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International Capital Movements and Relative Wages: Evidence from U.S. Manufacturing Industries

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Abstract
In this paper, we use a multi-sector specific factors model with international capital mobility to examine the effects of globalization on the skill premium in U.S. manufacturing industries. This model allows us to identify two channels through which globalization affects relative wages: effects of international capital flows transmitted through changes in interest rates, and effects of international trade in goods and services transmitted through changes in product prices. In addition, we identify two domestic forces which affect relative wages: variations in labor endowment and technological change. Our results reveal that changes in labor endowments had a negative effect on the skill premium, while the effect of technological progress was mixed. The main factors behind the rise in the skill premium were product price changes (for the full sample period) and international capital flows (during 1982-05).

Keywords: capital mobility, specific factors, skill premium, globalization, labor endowments, technological change

JEL Classification: F16, J31.

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1. Introduction

The U.S. economy has witnessed a significant increase in volatility and magnitude of international capital flows since 1980, as shown in Figure 1. In addition, while there were moderate net outflows of capital prior to 1980, the U.S. economy experienced a strong net inflow of foreign direct investment (FDI)[1] between 1980-90 and then again from 1996 to 2001. Between 2001 and 2005, net FDI flows have become substantially more volatile with large in-and outflows. One of the interesting implications of this reversal in U.S. international capital flows is its impact on the relative wages between skilled and unskilled workers, i.e. the skill premium. Provided that capital and skilled labor are complementary factors of production[2], net capital inflows constitute a positive demand shock for skilled labor causing a rise in the skill premium. Therefore, the reversal of international capital flows in the 80s and the second half of the 90s is a potential culprit for the rise in the U.S. skill premium that began in the early 80s and peaked around 2001 (see Figure 2).

The issue of whether capital flows cause changes in the skill premium has been examined in papers by Feenstra and Hanson [10], [11], [12], Sachs and Shatz [32], Eckel [8], Blonigen and Slaughter [4], Taylor and Driffield [34] and Figini and G¨org [13],[14], among others. Feenstra and Hanson [10] and Sachs and Shatz [32] formulate theoretical models in which they examine the impact of capital outflows from a skilled labor abundant economy like the United States. In both papers the capital outflow occurs in the form of outsourcing intermediate goods production to an unskilled labor abundant economy. Both papers investigate empirically the relationship between import shares, employment levels, and factor intensity and arrive at similar conclusions: foreign investment is an important factor in explaining relative wage changes. Eckel [8] formulates a 3x2 trade model with efficiency wages and demonstrates how capital movements, and not wage rigidities, are responsible for an increase in wage inequality[3]. Feenstra and Hanson [11], Taylor and Driffield [34], and Figini and G¨org [13], using industry-level data for Mexico, the UK, and Ireland, respectively, find that international capital flows affect the wage premium. Blonigen and Slaughter [4], in contrast, do not find significant effects of FDI on U.S. wage inequality.

The goal of this paper is to study the impact of capital flows on relative wages in the U.S. over the period 1958-2005, while at the same time taking account of other factors that potentially affect relative wages such as international trade in goods and services, total factor productivity (TFP) growth, factor-specific technological change, and changes in labor endowments. We formulate a multi-sector specific factors (SF) model of a small open economy with perfectly mobile international capital[4]. The specific factor is skilled labor, while both capital and unskilled labor are mobile across sectors. Exogenous changes in the international interest rate trigger capital outflows and inflows in this model[5]. The solution to this multi-sector SF models yields the

[1] Throughout this paper the terms FDI and capital flows are used interchangeably

[2] See Griliches [15], amongst others, for empirical evidence supporting the capital-skill complementarity hypothesis

[3] De Loo and Ziesmer [7] formulate a specific factors model with international capital mobility. Two forms of globalization are examined: exogenous product price changes and exogenous changes in interest rates. However, the model does not classify labor inputs as skilled or unskilled and thus does not address the skill premium issue

[4] For a discussion of why the SF model is an appropriate framework for analyzing the globalization and relative wage issue, see Engerman and Jones [9]. Also note that Kohli [24] contrasts the predictive capability of a SF model with a H-O model and finds the former better suited to analyze U.S. data.

[5] In particular, an increase (decrease) in the world interest rate leads to an instantaneous outflow (inflow) of capital from the economy.

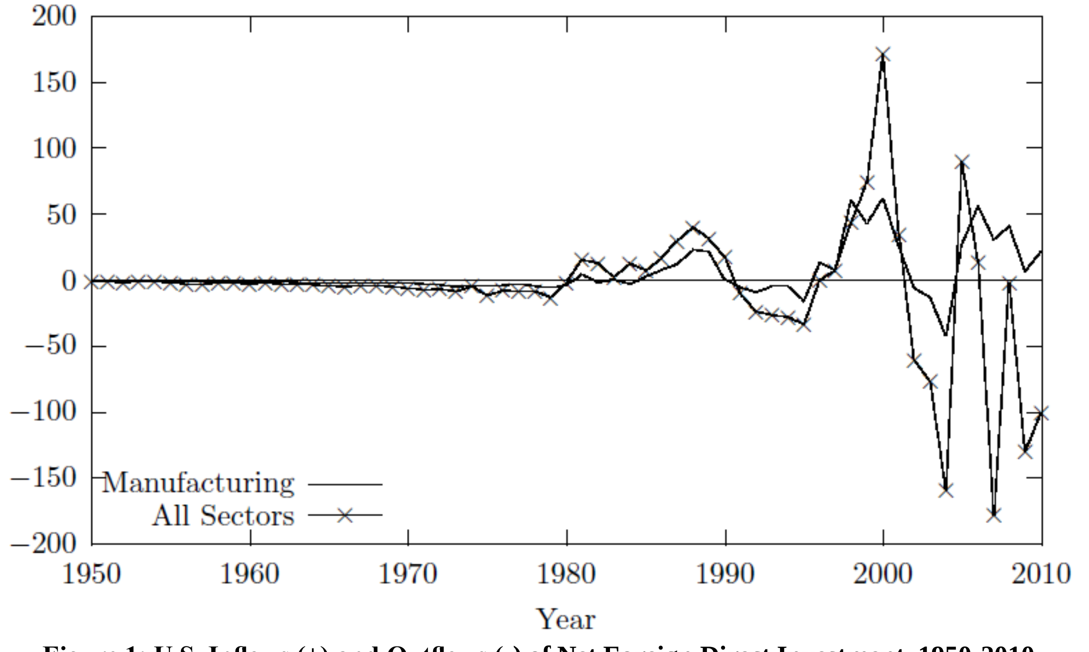

Figure 1: U.S. Inflows (+) and Outflows (-) of Net Foreign Direct Investment, 1950-2010. ***Source*****: BEA. Capital Inflows: FDI in the U.S.; Capital Outflows: U.S. Direct Investment Abroad (for years prior to 1977, Direct Investment Capital Outflows = Equity & Intercompany Accounts Outflows + Reinvested Earnings of Incorporated Affiliates). Numbers in Billion USD.**

