \frac{M}{\Gamma}\right]\bullet p*_Y - (1-\alpha_Y)\eta\bullet\theta* \right\}$$
$$w*_h = \frac{1}{D} \times \left\{ \alpha_Y \bullet d*_X + \alpha_Y(\eta - 1)\bullet b*_X + \left[-\alpha_X\eta + \frac{M}{\Gamma}\right]\bullet p*_Y + \alpha_Y\eta\bullet\theta* \right\}. \qquad \textbf{(8)}$$

Definitions of the terms D, A, Γ, and M are

$$D = A\,\eta + \frac{M}{\Gamma}, \quad A = \alpha_Y - \alpha_X, \quad \Gamma = \lambda_{hX} - \lambda_{\ell X}, \quad M = \delta_h(1-\lambda_{\ell X}) + \delta_{\ell}(1-\lambda_{hX}), \qquad \textbf{(9)}$$

where δ_h and δ_ℓ are factor substitution terms defined in the Appendix. All four terms in (9) are positive. The percent change in the skilled-unskilled wage differential follows from (8):

$$w*_h - w*_{\ell} = \frac{1}{D}\left[d*_X + (\eta - 1)\bullet b*_X - \eta\bullet(p*_Y - \theta*)\right]. \qquad \textbf{(10)}$$

Equations (8)-(10) summarize the wage effects of technology and trade on the assumption of sectoral mobility. According to (8) the absolute value of cost-saving technical change in the X sector ($b*_X>0$; see (3) above) lowers unskilled wages but raises skilled wages. The result follows from the neutrality of technical change in the cost function and elastic demand for X. Factor saving is overcome by the growth of X due to decline in p_X. As a result factor demand decreases for ℓ and increases for h.

An increase in the demand curve for X that is driven by technology ($d*_X>0$; see (7) above) lowers the unskilled wage but raises the skilled wage, since production shifts towards the skill intensive good X. Rising price of Y ($p*_Y>0$) increases unskilled wages but the effect on skilled wages is ambiguous, because the rise in p_Y brings about a fractional increase in the price of X through demand, and this fractional increase renders the effect of p^*_Y ambiguous in the equation for w^*_h. Rising markups ($\theta^*>0$) lower the unskilled wage but raise the skilled wage. All these effects are opposite in sign for low and high skilled wages.

Equation (10) shows that the *relative* skilled wage increases when technology drives demand towards X, falls when the price of Y increases, and rises when the markup on X increases ($\theta^*>0$). We can use (10) to decompose effects of domestic and foreign technology on relative wages. To do so, insert the definitions of d^*_X and b^*_X into (10) and set all other variations equal to zero. We arrive at the expression

$$w*_h - w*_\ell = \frac{1}{D} \times \left\{ \left[\mu_X + (\eta - 1)\beta_X \right] \bullet k*_X + \left[\nu_X + (\eta - 1)\gamma_X \right] \bullet K*_X \right\}, \qquad \textbf{(11)}$$

where coefficients of k^*_X and K^*_X are elasticities of the skill differential with respect to percent changes in domestic and foreign R&D. By (11) demand shift effects of domestic R&D stock ($\mu_X>0$) and cost reducing effects ($(\eta-1)\beta_X>0$) are mutually reinforcing for the skill differential. However the net effect of foreign R&D on the differential is ambiguous since demand shift could expand ($\nu_X>0$) or contract ($\nu_X<0$) the domestic X industry, while cost reduction could increase the skill differential ($(\eta-1)\gamma_X>0$).

B. Labor Imperfectly Mobile between Sectors

The implication that technology and trade have opposite effects on skilled and unskilled wages follows from the assumption of perfect inter-sectoral mobility. But the result is misleading if wages reflect sector-specific skills. In that event wages would have to be driven to entry-level wages elsewhere before experienced workers would leave. The result is that shocks would lower wages of *both* skilled and unskilled labor in a sector.

A simple model that includes these effects is as follows. Entry level wages are w_j, where j is the skill class and as before, j=ℓ,h. Let worker efficiency rise at the constant rate of e_j per year of sectoral experience, assume finite lived workers who are in the work force for T years, and for convenience let age be uniformly distributed. Then the steady state average age of a worker would be T/2, and the average wage per worker would be $(1+e_jT/2)w_j$. If e_j were the same across sectors there would be no sectoral wage differences in the steady state.

Now let sectoral labor demand decline due to a persistent shock. Since the wage of an experienced worker elsewhere is the entry level wage, the experienced wage would fall by approximately $w_je_jT/2$ on average before it would pay to change sectors[10]. Conversely, a positive shock would require a rise in entry level wages of $w_je_jT/2$ before workers would migrate from elsewhere. We conclude that sector-specific skills imply positive co-movements in wages, not movements in opposite directions as implied by (8). Furthermore, *quantity* trade shocks to a sector become theoretically important.

IV. Data Construction and Estimation Procedures

We construct two data sets in order to assess the wage effects of technology and trade. In each data set we employ two specifications of technology in our econometric models. The first specification is

$$\ell n(W_{ijt}) = a_i + YD_t'b_i + ID_t'c_i + \ell n(S_{jt})'d_i + \ell n(T_{jt})e_i + N_{jt}'f_i + u_{ijt}. \quad \textbf{(12)}$$

Here "I" stands for the education or work experience group, "j" is the sector or industry, and "t"

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[10] The approximation in the text ignores the effect of migration between sectors on the entry level wage in other sectors. Thus the entry level wage remains w_j in the receiving sector.

is time, and the real wage is W_{ijt}. The term a_i is a constant, YD_t is a vector of time dummies, and ID_t is a vector of industry dummies. It is important to include time dummies in the real wage equation because of errors in price deflators and changes in the method of paying workers that have replaced earnings with fringe benefits over time. We include industry dummies because industries vary in the amount of their training and skill requirements.

As far as the remaining variables in (12) are concerned, $\ell n\,(S_{jt})$ is a vector of regional innovation shares in logarithms, $\ell n\,(T_{jt})$ is the log of world innovation, N_{jt} is a vector of regional imports minus exports divided by U.S. domestic output, and u_{ijt} is a normally distributed error term. This specification allows the parameters b_i, c_i, d_i, e_i, and f_i to vary with education or experience. Note that we specify the regional innovation effects in terms of shares in order to detrend and separate effects of individual regions, making identification of regional effects possible. However there are also disadvantages in the specification: the log of the domestic innovation share cannot be entered simultaneously with logs of the foreign innovation shares, and the log of world innovation confounds domestic and foreign effects.

As a remedy for these problems we offer an alternative specification that writes the log of real wages as a function of the log of regional innovation *levels*:

$$\ell n(W_{ijt}) = a_i + YD_t' b_i + ID_t' c_i + \ell n(\mathrm{T}_{jt})' d_i + N_{jt}' e_i + u_{ijt}. \tag{13}$$

Here T_{jt} is a vector of log regional innovation levels, including that of the U.S. While this version separates domestic innovation from foreign innovation in principle, common trend in innovation introduces collinearity in the estimates.