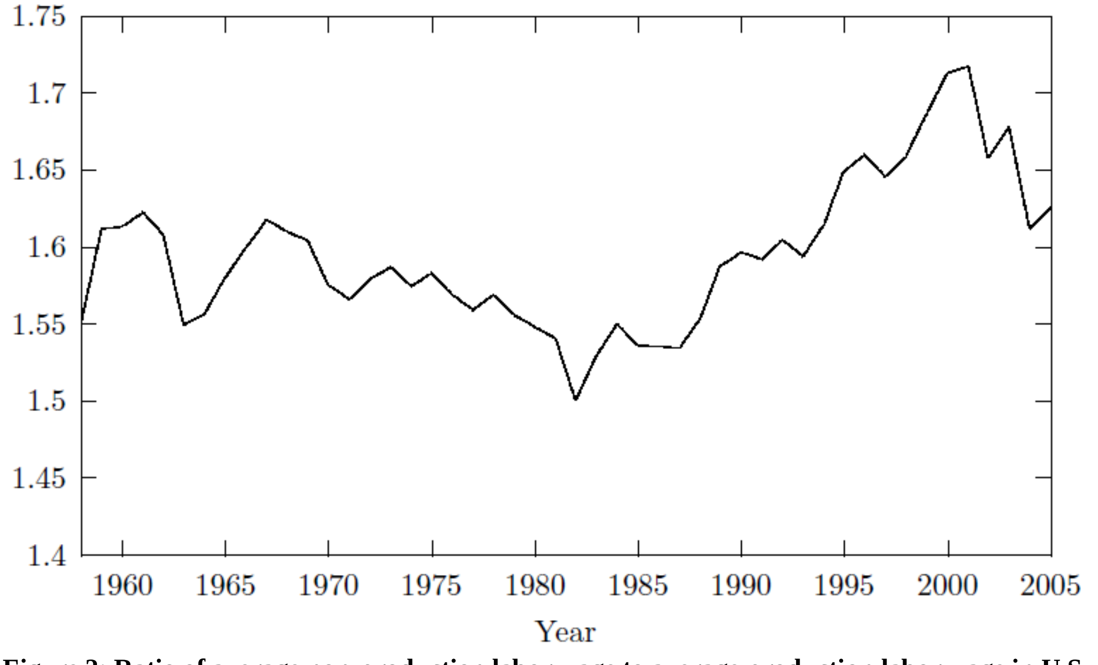

Figure 2: Ratio of average non-production labor wage to average production labor wage in U.S. manufacturing industries, 1958-2005

change in the relative wage rate as a function of changes in international interest rates as well as changes in product prices, TFP growth, factor-specific technological progress, and labor endowment changes. Using estimates of factor-demand elasticities and data on the U.S. manufacturing sector from 1958 to 2005, we calculate the change in the skill premium as predicted by the model and compare the predicted with the actual change[1]. We then calculate the contribution

[1] The literature on globalization and wage inequality deals primarily with U.S. manufacturing industries, mainly due to the unavailability of disaggregated wage data for skilled and unskilled workers in non-manufacturing industries. As Figure 1 reveals, the manufacturing sector has experienced, by and large,

to the predicted change by each of the exogenous forces. In addition to the full sample, we consider four subperiods: 1958-66, 1967-81, 1982-2000, and 2001-05.

Our main results are as follows. First, the net capital outflow that U.S. manufacturing industries experienced during the period 1958-81 had a depressing effect on the skill premium. In contrast, the net capital inflows that occurred in the majority of years between 1981 and 2000 had a positive effect on the skill premium. Second, trade effects working through product price changes caused an increase in the skill premium for all periods. Third, increases in non-production labor endowments worked towards depressing the skill premium, as did a fall in production labor endowment. Fourth, production labor specific technical change increased the skill premium, while non-production labor specific technical change had the opposite effect on the skill premium.

In terms of relative contributions, technology played the largest role in affecting the skill premium, followed by changes in interest rates and product prices, which had approximately equal contributions. Labor endowment changes had the least relative impact on skill premium changes.

The finding of this paper that capital movements played a significant role in affecting relative wages in the U.S. provides strong empirical support for the theoretical results of Feenstra and Hanson [10], Sachs and Shatz [32], and Eckel [8]. In addition, our results reflect findings from two distinct strands of the skill premium literature. With the labor economics literature, such as papers by Berman, Bound and Griliches [2] and Berman, Bound and Machin [3], we share the conclusion that (factor-specific) technological change is likely to be one of the primary forces which increased the skill premium. Like certain papers from the empirical trade literature, such as Sachs and Shatz [31], Leamer [28], and Krueger [26], we concur that product price changes may have strongly contributed to the observed increase in the skill premium.

The paper is organized as follows. The theoretical model is derived in section 2. In section 3 and 4 we discuss model simulation results and data issues, respectively. We present our main results in section 5. Section 6 concludes.

similar net capital flows as the overall economy.

2. The Theoretical Model

Our model is closely related to a class of models based upon the 2x3 SF model derived in Jones [18], which allow for international capital mobility (see, for instance, Thompson [35] and Jones, Neary and Ruane [21]). Our model is similar in this respect. However, it differs significantly in that it incorporates the multi-sectoral feature of an economy following Jones [19]. We consider a small open economy which produces m commodities in as many sectors of production. There are three factors of production in each sector. Two of these factors, capital (K) and production labor (P), are perfectly mobile between sectors, while the third factor, non-production labor (NP), is sector specific, i.e., immobile[1]. Production functions are continuous, twice differentiable, quasi-concave and exhibit diminishing returns to the variable factors. Domestic prices are exogenous and are assumed to be affected by globalization shocks. Capital is also assumed to be perfectly mobile internationally. Its return is determined in world markets and is exogenous. Production sectors are indexed by j =1, ..., m, and factors of production are indexed by i = K, NP, P . Aggregate factor endowments are denoted by Vi. Thus, there are a total of m + 2 factors of production in the economy. Let aKj,aNPj,aPj denote the quantity of the three factors required per unit of output in the jth sector, i.e., aij denote unit input coefficients. Let pj ,qj represent price and output of the jth sector and r, wNPj,and wP denote factor prices. Here r and wP denote the capital rental price[2] and production

[1] Here non-production workers are assumed to be skilled, while production workers are assumed to be unskilled labor. Note that an alternative modeling strategy would have been to assume capital to be sector specific as well. We do not pursue this approach as accurate data on sector specific capital rental rates are not available.