The specification of the *relative* wage equations in Tables 4, 7, and 8 is parallel to (12) and (13). For (12) the relative wage equation is

$$\ell n(W_{Cjt}/W_{HSjt}) = a_i + YD_t^{\prime}b_i + ID_t^{\prime}c_i + \ell n(S_{jt})^{\prime}d_i + \ell n(T_{jt})e_i + N_{jt}^{\prime}f_i + u_{ijt} \tag{12'}$$

At times we drop year dummies from (12') on the assumption that errors in the price deflators are the same at both skill levels, and that the substitution of fringes for earnings is similar. We also explore the relative wage version of the levels formulation, which is easily obtained from (13).

The first data set covers six major sectors spanning the private U.S. economy during 1973-1988. We employ measures of industrial science resources by sector for the United States and its largest competitors in technology: Japan, the U.K., France, and Germany. Evidence is limited to these countries over the sample period[11].

The second data set is comprised of twenty-four manufacturing industries over the period 1979-1993[12]. In this file we employ patents in the U. S. by the U.S. itself, by Western Europe, by Asia, and by Canada and Mexico. The patent indicators are restricted to manufacturing but the data do cover a large number of detailed manufacturing industries.

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[11] The six sectors are: agriculture, mining, and construction; high technology manufacturing (chemicals, machinery, electrical equipment, transportation equipment, and instruments); all other manufacturing; transportation, communication, and public utility services; wholesale and retail trade; and finance, real estate, and other services.

[12] The twenty-four manufacturing industries are food; textiles; apparel; inorganic and organic chemicals; plastics, resins, and fibers; pharmaceuticals and agricultural chemicals; other chemicals; petroleum refining; rubber and miscellaneous plastics; stone, clay, and glass; primary ferrous metals; primary nonferrous metals; fabricated metals; construction machinery; metalworking machinery; other machinery; electrical transmission and distribution equipment; electrical industrial apparatus; household audio and visual equipment; motor vehicles; aircraft; shipbuilding and parts; ordnance and missiles; and instruments.

A. Data on Six Major Sectors, 1973-1988

For each of the six major sectors we use the March Current Population Surveys to calculate cell means of the logarithm of individual weekly earnings[13]. Wage cells in these data are classified by sector, education, and intervals of work experience. We handle top coding of the wage data by multiplying top coded earnings by 1.5. Throughout we report estimates for two levels of education: high school graduates and college graduates and above[14]. Work experience categories are 1-5, 6-10, 11-20, 21-30, and 31-40 years. Since we stratify by schooling levels in the regressions reported below, there are thirty cells for each year of the data: five experience groups and six broad sectors. Following Murphy and Welch (1992) conditions for inclusion in a cell are that individuals be white, male, between the ages of 18 and 65, and full-time labor force participants[15]. These criteria eliminate changes in wage structure due to race, sex, and labor force participation; the use of cell means abstracts from individual determinants of wages. Since the data meeting these criteria amount to roughly 5000 annual observations, cell size is about 160.

The key determinants of weekly earnings for the purpose of this paper are cohort size, technology, and trade. Cohort size is defined as the share of the work force of a given age and level of education in an experience bracket[16]. The trade data are ratios of net imports by region to

[13] Results using annual and hourly earnings were close to those for weekly earnings.

[14] We considered two other educational levels, less than high school and some college. Results from regressions using less than high school were an extrapolation of findings for high school graduates. The results for workers with some college lie in between the findings for high school graduates and college graduates.

[15] See their paper for further details.

[16] The mapping of age groups into work experience groups is as follows.

value of U.S. industry output[17]. Regions include all of Western Europe, all of Asia (plus Africa and Oceania), and all of the Western Hemisphere. Thus, regions in the trade data are inclusive. There has recently been a debate in the trade literature over the use of quantity trade indicators, with trade economists arguing that prices encompass all the effects of interest and labor economists arguing that quantity indicators provide useful information in their own right. One response is that trade flows matter in the presence of sectoral immobility. Another is that *regional* trade flows, such as the ones that we use here, are exogenous-- the point seems especially reasonable given the rise of U.S. trade with Asia. Freeman (1995) argues that the exogenous element in trade flows is significant since reductions in trade barriers, the spread of technology, and rising skills in developing countries are exogenous events. Krugman (1995) mounts a theoretical defense of trade volumes. Finally, while data on prices might be sufficient statistics for the effects of trade in long run settings even so there is disagreement about the value of *official*

Years of Age	Years of Work Experience
20-29	1-5
25-34	6-10
35-44	11-20
45-54	21-30
55-64	31-40

The data by intervals of age are taken from U.S. Bureau of the Census, **Current Population Reports, Series P-20**(various years). The above mapping is used to assign age group shares for a schooling class in the Census data, to a level of work experience , following a suggestion in Mincer (1990). Clearly there are errors in the assignment of age group shares by schooling group, since no allowance is made for educational differences in the age groupings, though little can be done about this problem.

[17] The source of the net import data is U.S. Department of Commerce, **Highlights of Foreign Trade: Imports and Exports** (years 1973-1988). Domestic output by industry is reported in the **Statistical Abstract of the United States** (years 1973-1988), tables entitled, "National Income by Industrial Origin."

government price indexes for this purpose. Lawrence and Slaughter (1993) study government import price indexes that cover a wide range of industries and find no correlation between price changes and the intensity of unskilled labor. In contrast Leamer (1996) uses price index data for selected industries to show evidence of unusually sharp price declines in unskilled industries. For all these reasons we use of trade flows as indicators of trade effects.

The industrial science resources receive the most elaborate treatment of our wage determinants. Unlike trade flows, science resources *at the sectoral level* during our period are limited to the top five science and technology countries: the United States, Great Britain, France, West Germany, and Japan. However, these five countries account for two-thirds of world industrial scientists and engineers, main omissions being Canada and the smaller advanced countries of Europe. Asian countries besides Japan have few science resources during this period[18]. Data on sectoral science resources outside the U.S. are available at intervals of five to ten years. We could get around this problem of timing if we had patent data for broad sectors. But we cannot use patents to measure innovation here because of the breadth of coverage of our six sectors, the entire private U.S. economy, and the restriction of patent classifications largely to manufacturing industries. Nevertheless, any errors that are introduced by interpolation of the science resources data are likely to be small since Blank and Stigler (1957) find that the correlation between sectoral science resources measured ten years apart is on the order of 0.9.

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[18] Notable omitted countries of Europe are Belgium, Denmark, Italy, Netherlands, Norway, and Sweden. Omitted Asian countries are Hong Kong, Malaysia, Singapore, South Korea, and Taiwan. However, the largest omitted Asian science and technology country, South Korea, has fewer scientists and engineers than Canada: see Jamison (1990a, 1990b). During this period China, India, and Indonesia had little commercialization of inventions by industry and few science resources. See Evenson (1984) for additional details.

Since patents are not available we define a *latent* sectoral indicator of technology that is a two stage knowledge production function. This function depends on regional science and engineering knowledge stocks and labor force by sector. The upper level innovation function I_j for region j is a CES function,

$$I_{jt} = \left[BQ_{Ejt}^{-\rho} + (1-B)Q_{Sjt}^{-\rho} \right]^{-\frac{1}{\rho}}, \tag{14}$$

in which B is a distribution parameter determining relative importance of the engineering and science branches, $Q_{E\,j}$ is the lower level engineering innovation function, $Q_{S\,j}$ is the lower level science innovation function, and ρ determines the elasticity of substitution σ between engineering and science, since $\sigma=1/(1+\rho)$. The upper level knowledge production function distinguishes engineering from science. The data permit this distinction, and the distinction could be important. Lower level innovation sub-aggregates for region j are Cobb-Douglas:

$$Q_{ijt} = L_{ijt}^{\alpha_{ij}} K_{ijt}^{1-\alpha_{ij}}, \tag{15}$$

where i=E, S is the engineering or science branch, j is the region, t is time, L_{ijt} is the labor force in branch i, and K_{ijt} is the stock of regional knowledge in a branch. Equations (14) and (15) require data on labor force and knowledge stocks, L_{ijt} and K_{ijt}. Engineers and scientists in the six major sectors are available in our five top countries at intervals from census data in the individual countries and are interpolated for intervening years[19]. Regional stocks of knowledge can be constructed on an annual basis as follows. We use shares of the five countries in the world

[19] Zymelman (1980) is the source of the 1970 Census data on employment of S&Es in Japan and Europe. Jamison (1987, 1992) is the source of the data on Japan and Europe in 1980, 1985, and 1990.

engineering and chemical literatures, as reported in National Science Foundation (1993) during 1973-1988 as indicators of each of these country's shares in the world stock of engineering and science. Second, we multiply the regional engineering shares by stocks of world-wide engineering papers lagged 10 years, and the regional chemistry shares by the sum of the stocks of world-wide chemistry papers lagged 20 years and computer science papers lagged 10 years[20]. These computations give us estimates of regional scientists and engineers and regional stocks of science and engineering knowledge, which are L_{ijt} and K_{ijt} in our notation.

Given the parameters entering (14) and (15) we know the regional innovation amounts I_{jt} and are able to calculate world innovation as the sum over regions for the five leading countries, $T_t=\sum_j I_{jt}$, as well as the shares in innovation, $S_{jt}= I_{jt}/T_t$. But from the nonlinearity of these equations, innovation is not defined until the parameters B, ρ, α_E, and α_S are specified.

We obtain estimates of B, ρ, α_E, and α_S by performing a grid search using the wage regression (12) and judging the best fit by adjusted R^2. We search over a likely range for each of the parameters. We use values for B of 0.25, 0.5 and 0.75. According to (14) a rise in B amounts to an increase in the importance of engineering compared with science. To get at substitution between engineering and science we tried values for ρ of -0.75, -0.5, -0.25, 0, 0.25, 1, and 4. These values correspond to elasticities of substitution of 4, 2, 1.33, 1, 0.8, 0.5, and 0.2 in (14). Finally we tried values for α_E and α_S of 0.2, 0.4, 0.6, and 0.8, coinciding with increasing importance of the technical workforce compared with the stock of knowledge. It turns out that B=0.75, α_E=0.8, and α_S=0.4 are the preferred values. This suggests that engineering is the

[20] See Adams (1990) for details on the calculations of each of these world-wide article count stocks. The rate of obsolescence assumed for each stock is 11 percent per year.

predominant branch, that engineering workforce is more important than the engineering knowledge stock, and that the stock of scientific knowledge is more important than industrial scientists. As far as ρ is concerned the data *weakly* prefer values in the range of 0.25, 1, or 4. These values imply σ equal to 0.8, 0.5, and 0.2 and suggest inelastic substitution between engineering and science. Within this range the fit was about the same so we report results for $\rho=1$ ($\sigma=0.5$) below.

Means and standard deviations for world innovation, regional shares in world innovation, and regional net import penetration are shown in Panel A of Table 1 for the first of our data sets. For convenience we report innovation as well as trade indicators in arithmetic form. All innovation variables are based on the values of B, ρ, α_E, and α_S that we have specified. The estimated foreign and U.S. shares in world innovation are 0.63, and 0.37. Net import penetration is small on average, though it varies by sector and region.

Panel A of Table 2 reports simple correlations between the innovation and trade indicators in our first data set. Simple correlations do not suggest serious pairwise multicollinearity between the various regional indicators, although one of the shares must of course be dropped.

B. Data on Twenty-Four Manufacturing Industries, 1979-1993

The second data set covers manufacturing from 1979-1993. The wage data derive from the CPS extract of the National Bureau of Economic Research. They are prepared in a similar way to the first set of CPS data. Again we construct means by wage cells. As before, and for the same reasons, the data pertain to white males aged 18 to 65 who are full time participants in the labor force. However, in this case the wage cells are classified by education, industry, and year, but not work experience. The reason why we do not classify the wage data by work experience is that cell sizes become quite small in some of our three digit. Despite the fact that average cell size is about 600 for the two education groups and twenty-four industries, variation in cell size in these data is much larger than for the sectoral data.

Data on stocks of patents issued in the U.S. by region of origin are derived from the electronic version of **Patenting Trends in the U.S.**, U.S. Department of Commerce, Patent and Trademark Office (1995). We construct stocks of U.S. patents by region of the inventor, where regions are the U.S., Western Hemisphere, Europe, and Asia. Since the patent data start in 1963, we construct 16 year lagged stocks assuming a depreciation rate of 15 percent[21]. This calculation provides us with patent stocks by region of the world. By analogy with the previous section we calculate world innovation as the sum over regions, $T_t=\sum_j I_{jt}$, and shares in innovation as $S_{jt}= I_{jt}/T_t$. The advantage of these data over the earlier science resources data is that they allow for direct competition over the U.S. market. Moreover, we have seen in Section II that resident patent data are less meaningful than patents issued in the U.S., which are required to meet a minimum threshold of impact in the world's largest technology market.

Net imports follow the same industry lines as do wages and patents[22]. The set of underlying countries is also the same as the set in the patent data, and it includes all the major

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[21] This is most of the "perpetual" patent stock. The incomplete sixteen year stock captures 93 percent of the value of a level series extending into the indefinite past assuming a depreciation rate of 15 percent. In fact it captures more than this, since the series grows with time, and is therefore larger in the recent past.

[22] The source of imports and exports is a special tabulation by the U.S. Bureau of the Census prepared for this paper, by the industries noted in footnote 11.

science and technology countries of Europe, Asia, and the Western Hemisphere[23]. The data on U.S. value of shipments that normalize and detrend the net imports are drawn from electronic files of the U.S. Bureau of the Census (1995) for the same set of industries.