[2] The terms 'interest rate', 'user cost of capital', and 'capital rental price' are used interchangeably in this

labor wages, respectively, while wNPj denotes non-production labor wages in the jth sector. The following set of equations represents the equilibrium conditions for this model:

$$a_{NP_j} q_j = V_{NP_j} \quad \forall_j \tag{1}$$

$$\sum_j a_{NP_j} q_j = V_P \tag{2}$$

The above equations are factor market clearing conditions for labor inputs. Notice that a similar condition does not hold for capital inputs. With perfect capital mobility, the small open economy facing exogenous capital returns faces an infinitely elastic supply curve of capital. Demand conditions determine the amount of capital employed. Sectoral unit input coefficients are variable and are subject to technological change. In particular, changes in these coefficients can be decomposed as in Jones [20][1]:

$$\widehat{a_{ij}} = \widehat{c_{ij}} - \widehat{b_{ij}} \; \forall j, i. \tag{3}$$

Here, $\widehat{c_{ij}}$ denotes changes in input coefficients as a result of changes in relative factor prices, while $\widehat{b_{ij}}$ denotes exogenous technological progress (i.e., the reduction in the amount of factor i required to produce one unit of output *j*). Note that c_{ij} is a function of returns to sector specific factors as well as returns to the mobile factor:

$$c_{Kj} = c_{Kj}\left(r, w_{NP_j}, w_p\right) \quad \forall\, j \tag{4}$$

$$c_{NP_j} = c_{NP_j}\left(r, w_{NP_j}, w_p\right) \quad \forall\, j \tag{5}$$

$$c_{P_j} = c_{P_j}\left(r, w_{NP_j}, w_p\right) \quad \forall\, j \tag{6}$$

Next, zero-profit conditions are given by:

$$p_j = a_{k_j} r + a_{NP_j} w_{NP_j} + a_{P_j} w_p \quad \forall\, j \tag{7}$$

Using hat-calculus and denoting factor shares by θ, Equation (7) can be written as:

$$\widehat{p_j} = \theta_{K_j}\hat{r} + \theta_{NP_j}\widehat{w_{NP_{ij}}} + \theta_{P_j}\widehat{w_p} - \prod_j \forall j \tag{8}$$

where $\prod_j = \sum_i \theta_{ij}\widehat{b_{ij}}$ is a measure of TFP in sector *j*. To derive equation (8) we made use of the Wong-Viner Envelope Theorem, which implies that:

$$\theta_{K_j}\widehat{c_{K_j}} + \theta_{NP_j}\widehat{c_{NP_j}} + \theta_{P_j}\widehat{c_{P_j}} = 0 \;\forall j \tag{9}$$

From the factor market clearing equations (1)-(2) we get:

$$\widehat{q_j} = -\widehat{c_{NP_j}} + \theta_{P_j}\widehat{c_{P_j}} + \prod_{NP_j} + \widehat{V_{NP_j}} \;\forall j \tag{10}$$

$$\sum_j \lambda p_j \widehat{q_j} + \sum_j \lambda p_j \widehat{c_{p_j}} = \widehat{V_p} + \prod p \tag{11}$$

where $\prod_{NP} = \widehat{b_{NP_j}}$ and $\prod_P = \sum_j \lambda p_j \widehat{b_{p_j}}$ represent the reduction in the use of production labor across all sectors. Note that λ_{ij} is defined as $\frac{a_{ij} q_j}{V_i}$. Thus, we refer to $\prod j$ in equation (8) as sector-specific technological change (TFP) and to $\prod i$ as factor-specific technological change. Note that both these terms measure technological change holding factor prices constant. Replacing $\widehat{q_j}$ in equation (11) with (10) we get:

$$\sum_j \lambda p_j \widehat{cp_j} - \sum_j \lambda p_j \widehat{c_{Np_j}} + \sum_j \lambda p_j (\widehat{V_{Np_j}} + \prod NP_j) = \widehat{V_p} + \prod p \tag{12}$$

From equations (4)-(6) we get:

$$\widehat{c_{K_j}} = E^K_{K_j}\hat{r} + E^{NP}_{K_j}\widehat{w_{NP_j}} + E^P_{K_j}\widehat{w_p} \quad \forall_j \tag{13}$$

$$\widehat{c_{P_j}} = E^K_{p_j}\hat{r} + E^{NP}_{p_j}\widehat{w_{P_j}} + E^P_{p_j}\widehat{w_p} \quad \forall_j \tag{14}$$

$$\widehat{c_{NP_j}} = E^K_{NP_j}\hat{r} + E^{NP}_{NP_j}\widehat{w_{NP_j}} + E^P_{K_j}\widehat{w_{Np}} \quad \forall_j \tag{15}$$

where $E^K_{i_j} = (\frac{\partial c_{ij}}{\partial w_k})(\frac{w_k}{c_{ij}})$ for $k = K, NP, P$ is defined as the elasticity of cij with respect to changes in w_k, holding all other factor prices constant[2].

To solve this model for mobile factor prices, substitute equations (14) and (15) in equation (12). This yields:

$$\sum_j \lambda p_j (E^K_{p_j}\hat{r} + E^{NP}_{p_j}\widehat{w_{NP_j}} + E^P_{p_j}\widehat{w_p}) - \sum_j \lambda p_j\, (E^K_{Np_j}\hat{r} + E^{NP}_{Np_j}\widehat{w_{NP_j}} + E^P_{Np_j}\widehat{w_p}) + \sum_j \lambda p_j \widehat{V^*_{NP_j}} = \widehat{V^*_p} \tag{16}$$

paper.

[1] Here $\hat{X} = dX/X$.

[2] Note that due to the zero-homogeneity of c_{ij}, $\sum_k E^K_{i_j} = 0 \;\forall_i \forall_j$ and $\sum_i \theta_{ij} E^K_{i_j} = 0 \;\forall k, j$. Further, by symmetry, $E^K_{i_j} = \frac{\theta_{kj}}{\theta_{ij}} E^i_{k_j} \forall i, j$.

where $\widehat{V_p^*} = \widehat{V_\iota} + \prod i$. With $\varepsilon_{ij} = E_{pj}^i - E_{NPj}^i$ Equation (16) can be rewritten as[1]:

$$\hat{r}\sum_j \lambda p_j \varepsilon_{Kj} + \sum_j \lambda p_j\, \varepsilon_{Np_j}\widehat{w_{NP_J}} + \widehat{w_p}\sum_j \lambda p_j \varepsilon_{pj} = \widehat{V_p^*} - \sum_j \lambda p_j\, \widehat{V_{NP_J}^*} \quad (17)$$

Equation (17) together with equation (8) can be used to solve for $\widehat{w_{NP_J}}$ and $\widehat{V_{NP_J}^*}$. To do so, rewrite Equation (8) as:

$$\widehat{w_{NP_J}} = \frac{1}{\theta_{NPj}}(p_J + \prod J - \theta_{kJ}\,\hat{r} - \theta_{pj}\widehat{wp})\forall j \quad (18)$$

Using the above in equation (17) we get:

$$\hat{r}\sum_j \lambda p_j \varepsilon_{Kj} + \sum_j \lambda p_j \frac{\varepsilon_{Np_j}}{\theta_{Np_j}}\left(\widehat{p_J} + \prod_j -\hat{r}\theta_{kj} - \theta_{pj}\widehat{w_p}\right) + \widehat{w_p}\sum_j \lambda p_j \varepsilon_{pj} = \widehat{V_p^*} - \sum_j \lambda p_j\, \widehat{V_{NP_J}^*} \quad (19)$$

That gives us:

$$\hat{r}\sum_j \lambda p_j(\varepsilon_{Kj} - \frac{\varepsilon_{Np_j}}{\theta_{Np_j}}\theta_{kj}) + \sum_j \lambda p_j \frac{\varepsilon_{Np_j}}{\theta_{Np_j}}(\widehat{p_J} + \prod_j) + \widehat{w_p}\sum_j \lambda p_j(\varepsilon_{pj} - \frac{\varepsilon_{Np_j}}{\theta_{Np_j}}) = \widehat{V_p^*} - \sum_j \lambda p_j\, \widehat{V_{NP_J}^*} \quad (20)$$

Using equation (20) we can solve for $\widehat{w_p}$:

$$\widehat{w_p} = \frac{1}{\sum_j \lambda p_j(\varepsilon_{pj} - \frac{\varepsilon_{Np_j}}{\theta_{Np_j}}\theta_{p_j})}.[\widehat{V_p^*} - \sum_j \lambda p_j\, \widehat{V_{NP_J}^*} - \sum_j \lambda p_j \frac{\varepsilon_{Np_j}}{\theta_{Np_j}}(\widehat{p_J} + \prod_j) - \hat{r}\sum_j \lambda p_j\,(\varepsilon_{Kj} - \frac{\varepsilon_{Np_j}}{\theta_{Np_j}}\theta_{kj})] \quad (21)$$

Using this solution in equation (18) we can solve for $\widehat{V_{NP_J}^*}$:

$$\widehat{w_{NpJ}} = \frac{1}{\theta_{Np_j}}(\widehat{p_J} + \prod_j -\theta_{kj}\hat{r}_j) - \frac{\theta_{p_j}}{\theta_{Np_j}}.\frac{1}{\sum_j \lambda p_j(\varepsilon_{pj} - -\frac{\varepsilon_{Np_j}}{\theta_{Np_j}}\theta_{p_j})}.[\widehat{V_p^*} - \sum_j \lambda p_j\, \widehat{V_{NP_J}^*} - \sum_j \lambda p_j \frac{\varepsilon_{Np_j}}{\theta_{Np_j}}(\widehat{p_J} + \prod_j) - \hat{r}\sum_j \lambda p_j\,(\varepsilon_{Kj} - \frac{\varepsilon_{Np_j}}{\theta_{Np_j}}\theta_{kj})]\ \forall j \quad (22)$$

$$\widehat{w_{NpJ}} - \widehat{w_p} = \frac{1}{\theta_{Np_j}}(\widehat{p_J} + \prod_j -\theta_{kj}\hat{r}_j) - (1 + \frac{\theta_{p_j}}{\theta_{Np_j}}).\frac{1}{\sum_j \lambda p_j(\varepsilon_{pj} - -\frac{\varepsilon_{Np_j}}{\theta_{Np_j}}\theta_{p_j})}.[\widehat{V_p^*} - \sum_j \lambda p_j\, \widehat{V_{NP_J}^*} - \sum_j \lambda p_j \frac{\varepsilon_{Np_j}}{\theta_{Np_j}}(\widehat{p_J} + \prod_j) - \hat{r}\sum_j \lambda p_j\,(\varepsilon_{Kj} - \frac{\varepsilon_{Np_j}}{\theta_{Np_j}}\theta_{kj})]\ \forall j \quad (23)$$

Before proceeding to the next section, certain characteristics of the above solution in equation (23) should be considered. First, changes in sectoral skill premiums are functions of interest rate changes, product price changes, changes in labor endowments, and factor-specific as well as sector-specific technological change. Second, changes in the skill premium also depends on factor intensities (ε) and factor elasticities (λ) in all sectors. Third, without making unreasonable ad hoc assumptions about these intensities and elasticities, it is not possible to determine the sign of the partial derivatives of the sectoral skill premium ($\widehat{w_{NpJ}} - \widehat{w_p}$) with respect to the exogenous variables.

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[1] Note that ε_{ij} is the change in V_{pj}/V_{NPj} due to a change in the factor price of input i.

3. Simulation Results

In this paper, we are interested in how the changes in the skill premium $(\widehat{w_{Npj}} - \widehat{w_p})$ respond to changes in interest rates, product prices, TFP growth, factor-specific technological change, and changes in labor endowments. Since the analytical partial derivatives of the sectoral skill premium with respect to the exogenous parameters cannot be signed without strong assumptions, we compute instead a numerical solution for a simplified version of the above model. Based on these simulations, it is straightforward to find the sign and magnitude of the skill premium change with respect to the different parameter changes.

For the numerical simulations, we reduce the number of sectors to two, denoted by 1 and 2. For the two sectors, zero-profit conditions are given by:

$$p_1 q_1 = rK_1 + w_p V_{p1} + w_{Np1}\bar{V}_{Np1} \quad (24)$$

$$p_2 q_2 = rK_2 + w_p V_{p2} + w_{Np2}\bar{V}_{Np2} \quad (25)$$

where p, q denote prices and quantity respectively; K denotes the endogenously determined quantity of capital; $\bar{V}_{\mathrm{NPj}}$ denotes the fixed quantity of sector specific non-production labor; and V_P denotes the mobile factor. r, w_P ,$w_{NP}j$ denote returns to the factors of production. Market clearing for the mobile factor is given by:

$$V_{p1} + V_{p2} = \bar{V}_p \quad (26)$$

Output in the two sectors is determined via a 'nested' CES production function as proposed by Krusell et al [23]. The advantage of using such a specification is that it allows for varying elasticity of substitution between factors of production:

$$q_1 = A_1\left[\mu_1(\delta_p V_{p1})^{-\sigma} + (1-\mu_1)\{\lambda_1(\delta_k K_1)^{-\rho} + (1-\lambda_1)(\delta_{NP1}\bar{V}_{Np1})^{-\rho}\}^{\frac{\sigma}{\rho}}\right]^{-\frac{1}{\sigma}} \quad (27)$$

$$q_2 = A_2\left[\mu_2(\delta_p V_{p1})^{-\sigma} + (1-\mu_2)\{\lambda_2(\delta_k K_2)^{-\rho} + (1-\lambda_2)(\delta_{NP2}\bar{V}_{Np2})^{-\rho}\}^{\frac{\sigma}{\rho}}\right]^{-\frac{1}{\sigma}} \quad (28)$$