Means and standard deviations for innovation and trade indicators in the second data set are shown in panel B of Table 1. The mean share of Europe is 0.23 in these data, the share of Asia is 0.13, and the Western Hemisphere is 0.02; thus the share of the U.S. is 0.62, which is larger than the U.S. share in industrial science resources, even when restricted to five countries. Net import penetration is larger for Asia, and it is larger than before, reflecting restriction to manufacturing and the more recent sample period. Panel B of Table 2 reports simple correlations among trade and technology variables in the second file. Again, simple correlations suggest that pairwise collinearity problems at least, are not severe in these data.

V. Empirical Results

A. Regression Findings for Six Major Sectors, 1973-1988

Tables 3 and 4 report regressions for the six major sectors. All the real wage equations in Table 3 include year dummies, industry dummies, work experience dummies, and cohort size. Half the relative wage regressions in Table 4 include time dummies but half do not. The reason is that we are unsure whether errors associated with trend are common to college and high school trained workers. All regressions are corrected for grouping by industry and intra-class correlation

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[23] The countries include the OECD countries of Europe, the U.S., Canada, and Mexico in the Western Hemisphere; Hong Kong, India, Indonesia, Japan, Malaysia, Singapore, South Korea, and Taiwan in Asia.

of the error terms, which overstate reported t-statistics unless grouping is taken into account.[24] The grouping problem is due to the fact that technology and trade indicators are at the industry level, while the wage data are at the level of experience and industry.

Equations 3.1-3.4 report results for high school while 3.5-3.8 report results for college graduates. Equations 3.1 and 3.5 include trade flows but not innovation. All the rest include innovation as well as trade. The trade data suggest relatively minor effects on real wages once time effects are held constant. In general, trade effects weaken once technology is brought into the equations. Looking across the Table, trade effects are insignificant except for trade with the Western Hemisphere, which favors college trained workers. Effects of trade are usually in the same direction across groups, consistent with the specific skills interpretation of III.B.

Equations 3.2 and 3.6 include the foreign share in innovation as well as the logarithm of world innovation. The foreign share is negative and moderately significant at both skill levels, while the log of innovation is negative and significant in the high school equation 3.2, but essentially zero in the college equation 3.6. This suggests that world innovation favors college trained workers. Equations 3.3 and 3.7 replace the foreign innovation share with the complementary U.S. share. Although U.S. share is insignificant in both equations, its positive sign suggests a positive shock to the labor market.

Though the share formulation limits collinearity among the technology indicators it has the disadvantage of combining U.S. with foreign technology in a total stock of innovation. Equations 3.4 and 3.8 choose the innovation *level* specification so the two can be separated. Foreign innovation reduces high school wages, while U.S. innovation raises college earnings.

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[24] See Moulton (1986) for a discussion.

The dependent variable in Table 4 is the difference in logarithms of mean college and high school wages. Table 4 thus provides direct comparisons of technology and trade effects on the skill differential. All equations include industry dummies, cohort size, technology, and trade. However 4.1, 4.3, and 4.5 drop year dummies on the assumption that time effects are common to the two skill levels. Leaving out time dummies we see that trade does matter. Trade with Europe and Western Hemisphere increases the skill differential, while trade with Asia decreases it. But except for Western Hemisphere trade, time dummies eliminate trade effects in 4.2, 4.4, and 4.6.

Equations 4.1-4.4 report technology results for the share specification. The only significant effect is that of world innovation, which strongly favors college trained workers. Equations 4.5 and 4.6 use the level specification of technology. The main significant finding is that foreign innovation rather than U.S. favors skilled workers. The result in equations 4.1-4.4, that world innovation favors the college trained, is due to foreign innovation. This finding reappears in the evidence on manufacturing reported below.

B. Regressions for Twenty-Four Manufacturing Industries, 1979-1993

Tables 5 through 8 present the results for manufacturing industries. Tables 5 and 6 are real wage regressions while 7 and 8 are relative wage regressions. Recall that the technology indicators are based on patents issued in the U.S. and assigned to a particular industry, to inventors world-wide. Several points are worth noting before discussing the results. First, the technology indicators are patents, so we have inventive output rather than inventive input in these data. Second, patents from other countries are direct rivals of U.S. patents for market share; and third, the share of U.S. patents indicates success in commercialization of ideas. All this suggests that the domestic patent share or stock is more likely to increase demand for domestic labor than the domestic share of science resources. Conversely, the foreign patent share or stock is more likely to decrease domestic labor demand than the foreign share of science resources.

The results in Table 5 support this interpretation. To provide comparability with earlier results Table 5 employs technology indicators that are the patent counterparts to the innovation measures of Table 3: the foreign indicators are limited once more to Britain, France, Germany, and Japan. All equations include time and industry dummies. Equations 5.1 and 5.5 omit the patent indicators. We find that trade matters for real wages; within manufacturing trade with Europe is linked with falling wages, while trade with Western Hemisphere is linked to rising wages. Yet the trade effects disappear once we include the patent indicators in the equations.

Equations 5.2 and 5.6 are comparable to 3.2 and 3.6. Both specifications employ the aggregate share of foreign invention accompanied by the logarithm of world invention. As in Table 3 we observe that the aggregate share of foreign invention decreases U.S. wages at both skill levels. The same sign is observed across education groups nearly throughout the table, suggesting sectoral immobility. For example, the total stock of U.S. patents has a consistently negative effect on earnings.

Equations 5.3 and 5.7 are counterparts to 3.3 and 3.7. As in Table 3 the U.S. share replaces the foreign share, this time in the U.S. patent stock. It is interesting that the U.S. patent share is strongly linked with higher wages at both levels of skill, and even more so for high school graduates. Equations 5.4 and 5.8 correspond to 3.4 and 3.8. Both employ the level specification and both enter the log of the foreign stock in addition to the log of the U.S. stock. Equations 5.4

and 5.8 confirm, at a higher level of significance than 3.4 and 3.8, that foreign patents are linked with lower wages, while U.S. held patents are linked to higher wages.

Table 6 expands Table 5 by including patent indicators for the rest of Europe, Asia, and the Western Hemisphere, and it carries out a decomposition of the patent indicators by region[25]. Also we add net import penetration of the rest of Europe and Asia to the vector of trade indicators in this table. Equations 6.1 and 6.5 are comparable to 5.1 and 5.5, except that they separate the top European patent share in U.S. patents from the Japanese share. The effect of the top European patent share is not the same for the two levels of skill. The effect of the Japanese patent share is to reduce wages at both skill levels. The log of the U.S. patent stock has the same magnitude of effect as in Table 5. Trade effects are insignificant holding technology and time constant, as throughout the Table.

Equations 6.2 and 6.6 add patent shares and net import penetration for the rest of Europe and Asia to the top European and Japanese shares. For high school graduates the effect of foreign patents is negative and significant. The same holds for college graduates except for the top European patent share. However, it is not clear that we have separated all the effects.

The pairs of equations, 6.3 and 6.7 and 6.4 and 6.8, are comparable with 6.1 and 6.5 and 6.2 and 6.6 respectively, except that log patent stocks replace patent shares. The effects we have noted for foreign patent stocks remain qualitatively the same for foreign patent shares. The main result is to confirm that the U.S. patent stock still is associated with higher U.S. wages, and especially high school wages despite the addition of several foreign patent stocks.