Here A_1 and A_2 are the sector specific (neutral) technological change parameters, while δ represents factor specific (skill-biased) technical change. μ and λ denote the share parameters. In this specification the elasticity of substitution between V_p and K is identical to the elasticity of substitution between V_p and V_{Np}. This is given by $\frac{1}{1+\sigma}$ The elasticity of substitution between K and V_{Np} is given by $\frac{1}{1+\rho}$. Here $\sigma, \rho \in [-1, \infty]$. If $\sigma = \rho = 0$ then we have a Cobb-Douglas in 3 factors. As these parameters approach -1 we get greater substitutability than in the C-D case. Thus, for $\rho > \sigma$ we get capital-skill complementarity. In both sectors, wages of mobile factors equal the value of their marginal product:

$$w_p = \frac{p_1 \delta_P^{-\sigma} \mu_1 q_1^{1+\sigma}}{A_1^{\sigma} V_{P_1}^{1+\sigma}} \quad (29)$$

$$w_p = \frac{p_2 \delta_P^{-\sigma} \mu_2 q_2^{1+\sigma}}{A_2^{\sigma} V_{P_2}^{1+\sigma}} \quad (30)$$

Finally, in both sectors the marginal product of capital must equal the exogenously determined interest rate:

$$r = \frac{p_1 \delta_k^{-\rho} \lambda_1 (1-\mu_1) q_1^{1+\sigma} \{\lambda_1(\delta_k K_1)^{-\rho} + (1-\lambda_1)(\delta_{NP1}\bar{V}_{Np1})^{-\rho}\}^{\frac{\sigma}{\rho}-1}}{A_1^{\sigma} K_1^{1+\rho}} \quad (31)$$

$$r = \frac{p_2 \delta_k^{-\rho} 2 (1-\mu_2) q_2^{1+\sigma} \{\lambda_2(\delta_k K_2)^{-\rho} + (1-\lambda_2)(\delta_{NP2}\bar{V}_{Np2})^{-\rho}\}^{\frac{\sigma}{\rho}-1}}{A_2^{\sigma} K_2^{1+\rho}} \quad (32)$$

Table 1: Parameter Values

σ	-.33	μ_1	.20	$\bar{V}_p$	270	p_1	1	δ_P	1
ρ	.66	λ_1	.55	$\bar{V}_{Np1}$	100	p_2	1	δ_{NP1}	1
μ_1	.55	λ_2	.50	$\bar{V}_{Np2}$	100	A_1	1	δ_{NP2}	1

Source: Authors

The parameter values used in the simulated models are given in Table 1. These values were chosen to mimic the values of relative prices and quantities for the U.S. manufacturing industries for average values over the period 1958-05. For example, the average ratio of production to non-production workers in U.S. manufacturing industries for this period is 2.7, which is the number we use in our simulations. The revenue share for production labor in sector 1 is assumed to be 55%, while that for non-production labor in sector 2 is 40%. Thus, production labor is used most intensively in sector 1, while non-production labor is used most intensively in sector 2 (Factor intensity is defined as follows: sector 1 uses factor P intensively and sector 2 uses factor NP intensively iffθ_P1⁄(θ_P2>θ_NP1⁄θ_NP2)). The elasticities of substitution among factors were chosen following Johnson [17] such that they reflect capital-skill complementarity. Table 2 presents the simulation results.

Table 2: Simulation Results

	Base	$\bar{r}$	p_1	p_2	A_1	A_2	δ_k	δ_p	δ_{NP1}	δ_{NP2}	$\bar{V}_p$	$\bar{V}_{Np1}$	$\bar{V}_{Np2}$
k_1	315	-7.7	9.0	-0.9	9.0	-0.9	-1.6	3.4	6.9	-3.7	3.4	6.9	-3.7
k_2	339	-7.9	-1.2	9.8	-1.2	9.8	-1.4	0.3	-0.3	9.6	0.3	-0.3	9.6
w_p	.50	-0.9	10.3	0.7	10.3	0.7	0.8	7.3	2.3	3.0	-2.5	2.3	2.9
w_{Np1}	.55	-3.6	15.3	-1.4	15.3	-1.4	3.6	5.7	4.8	-6.0	5.7	-4.7	-6.0
w_{Np2}	.76	-4.1	-2.0	16.8	-2.0	16.8	4.1	0.5	-0.5	9.3	0.5	-0.5	-0.6
Q_1	205	-1.2	2.6	-1.7	12.8	-1.7	1.1	6.7	4.0	-7.0	6.7	4.0	-7.0
Q_2	126	-2.4	-2.4	4.9	-2.4	15.4	2.3	0.7	-0.6	9.2	0.7	-0.6	9.2
V_{p1}	238	0.2	2.1	-2.7	2.1	-2.7	-0.1	0.7	0.5	-10.9	10.7	0.5	-10.9
V_{p2}	32.2	-1.1	-15.7	19.8	-15.7	19.8	1.0	-5.0	-3.9	4.7	4.5	-3.9	4.7
$(\frac{w_{Np}}{w_p})_1$	1.10	-2.8	4.6	-2.1	4.6	-2.1	2.7	-1.5	2.5	-8.6	8.4	-6.8	-8.6
$(\frac{w_{Np}}{w_p})_2$	1.52	-3.3	-11.2	16.1	-11.2	16.1	3.2	-6.3	-2.7	6.3	3.1	-2.7	-3.4
$(\frac{w_{Np}}{w_p})$	1.31	-3.1	-4.6	8.4	-4.5	8.4	3.0	-4.3	-0.5	-0.2	5.3	-4.4	-5.7

Source: Authors

For the benchmark simulation, we set the inter-industry capital ratio between sector 1 and 2 to .93, which implies an average non-production to production wage ratio of 1.31. This number is close to the actual ratio of 1.61 (the average ratio for U.S. manufacturing industries over the sample period). In Table 2, we present the change in the skill premium (sectoral as well as average) between non-production and production workers for a 10% increase in endowments, product prices, factor-specific technological change, interest rates and TFP growth. The forces that cause an increase in the skill premium are: an increase in the endowment of production labor; an increase in product price of sector 2; TFP growth in sector 2; and capital specific technological progress. In contrast, the skill premium falls with production labor specific technological progress; non-production labor specific technological progress; TFP growth in sector 1; a higher price of good 1; an increase in interest rates; and larger endowment of non-production labor.

The critical conclusion to be drawn from these results regards the change in the skill premium due changes in the interest rates. We find that the average skill premium declines by less than 10%. Thus, for parameters chosen in the benchmark case there is an inverse relationship between interest rate changes and the skill premium. Recalling that interest rate increases are an indicator for capital outflows, this decline in the skill premium is expected as with less capital, the demand for skilled workers decline. Also note that an increase in the price of good 2 (the skilled-labor intensive good) causes a rise in the skill premium, while an increase in the price of the unskilled labor intensive good implies a decline in the premium. Therefore, the model predicts Stolper-Samuelson type effects of product price changes as well.

4. Data

To obtain the equilibrium factor price changes, we first write out the full system of equilibrium equations as given in (8) and (20):

$$\begin{bmatrix} \hat{p}_1 + \widehat{\Pi}_1 - \theta_{k1}\hat{r} \\ . \\ . \\ . \\ \widehat{p_m} + \widehat{\Pi}_m - \theta_{km}\hat{r} \\ \widehat{V_P^*} - \sum_j \lambda p_j \widehat{V_{NP}^*}_j - \hat{r}\sum_j \lambda p_j\, \varepsilon_{Kj} \end{bmatrix} = \begin{bmatrix} \theta_{NP1} & 0 & . & . & 0 & \theta_{P1} \\ 0 & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & 0 & . \\ 0 & . & . & 0 & \theta_{NPm} & \theta_{Pm} \\ \lambda p_1 \varepsilon_{NP1} & . & . & . & \lambda p_m \varepsilon_{NPm} & \sum_j \lambda p_j\, \varepsilon_{Pj} \end{bmatrix} \begin{bmatrix} \widehat{w_{NP1}} \\ . \\ . \\ . \\ \widehat{w_{NPm}} \\ \widehat{w_p} \end{bmatrix} \quad (33)$$

To calculate the factor price changes, we need data for the elements of the LHS vector and the RHS matrix. The data set we use is the latest version of the NBER-CES Manufacturing Database [29]. This database contains annual information on all U.S. manufacturing industries from 1958 to 2005. At the 4-digit 1972 SIC level there are 448 industries. Due to missing data, we exclude SIC 2384, 2794 and 3292 from our analysis. Note that all growth rates in period t are defined as the change between period t + 1 and t relative to period t (see Leamer [28] for a similar definition). Growth rates are thus forward looking. As a result, we lose observations for 2005. The λ variables in the matrix above are functions of factor-demand elasticities. These elasticities are not directly observed and must be estimated. A detailed description of how we estimate these elasticities is given in Appendix A. Appendix B contains a brief description of how we construct the remaining variables. Table 3 provides descriptive statistics for the key exogenous variables, and for the actual factor price changes observed in the data. Note that while some of the statistics are computed by pooling over all industries and over the entire sample period, others are computed by pooling over industries only.

Table 3: Descriptive Statistics

variable	Mean	S.D.	Min	Max	Obs.
$\hat{p}_j$	-.015	.0515	-.7009	.98	20492
Π_j	.0064	.0405	-.9321	1.7659	20492
$\widetilde{\Pi}_m$	.0065	.0379	-.9262	1.7382	20492
Π_P	.0357	.0317	-.0397	.112	47
Π_{NP}	.0354	.0464	-.0947	.1453	47
$\widehat{V_P}$	-.0044	.0396	-.1017	.0589	47
$\widehat{V_{NP}}$	.002	.0265	-.065	.0491	47
$\widehat{W_{Pj}}$	.0478	.056	-.5859	1.4518	20492
$\widehat{W_{NPj}}$	.0543	.1553	-.9250	12.22	20492
$\hat{r}(Moody'sBaa)$	.011	.0965	-.1831	.2788	47

Source: Authors

Several issues need to be discussed at this point. First, we use the production and non-production labor classification from the NBER data set as a proxy for unskilled and skilled workers. This approximation has been criticized on the grounds that production worker category may include workers with high education levels or skills, while the group of non-production workers may include workers with low education levels or skills. However, we maintain this classification since it is a reasonable approximation used widely in the literature. In addition, results by Kahn and Lim [22] show a high correlation between cost-shares based on the two classification schemes indicating that the two schemes are close substitutes. Second, due to the lack of (manufacturing) sector specific data on labor endowments, we use growth rates of observed labor employment instead. Kosters [25] (Table 1-6) presents estimates for changes in the proportion of the work force from 1973-88 for workers with 12 years of education or less, and for workers with 16 or more years of education. Translated into annual growth rates, his estimates show that the endowment of skilled and unskilled workers grew at a rate of -.0076 and .0048, respectively. The corresponding growth rates for skilled and unskilled workers using average manufacturing employment data are -.0078 and .0104, respectively. The substantial co-movement between the change in labor endowments and the change in employment indicates that the approximation error is likely to be small. Third, capital factor shares are computed as 1 minus labor and materials factor shares, i.e., as a residual. This implies that our definition of capital factor shares includes payments to other sector-specific assets as well and is thus larger than the true capital share. Similarly, since we do not have data on the quantity of these other assets or on industry-specific depreciation rates and consumption of fixed capital, we compute the ex post rental price of capital as value added less total labor compensation divided by the capital stock (Errors in the NBER dataset resulted in a negative rental price of capital for a few industries. These values were arbitrarily fixed at an uniform rate of 10%.). Compared to the true rental price of capital, our computed one is upward biased.

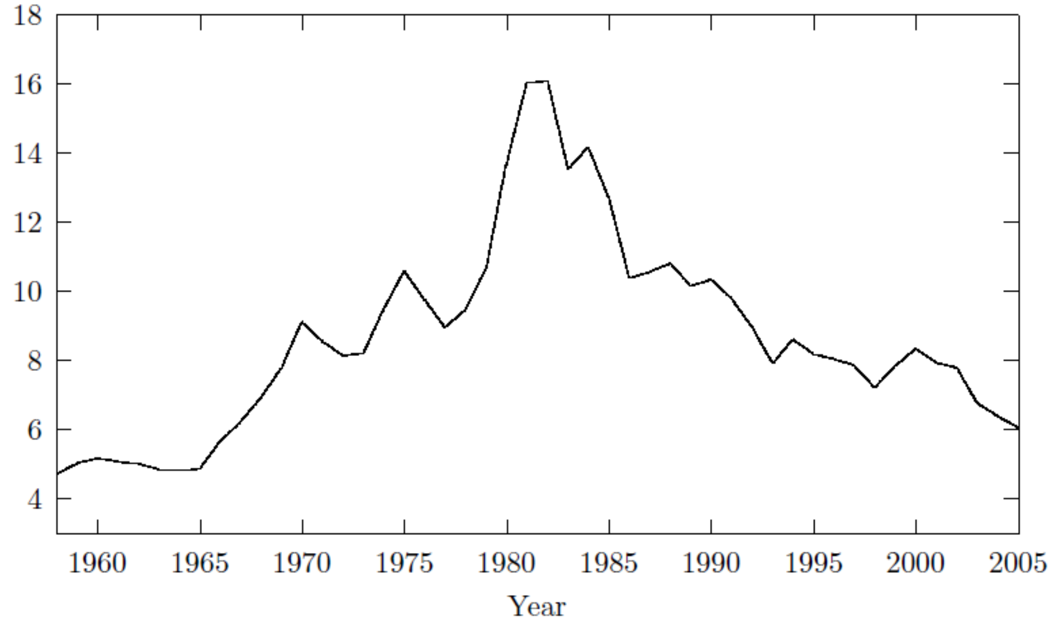

Figure 3: Moody's Baa rate, 1958-200
***Source*: Economic Report of the President, 2011. Table B-73.**

Fourth, the empirical implementation of equation (33) requires data on international interest rates. An obvious choice, the 1-year London Interbank Offer Rate on U.S. Dollar Deposits (LIBOR), is not available for the entire sample period. We therefore use a close proxy (see Figure 3), the Moody's Baa series[13], which is also used by Feenstra and Hanson [12][14] . This measure yields a positive average annual growth rate of 1.1% over the sample period and a negative average growth rate of 3.3% during 1982-05. According to the international capital flow mechanism outlined earlier, these growth rates are consistent with observed flows for the manufacturing sector, i.e., net outflows prior to 1982 and mostly net inflows in subsequent years. Fifth, our theoretical model does not include intermediate inputs. In the empirical analysis, we account for the impact of intermediate inputs on product prices by deriving a value-added price change measure. This is done, as in Leamer [28], by subtracting from the vector of product price changes the inner product of a diagonal matrix with material cost-shares on its main diagonal and a vector of growth rates of material deflators. Sixth, according to equation (3), changes in unit input coefficients can be decomposed into changes due to factor

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[13] Annual percent yield on corporate bonds (Moody's Baa: *Economic Report of the President, 2011. Table B-73).* Note that this is an *ex ante* measure of the rental price of capital.