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[25] The bulk of Western Hemisphere patents originates in Canada, raising the question of the separability of Canadian patents from U.S. patents given that many Canadian firms are U.S. subsidiaries.

The empirical work concludes with Tables 7 and 8, which are relative wage versions of Tables 5 and 6. The arrangement of Table 7 is the same as Table 4, and the content of the technology and trade indicators is similar. All equations include industry dummies, but odd-numbered equations omit year dummies since year effects may be the same for both skill levels. As before trade effects are generally weak, especially when time effects are included in the equations. Equations 7.1 to 7.4 show that the total stock of U.S. patents and the top foreign share raise the relative wage of college graduates while the U.S. share lowers the relative wage. Equations 7.5 and 7.6 employ the levels specification of technology. They show that the foreign stock raises the skill differential while the U.S. stock reduces it.

Table 8 carries out regional decompositions of technology and trade effects on relative wages just as Table 6 did for real wages. Equations 8.1 and 8.2, which use the share specification of technology, reveal that the significance of top European patent share, as opposed to Japanese, depends on whether time effects are included in the regression. However, the total patent stock is unshakeably linked with a rise in the wage differential. Equations 8.3 and 8.4 use the level specification of technology; as in 8.1 and 8.2, the distribution of European and Japanese effects depends on inclusion of time dummies. However the U.S. stock of patents in both cases lowers the skill differential. Equations 8.5 and 8.6 include the full battery of technology and trade variables in the level specification. Technology stocks for other European and other Asian countries matter, especially for high school earnings. Other Europe reduces the skill differential, and other Asia increases it, though it is again unclear that we have kept all the effects.

VI. Discussion and Conclusion

This paper has presented theory and evidence that explains the association between U.S. wages, foreign and domestic technology, and trade. We believe that some ground has been gained on the problem of *explaining* changes in the wage structure. In particular, we find consistent patterns for technology on real wages of high and low skilled workers: (i), in the majority of cases, technology and trade have the same direction of effect on wages at both levels of skill, not opposing effects; (ii), a rise in the share of the U.S. in world innovation or in U.S. patents is associated with an increase in U.S. wages, while (iii), an increase in foreign shares is usually associated with a decrease. Turning to relative wages of college and high school graduates, we find that (iv), foreign shares in world innovation and U.S. patents are typically associated with an decrease in the skill differential, but that (v), the stock of world innovation and the stock of U.S. patents both increase the skill differential. Finally, and (vi), the effects of trade on real wages are generally insignificant once technology indicators are included in our regressions. These findings suggest that sectoral labor immobility is an important part of the interaction between the U.S. labor market, technology, and trade, especially for less skilled workers. They also suggest that technology rather than trade *in and of itself*, is the key explanatory element in the twists of the wage structure of recent years.

Table 1
Means and Standard Deviations of the Major Variables

Variable	Mean (Standard Deviation)
Panel A. Six Major Sectors, 1973-1988[a].	
Innovation Variables:	
World Innovation Function[b] (based on scientists and engineers in 100 thousands per sector, and stocks of scientific papers in 100 thousands per region)	0.61 (0.44)
Top Foreign share of World Innovation function[c]	0.63 (0.09)
Trade Variables:	
European net import penetration[d]	0.00 (0.02)
Japanese net import penetration[d]	0.02 (0.05)
All Western Hemisphere net import penetration[d]	0.00 (0.07)
Panel B. Twenty-Four Manufacturing Industries, 1979-1993[e].	
Patent Variables:	
Total Stock of Patents Issued in the U.S.[f] (in 100 thousands per industry)	0.21 (0.23)
Share of West. Eur. Patent Stock in the total Stock of Patents Issued in the U.S.[f]	0.24 (0.05)
Share of Asian Patent Stock in the total Stock of Patents Issued in the U.S.[f]	0.14 (0.07)
Share of Major W. Hem. Patent Stock in the total Stock of Patents Issued in the U.S.[f]	0.02 (0.01)
Trade Variables:	
Net import penetration, Western Europe[g]	-0.02 (0.13)
Net import penetration, Asia[g]	0.06 (0.18)
Net import penetration, Major Western Hemisphere[g]	-0.01 (0.05)

Notes. **Panel A.** [a] Number of observations is 960 or 480 in each education group. [b] World innovation function is a two level production function summed over regions, of regional stocks of scientific papers interacted with regional stocks of industrial scientific personnel in engineering and in science. See equations (14) and (15) of the text. [c] Top Foreign consists of Britain, France, Germany, and Japan. [d] Net import penetration is defined as imports minus exports divided by U.S. domestic output, all in current dollars. Europe in this data set consists of France, West Germany, and the United Kingdom. Western Hemisphere includes all Western Hemisphere countries besides the U.S. **Panel B.** [e] Number of observations is 720 or 360 in each education group. [f] Europe consists of all of Western Europe. Asia consists of main Asian trading partners of the U.S.: Japan, South Korea, Hong Kong Taiwan, Singapore, Indonesia, India, and Malaysia. Major Western Hemisphere is restricted to Canada and Mexico. Stocks of patents are sums of lagged values over the previous sixteen years, depreciated at 15 per cent per year. [g] Regions for the trade penetration data are identical to regions for the patent stock data.

Table 2
Correlations of Science-Based Innovation Indicators and Net Import Penetration

Panel A. Data Covering Six Major Sectors, 1973-1988.

	log (Top Foreign share in innov.)	log(world innov.)	European net import pen.	Japanese net import pen.	West. Hem. net import penetration
log(Top Foreign. share in innov.)	1.0	0.39	-0.32	-0.05	0.29
log(world innov.)		1.0	-0.01	0.34	-0.21
European net import penetration			1.0	0.30	-0.05
Japanese net import penetration				1.0	0.33
West. Hem. net import penetration					1.0

Notes. Number of observations is 480. See Table 1 and the text for the definition of variables entering the table.

Table 2
Correlations of Patent Indicators and Net Import Penetration

Panel B. Data Covering Twenty-Four Manufacturing Industries, 1979-1993.

	log(W. Eur. share in U.S. pat. Stock)	log(Asian share in U.S. pat. Stock)	log (Maj. W. Hem. Share in U.S. pat. Stock)	log(U.S. pat. Stock)	W. Eur. net import pen.	Asia net import pen.	Maj. W. Hem. net import pen.
log (W. Eur. share in U.S. pat. stock .)	1.0	0.13	-0.19	-0.08	0.17	-0.20	-0.23
log (Asia share in U.S. pat. stock)		1.0	-0.10	0.30	-0.13	0.23	-0.14
log (Maj.W. Hem. share in U.S. pat. Stock)			1.0	-0.01	0.21	-0.12	0.20
log (U.S. pat. stock)				1.0	-0.05	0.24	-0.24
W. Eur. net import pen.					1.0	-0.41	0.65
Asia net import pen.						1.0	-0.19
W. Hem. net import pen.							1.0

Notes. Number of observations is 360. See Table 1 and the text for the definition of variables entering the table.