[14] For a small open economy, the domestic interest rate must be equated to the world interest rate. Therefore, changes in the domestic interest rate triggers off capital ows similar to those due to changes in the world interest rate.

price variations (holding technology constant) and changes due to technological progress (holding factor prices constant). Since we only observe $\widehat{a_{ij}}$ in the data, we proceed by constructing an estimate for $\widehat{c_{ij}}$ and then use (3) to construct a measure of $\widehat{b_{ij}}$ Using the estimated factor-demand elasticities (see Appendix A), we derive an estimate of $\widehat{c_{ij}}$ using the following equations[15]

$$\overline{\widehat{c_{K_j}}} = E^K_{K_j}\hat{r}_j + E^P_K\widehat{w_{NP_j}} + E^{NP}_K\widehat{w_{Npj}} \quad \forall_j \tag{34}$$

$$\overline{\widehat{c_{P_j}}} = E^K_P\hat{r}_j + E^P_P\widehat{w_{P_j}} + E^{NP}_P\widehat{w_{Npj}} \quad \forall_j \tag{35}$$

$$\overline{\widehat{c_{NP_j}}} = E^K_{NP}\hat{\hat{r}}_j + E^P_{NP}\widehat{w_{NP_j}} + E^{NP}_{NP}\widehat{w_{Npj}} \quad \forall_j \tag{36}$$

where $\overline{\widehat{c_{ij}}}$ is the predicted value of $\widehat{c_{ij}}$[16].

Finally, the assumption of perfect mobility of procij bduction labor (and capital, for our second model) across sectors is a potential source of error when we apply our model to the data. This is due to the fact that in the data, returns for these two factors of production vary across sectors. To adjust for this empirical fact, we proceed as in Feenstra and Hanson [12] and modify the zero-profit conditions so that all factor returns are indexed by j:

$$\widehat{p_j} = \theta_{K_j}\hat{r}_j + \theta_{P_j}\widehat{w_{P_{ij}}} + \theta_{NP_j}\widehat{w_{Np}} - \prod_j \forall j \tag{37}$$

Rewriting the last equation yields:

$$\widehat{p_j} = \theta_{K_j}\hat{r}_j + \theta_{NP_j}\widehat{w_{NP_j}} + \theta_{P_j}\widehat{w_p} + \theta_{P_j}\widehat{(w_{pj}} - \widehat{w_{pj}}) + \theta_{K_j}(\widehat{r_j} - \hat{r}) - \prod_j \forall j \tag{38}$$

Equation (38) is identical to equation (8) except for the extra term on the RHS[17]. Following Feenstra and Hanson we add these two terms to Π_j and call the resulting expression effective TFP,$\widetilde{\Pi_j}$. Thus we have:

$$\widehat{p_j} = \theta_{K_j}\hat{r}_j + \theta_{NP_j}\widehat{w_{NP_j}} + \theta_{P_j}\widehat{w} - \widetilde{\Pi_j}\ \forall j \tag{39}$$

With these caveats in mind, we calculate the predicted skill premium growth rate as the manufacturing sector average of differences between $\widehat{w_{NP_j}}$ and $\widehat{w_P}$, followed by a decomposition of the total effect into the changes caused by globalization, endowment, and technological change. To calculate the impact of a particular factor, say product price change, we set all other exogenous variables in the LHS vector of (33), i.e., $\widehat{V_p^*} - \sum_j \lambda p_j \widehat{V^*_{NP_j}} - \hat{r}\sum_j \lambda p_j \varepsilon_{Kj}, \widetilde{\Pi_j}$, and $-\theta_{Kj}\hat{r}$ to zero.

5. Model Predictions and Decomposition

Our main results are presented in Table 4. All numbers are averages of annual growth rates. Over the sample period from 1958-05 the skill premium in U.S. manufacturing industries grew at a modest rate of .11% per year. The skill premium growth rates reported for the four subperiods, 1958-66, 1967-81, 1982-2000, and 2001-05, correspond to different trends in the skill-premium.

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[15] Note that there are two differences between (13)-(15) and (34)-(36). First, the returns to mobile factors are industry-specific in equations (34)-(36). Second, the elasticities are now identical across industries. Both changes are necessary to be consistent with the estimation described in Appendix B.

[16] Note that for estimating elasticities, as well as for calculating $\overline{\widehat{c_{ij}}}$ use a sectoral user-cost of capital measure.

[17] We construct wbP as the growth rate of average manufacturing factor returns to production labor

Table 4: Observed and Predicted Average Annual Skill Premium Growth Rates

Years	Observed	Predicted	Correlations
1958-05	.0011	.0279	.1017
1958-66	.0049	.0493	.1268
1967-81	-.005	-.0331	.1158
1982-00	.0072	.0555	-.1867
2001-05	-.0133	.0777	.5136

Source: Authors

Comparing the actual growth rates with the growth rates predicted by our model, we find that the model correctly predicts the direction of changes for the entire sample period and for three of the four sub-periods. Only for the 2001-05 subperiod does the model predict a further rise in the skill premium, while the actual skill premium declined. In terms of magnitudes, the model over-predicts for the entire period (2.8% predicted growth as compared to .11% actual growth) as well as for each of the subperiods. The correlation coefficients reported in the last column of Table 4 reveal that the co-movement between the predicted and actual growth rates is fairly low except for the final subperiod. Figure 4 depicts the observed and predicted growth rates for the entire period. The difference in magnitude between the volatile predicted values and the rather smooth observed skill premium values is clearly visible from this figure.