Table 3
Mean Log (Weekly Earnings) Regressions: Six Major Sectors, 1973-1988
Effects of Science-Based Regional Innovation *Shares* and *Levels*, and Trade
(grouped t-statistics in Parentheses)

Variable or Statistic	High School Graduates				College Graduates+			
	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8
Year Dummies, Sectoral Dummies, Experience Dummies, Cohort Size	yes	yes	yes	yes	yes	yes	yes	yes
Innovation *Share* Specification:								
log (world innovation)		-0.15 (-2.3)	-0.14 (-2.4)			0.07 (1.1)	0.07 (1.2)	
log (foreign share in world innovation)		-0.24 (-2.1)				-0.19 (-2.2)		
log (U.S. share in world innovation)			0.09 (1.6)				0.07 (1.6)	
Innovation *Level* Specification:								
log (foreign innovation)				-0.18 (-3.5)				-0.01 (-0.1)
log (U.S. innovation)				0.02 (0.5)				0.07 (2.2)
Trade Variables:								
Eur. net import penetration	0.25 (1.0)	0.56 (2.0)	0.62 (1.9)	0.58 (2.0)	0.44 (1.2)	0.66 (1.9)	0.39 (1.9)	0.59 (2.0)
Asian net import penetration	0.21 (2.5)	0.05 (0.4)	0.05 (0.4)	0.05 (0.3)	-0.01 (-0.0)	-0.05 (-0.3)	0.04 (0.3)	-0.00 (-0.0)
West. Hem. net import penetration	0.07 (0.4)	0.03 (0.2)	0.11 (0.6)	0.03 (0.2)	0.59 (2.1)	0.54 (2.4)	0.58 (2.3)	0.50 (2.5)
Adjusted R^2	0.97	0.97	0.97	0.97	0.92	0.93	0.93	0.93
Root MSE	0.05	0.05	0.05	0.05	0.08	0.07	0.07	0.07

Notes. Number of observations is 480. For each education group the data cover six sectors, five experience groups per sector, and sixteen years.

Table 4
Regressions Explaining Differences in Means of
College and High School Weekly Earnings, Six Major Sectors, 1973-1988:
Effects of Regional Science-Based Innovation *Shares* and *Levels*, and Trade
(t-statistics corrected for grouping in parentheses)

Variable or Statistic	Difference in College-High School Mean Log (Weekly Earnings)					
	4.1	4.2	4.3	4.4	4.5	4.6
Work Experience Dummies, Cohort Size	yes	yes	yes	yes	yes	yes
Year Dummies	no	yes	no	yes	no	yes
Innovation *Share* Specification:						
log(world innovation function)	0.14 (7.0)	0.21 (2.7)	0.14 (5.4)	0.22 (2.7)		
log (Foreign share in World innovation)	0.18 (1.0)	0.05 (0.3)				
log (U.S. share in world innovation)			-0.07 (-1.0)	-0.02 (-0.2)		
Innovation *Level* Specification:						
log (Foreign innovation function)					0.15 (3.2)	0.17 (2.0)
log (U.S. innovation function)					-0.01 (-0.2)	0.05 (0.8)
Trade Variables:						
Eur. net import penetration	1.07 (2.4)	0.10 (0.5)	1.02 (2.0)	0.08 (0.3)	1.06 (2.1)	0.14 (0.6)
Asian net import penetration	-0.45 (-2.7)	-0.10 (-1.2)	-0.46 (-3.1)	-0.10 (-1.0)	-0.45 (-2.9)	-0.10 (-1.0)
West. Hemis. net import penetration	0.87 (2.5)	0.51 (2.2)	0.89 (2.3)	0.51 (2.2)	0.88 (2.4)	0.51 (2.3)
Adjusted R^2	0.37	0.43	0.37	0.43	0.37	0.43
Root MSE	0.08	0.08	0.08	0.08	0.08	0.08

Notes. Number of observations is 480. The data cover six major sectors, five experience groups per sector, and sixteen years.

Table 5
Mean Log (Weekly Earnings) Regressions: Twenty-Four Manufacturing Industries, 1979-1993
Effects of *Shares* and *Levels* in the U.S. Patent Stock, and Trade
(grouped t-statistics in Parentheses)

Variable or Statistic	High School Graduates				College Graduates+			
	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8
Year Dummies, Industry Dummies	yes	yes	yes	yes	yes	yes	yes	yes
Patent *Share* Specification:								
log (U.S. Patent Stock*)		-0.08 (-15.4)	-0.08 (-13.7)			-0.03 (-4.8)	-0.03 (-4.3)	
log (Top Foreign share in U.S. Patent Stock)		-0.23 (-16.7)				-0.12 (-7.1)		
log (U.S. share in U.S. Patent Stock)			0.49 (13.6)				0.24 (5.7)	
Patent *Level* Specification:								
log (Top Foreign Stock of U.S. Patents)				-0.18 (-17.5)				-0.09 (-7.1)
log (U.S. Stock of U.S. Patents)				0.10 (11.1)				0.06 (5.3)
Trade Variables:								
Eur. net import penetration	-0.50 (-5.2)	0.12 (1.7)	0.00 (0.0)	0.11 (1.5)	-0.37 (-4.1)	-0.08 (-0.8)	-0.16 (-1.7)	-0.09 (-0.9)
Asian net import penetration	-0.02 (-0.4)	-0.02 (-0.4)	-0.02 (-0.4)	-0.02 (-0.4)	-0.08 (-1.5)	-0.08 (-1.4)	-0.07 (-1.5)	-0.07 (-1.5)
Major West. Hem. net import penetration	1.08 (9.2)	-0.13 (-1.3)	0.30 (2.9)	-0.07 (-0.6)	0.67 (6.1)	0.10 (0.7)	0.35 (2.9)	0.14 (1.1)
Adjusted R^2	0.70	0.86	0.84	0.86	0.57	0.63	0.61	0.62
Root MSE	0.07	0.05	0.05	0.05	0.07	0.06	0.06	0.06

Notes. Number of observations is 360. For each education group the data cover twenty-four manufacturing industries and fifteen years. For definitions of the industry groups see the text and footnote 12.

Table 6
Mean Log (Weekly Earnings) Regressions: Twenty-Four Manufacturing Industries, 1979-1993
Disaggregate Regional Effects of *Shares* and *Levels* in the U.S. Patent Stock, and Trade
(t-statistics in Parentheses)

Variable or Statistic	High School Graduates				College Graduates+			
	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8
Year Dummies, Industry Dummies	yes	yes	yes	yes	yes	yes	yes	yes
Patent *Share* Specification:								
log (U.S. Pat. Stock)	-0.08 (-14.7)	-0.07 (-7.8)			-0.04 (-5.4)	-0.04 (-4.4)		
log (Top Eur. share in U.S. Pat. Stock)	-0.14 (-6.1)	-0.15 (-4.6)			0.01 (0.4)	0.09 (2.3)		
log (Other Eur. Share in U.S. Pat. Stock)		0.01 (0.2)				-0.19 (-3.9)		
log (Japanese share in U.S. Pat. Stock)	-0.09 (-5.0)	-0.06 (-7.8)			-0.11 (-5.2)	-0.05 (-1.9)		
log (Other Asia share in U.S. Pat. Stock)		-0.02 (-2.1)				-0.01 (-1.0)		
log (Major West. Hemis. share in U.S. Pat. Stock)		0.01 (0.3)				-0.01 (-0.3)		
Patent *Level* Specification:								
log (Top Eur. stock of U.S. Patents)			-0.13 (-5.7)	-0.13 (-4.2)			0.02 (0.8)	0.11 (2.9)
log (Other Eur. stock of U.S. Patents)				-0.02 (-0.5)				-0.19 (-4.2)
log (Japanese stock of U.S. Patents)			-0.06 (-3.5)	-0.03 (-1.2)			-0.10 (-4.7)	-0.03 (-1.2)
log (Other Asia stock of U.S. Patents)				-0.01 (-1.8)				-0.01 (-0.7)
log (Major West. Hemis. stock of U.S. Patents)				0.02 (0.6)				-0.00 (-0.1)
log (U.S. stock of U.S. Patents)			0.11 (10.1)	0.10 (4.5)			0.04 (3.3)	0.08 (2.9)

Table 6
Mean Log (Weekly Earnings) Regressions: Twenty-Four Manufacturing Industries, 1979-1993
Disaggregate Regional Effects of *Shares* and *Levels* in the U.S. Patent Stock, and Trade
(t-statistics in Parentheses)

Variable or Statistic	High School Graduates				College Graduates+			
	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8
Trade Variables:								
Top Eur. net import penetration	0.02 (0.3)	-0.00 (-0.0)	0.02 (0.3)	-0.03 (-0.1)	-0.02 (-0.2)	-0.25 (-1.2)	-0.03 (-0.3)	-0.23 (-1.1)
Other Eur. net import penetration		-0.00 (-0.0)		-0.03 (-0.1)		0.40 (1.2)		0.37 (1.1)
Japanese net import penetration	-0.01 (-0.3)	0.15 (3.0)	-0.01 (-0.4)	0.15 (2.9)	-0.06 (-1.2)	-0.01 (-0.2)	-0.06 (-1.2)	-0.02 (-0.3)
Other Asia net import penetration		-0.41 (-4.7)		-0.40 (-4.6)		-0.17 (-1.6)		-0.16 (-1.6)
Major West. Hem. net import penetration	-0.13 (-1.3)	0.07 (0.6)	-0.07 (-0.6)	0.12 (1.0)	0.04 (0.3)	-0.27 (-1.9)	0.08 (0.6)	-0.23 (-1.5)
Adjusted R^2	0.86	0.87	0.86	0.87	0.64	0.68	0.63	0.68
Root MSE	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06

Notes. Number of observations is 360. For each education group the data cover twenty-four manufacturing industries and fifteen years.

Table 7
Mean Log (Weekly Earnings) Regressions: Twenty-Four Manufacturing Industries, 1979-1993
Effects of *Shares* and *Levels* in the U.S. Patent Stock and Trade
(t-statistics in Parentheses)

Variable or Statistic	Difference in College-High School Mean Log (Weekly Earnings)					
	7.1	7.2	7.3	7.4	7.5	7.6
Industry Dummies[a]	yes	yes	yes	yes	yes	yes
Year Dummies	no	yes	no	yes	no	yes
Patent *Share* Specification:						
log (U.S. Pat. Stock)	0.07 (8.4)	0.05 (6.5)	0.07 (8.6)	0.05 (6.5)		
log (Top Foreign share in U.S. Pat. Stock)	0.20 (11.6)	0.10 (5.3)				
log (U.S. share in U.S. Pat. Stock)			-0.47 (-12.8)	-0.24 (-5.2)		
Patent *Level* Specification:						
log (Top Foreign Stock of U.S. Patents)					0.16 (12.9)	0.09 (6.0)
log (U.S. Stock of U.S. Patents)					-0.10 (-8.2)	-0.04 (-3.0)
Trade Variables:						
Top Eur. net import penetration	-0.30 (-2.6)	-0.20 (-1.9)	-0.25 (-2.3)	-0.16 (-1.5)	-0.30 (-2.6)	-0.20 (-1.9)
Japanese net import penetration	-0.09 (-1.6)	-0.06 (-1.0)	-0.08 (-1.4)	-0.06 (-1.0)	-0.09 (-1.6)	-0.06 (-1.0)
Major West. Hemis. net import penetration	0.53 (3.5)	0.23 (1.6)	0.21 (1.5)	0.05 (0.4)	0.47 (3.2)	0.21 (1.5)
Adjusted R^2	0.58	0.66	0.61	0.66	0.59	0.66
Root MSE	0.08	0.07	0.08	0.07	0.08	0.07

Notes. Number of observations is 360. For each education group the data cover twenty-four manufacturing industries and fifteen years. For definitions of the industry dummies see the notes to Table 5.

Table 8
Mean Log (Weekly Earnings) Regressions: Twenty-Four Manufacturing Industries, 1979-1993
Disaggregate Regional Effects of *Shares* and *Levels* in the U.S. Patent Stock and Trade
(t-statistics in Parentheses)

Variable or Statistic	Difference in College-High School Mean Log (Weekly Earnings)					
	8.1	8.2	8.3	8.4	8.5	8.6
Industry Dummies[a]	yes	yes	yes	yes	yes	yes
Year Dummies	no	yes	no	yes	no	yes
Patent *Share* Specification:						
log (U.S. Pat. Stock)	0.07 (8.3)	0.04 (5.6)				
log (Top Eur. share in U.S. Pat. Stock)	-0.01 (-0.5)	0.15 (4.7)				
log (Japanese share in U.S. Pat. Stock)	0.14 (10.9)	-0.03 (-1.1)				
Patent *Level* Specification:						
log (Top Eur. Stock of U.S. Patents)			-0.01 (-0.5)	0.15 (4.9)	0.24 (6.1)	0.24 (6.0)
log (Other Eur. Stock of U.S. Patents)					-0.32 (-8.2)	-0.18 (-3.6)
log (Japanese Stock of U.S. Patents)			0.12 (9.2)	-0.04 (-1.7)	0.09 (3.9)	-0.01 (-0.2)
log (Other Asia Stock of U.S. Patents)					0.03 (3.5)	0.01 (0.7)
log (Major West. Hemis. Stock of U.S. Patents)					0.08 (2.6)	-0.02 (-0.6)
log (U.S. Stock of U.S. Patents)			-0.05 (-3.1)	-0.06 (-4.3)	-0.09 (-3.4)	-0.02 (-0.7)
Trade Variables:						
Top Eur. net import penetration	-0.32 (-2.9)	-0.05 (-0.4)	-0.31 (-2.9)	-0.04 (-0.4)	-0.45 (-2.0)	-0.25 (-1.1)
Other Eur. net import penetration					0.59 (1.7)	0.40 (1.1)
Japanese net import penetration	-0.10 (-1.8)	-0.05 (-0.9)	-0.10 (-1.8)	-0.05 (-0.9)	-0.13 (-2.0)	-0.16 (-2.5)

Table 8
Mean Log (Weekly Earnings) Regressions: Twenty-Four Manufacturing Industries, 1979-1993
Disaggregate Regional Effects of *Shares* and *Levels* in the U.S. Patent Stock and Trade
(t-statistics in Parentheses)

Variable or Statistic	Difference in College-High School Mean Log (Weekly Earnings)					
	8.1	8.2	8.3	8.4	8.5	8.6
Trade Variables (cont.)						
Other Asia net import penetration					0.13 (1.1)	0.24 (2.1)
West. Hem. net import penetration	0.42 (2.9)	0.17 (1.2)	0.41 (2.8)	0.14 (1.0)	-0.45 (-2.9)	-0.34 (-2.2)
Adjusted R^2	0.61	0.66	0.61	0.67	0.72	0.73
Root MSE	0.07	0.07	0.07	0.07	0.06	0.06

Notes. Number of observations is 360. For each education group the data cover twenty-four manufacturing industries and fifteen years. For definitions of the industry dummies see the notes to Table 5.

Appendix

This Appendix derives the comparative statics wage equations (8)-(10) of the text. These equations are based on the log differential of (1)-(7). First, insert (1) into (3) and log differentiate. The result is

$$\begin{aligned} \lambda_{hX} X* + \lambda_{hY} Y* &= \lambda_{hX} b*_X - \left[\lambda_{hX} c*_{hX} + \lambda_{hY} c*_{hY} \right] \\ \lambda_{\ell X} X* + \lambda_{\ell Y} Y* &= \lambda_{\ell X} b*_X - \left[\lambda_{\ell X} c*_{\ell X} + \lambda_{\ell Y} c*_{\ell Y} \right], \end{aligned} \qquad \textbf{(A.1)}$$

in which the λ_{ij} are employment shares of input I in industry j and the c_{ij} are derivatives of unit costs with respect to input I in sector j. As before X* and Y* are percent changes in sectoral outputs and $b*_X$ is the absolute value of the factor neutral percent reduction in unit costs. From (2) $b*_X$ is given by the absolute value of the percentage change in stocks of R&D:

$$b*_X = -\beta_X k*_X - \gamma_X K*_X . \qquad \textbf{(A.2)}$$

In a similar way substituting (1) into (4) and log differentiating yields,

$$\begin{aligned} \alpha_X w*_\ell + (1-\alpha_X) w*_h &= -\left[\alpha_X c*_{\ell X} + (1-\alpha_X) c*_{hX} \right] + p*_X + b*_X + \theta*_X \\ \alpha_Y w*_\ell + (1-\alpha_Y) w*_h &= -\left[\alpha_Y c*_{\ell Y} + (1-\alpha_Y) c*_{hY} \right] + p*_Y , \end{aligned} \qquad \textbf{(A.3)}$$

where the α_j and $1\text{-}\alpha_j$ are shares of unskilled and skilled labor in unit cost, which are constant given our Cobb-Douglas assumption. The bracketed terms on the right of (A.3) are equal to zero because of cost minimization. Using this fact we find that

$$\begin{aligned} c*_{\ell j} &= -(1-\alpha_j)(c*_{hj} - c*_{\ell j}) \\ -c*_{hj} &= -\alpha_j (c*_{hj} - c*_{\ell j}), \quad (j = X, Y). \end{aligned} \qquad \textbf{(A.4)}$$

Notice that the simplified form of (A.3) is

$$\begin{aligned} \alpha_X w*_\ell + (1-\alpha_X) w*_h &= p*_X + b*_X + \theta*_X \\ \alpha_Y w*_\ell + (1-\alpha_Y) w*_h &= p*_Y . \end{aligned} \qquad \textbf{(A.3')}$$

Now use the definition of the elasticity of substitution,

$$c*_{hj} - c*_{\ell j} = \sigma_j (w*_\ell - w*_h) \qquad \textbf{(A.5)}$$

in (A.4) and then substitute in (A.1). Since σ_j=1 in our Cobb-Douglas case, the result is

$$\lambda_{hX} X* + \lambda_{hY} Y* = \lambda_{hX} b*_X - \delta_h (w*_\ell - w*_h)$$
$$\lambda_{\ell X} X* + \lambda_{\ell Y} Y* = \lambda_{\ell X} b*_X + \delta_\ell (w*_\ell - w*_h). \qquad \textbf{(A.1')}$$

The terms δ_i in (A.1') are factor substitution terms since they depend on the elasticities of substitution. Given our Cobb-Douglas technology these are

$$\delta_h = \lambda_{hX} \alpha_X + \lambda_{hY} \alpha_Y$$
$$\delta_\ell = \lambda_{\ell X} (1 - \alpha_X) + \lambda_{\ell Y} (1 - \alpha_Y). \qquad \textbf{(A.6)}$$

It remains to incorporate the demand conditions for X into the system represented by (A.1') and (A.3'). Inserting (7) into (6) and log differentiating we obtain

$$X* = \mu_X k*_X + \nu_X K*_X - p*_X \equiv d*_X - \eta p*_X . \qquad \textbf{(A.7)}$$

The second equality reflects the roll-up into $d*_X$ of the percentage change in domestic and foreign R&D capital $k*_X$ and $K*_X$.

Solving (A.1') for X*, then equating the solution with (A.7) and solving for $p*_X$ yields

$$p*_X = \left(\frac{1}{\eta + \frac{M}{\Gamma A}} \right) d*_X + \left(\frac{1 + \frac{M}{\Gamma A}}{\eta + \frac{M}{\Gamma A}} \right) b*_X + \left(\frac{\frac{M}{\Gamma A}}{\eta + \frac{M}{\Gamma A}} \right) \left(p*_Y - \theta*\right), \qquad \textbf{(A.8)}$$

where A, Γ, and M are

$$A = \alpha_Y - \alpha_X > 0, \quad \Gamma = \lambda_{hX} - \lambda_{\ell X} > 0, \quad M = \delta_h (1 - \lambda_{\ell X}) + \delta_\ell (1 - \lambda_{hX}) > 0 .$$

Now use (A.3') to solve for $w*_\ell$ and $w*_h$ in terms of changes in prices and technology. We find

$$w*_\ell = \frac{1}{A} \times \left[(1 - \alpha_X) p*_Y - (1 - \alpha_Y)(p*_X - b*_X + \theta*) \right]$$
$$w*_h = \frac{1}{A} \times \left[- \alpha_X p*_Y + \alpha_Y (p*_X - b*_X + \theta*) \right]. \qquad \textbf{(A.9)}$$

Finally, using (A.8) to eliminate the endogenous price $p*_X$ from (A.9) we obtain the comparative statics equations (8)-(10) of the text.

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