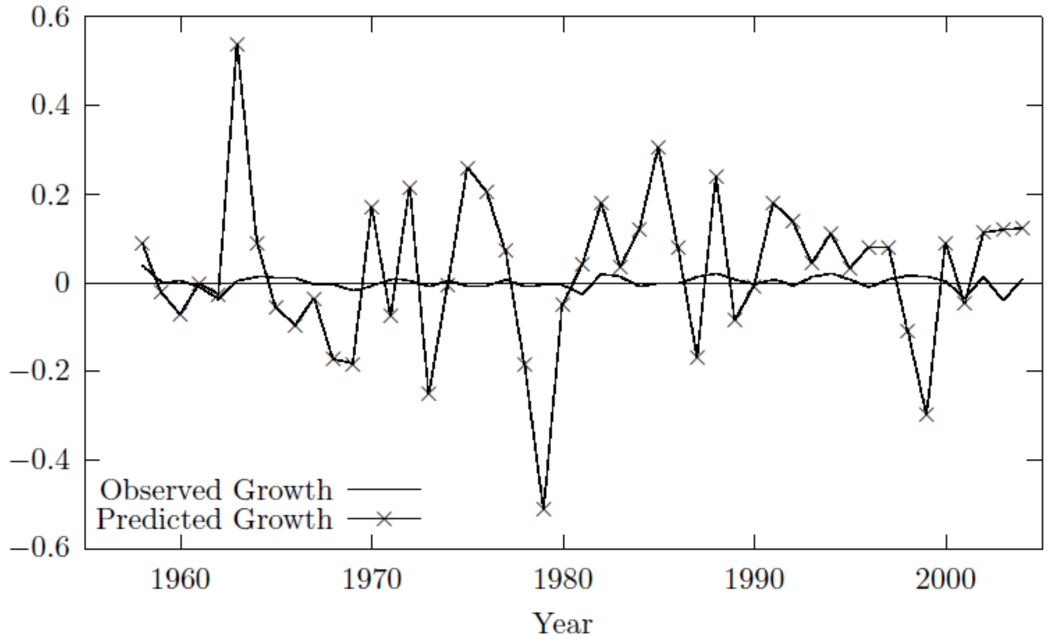

Figure 4: Actual and Predicted Skill Premium Growth Rates in U.S. Manufacturing Industries, 1958-2005

Source: Authors

Table 5 contains the decomposition of the predicted skill premium growth rates. Globalization (i.e., product price changes and interest rate changes) had a positive effect on the skill premium for the entire period as well as for the periods after 1981. The impact of technological change mirrors that of globalization, while endowment changes, for the entire period and for all sub-periods, caused a decline in the skill premium.

To better understand the impact of changes of these three broad categories on the skill premium, we further decompose each category into their constituent parts (see Table 6). The striking result which emerges from this decomposition is that interest rate changes had a positive effect on the skill premium from 1982 onward. As mentioned earlier, this is exactly the period when capital inflows started to become the norm. Globalization working through product price changes had a positive effect on the skill premium for all sub-periods as well as the entire period.

Table 5: Decomposition of the Predicted Skill Premium Growth Rate

Years	Globalization	Technology	Endowments
1958-05	.0368	.0071	-.0159
1958-66	-.0231	.0748	-.0023
1967-81	-.0048	.0044	-.0327
1982-00	.076	-.0154	-.0051
2001-05	.1413	-.0287	-.0349

Source: Authors

Table 6: Decomposition of Individual Effects

	Globalization			Technology		Endowments	
Years	Price	Interest rate	TFP	P specific	NP specific	P labor	NP labor
1958-05	.0436	-.0068	-.0101	.0567	-.0395	-.0072	-.0087
1958-66	.0059	-.0249	.0639	.0651	-.0543	.0303	-.0327
1967-81	.0613	-.0662	-.0232	.0306	-.003	-.012	-.0207
1982-00	.0435	.0325	-.0271	.064	-.0523	-.007	.0018
2001-05	.0718	.0696	-.0473	.1014	-.0829	-.0748	.0399

Source: Authors

Table 7: Contributions by Factor (in %) and Residual

	Explained Variation: Contribution by Factor				*Residual*
Years	*Price*	*Interest Rate*	*Technology*	*Endowments*	
1958-05	25.5	27.2	31.2	16.0	49.5
1958-66	23.5	19.5	36.8	20.2	49.5
1967-81	28.5	27.7	29.3	14.5	51.4
1982-00	29.0	28.3	30.9	11.8	47.9
2001-05	40.0	20.4	28.9	10.7	42.8

Source: Authors

As expected, the observed decrease in the endowment of production workers had a negative effect on the predicted skill premium over the full sample period, as did the increase in the number of non-production workers[18]. Similar changes in the supply of production and non-production workers for the various subperiods explain the pattern of skill premium changes shown in the last two columns of Table 6. Production labor specific technological change had a positive effect on the skill premium for the full sample as well as during each subperiod, while non-production labor specific technical change lowered the skill premium in all periods. Interestingly, except for one subperiod (1958-66), TFP growth always contributed to a decline in the skill premium.

Table 7 presents the relative contribution to the explained variation by each factor as well as the residual (unexplained variation)[19].

[18] The actual annual growth rates for production and non-production workers for the entire sample period are -.4% and .2%, respectively.

[19] Note that the four contribution shares add up to 100. The contribution by each factor i is defined as:

While we report shares for price and interest rate changes separately, the shares for technology and endowments are reported as an aggregate over their components. The numbers for the residual shares show that for the entire sample period, as well as most subperiods, approximately 50% of the observed variation in the skill premium is explained by the model. The explained variation breaks down as follows. Interest rate and product price changes each account for roughly a quarter of the predicted changes in the skill premium. Technology accounts for 31%, while labor endowment changes account for 16%. These relative contributions do not vary drastically over the four sub-periods. However, the impact of product price changes appears to increase over time, while that of labor endowment changes seems to decline[20].

6. Summary and Conclusions

This paper contributes to the globalization and wage inequality literature in two ways. First, by assuming that interest rates are determined in the world market, we allow for capital to be an endogenous variable that is mobile internationally. Thus, we provide direct empirical evidence on the effects of international capital movements on relative wages. Second, by using a multi-sector specific-factors model which we apply to U.S. manufacturing data, we avoid the 'factor-price' insensitivity result of the Heckscher-Ohlin model. Therefore, we are able to provide evidence on the relative impact of globalization, technological progress (sector and factor-specific), and labor endowment changes on movements in the U.S. skill premium.

Several results emerge from our analysis. First, the net capital outflow that occurred during the period 1958-82 had a depressing effect on the skill premium. In contrast, the net capital inflows that were prevalent between 1981 and 2001 had a positive effect on the skill premium. Second, globalization effects working through product price changes caused an increase in the skill premium for all periods. Third, increases in non-production labor endowments worked towards depressing the skill premium, as did the decline in the supply of production workers. Fourth, production labor specific technical change increased the skill premium, while non-production labor specific technical change and TFP growth reduced the skill premium. Finally, in terms of relative contributions, globalization effects, working through changes in interest rates and product prices, had the biggest impact on the skill premium, followed by technology, while labor endowment changes had the least relative impact on skill premium changes.

There are two possible explanations for the large differences in magnitude between the actual and predicted skill premium growth rates. First, our model does not take into account capital market imperfections, impediments to capital mobility, and risk and uncertainty with respect to foreign direct investment. This may lead to biased predictions. Second, in some sectors such as autos and chemicals, the U.S. may be

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$\frac{\text{abs}(\text{predicted}_i)}{\sum abs(\text{predicted}_j}$. The residual share is defined as: $\frac{\text{abs}(\text{actual}-\text{predicted})}{\text{abs}(\text{actual}-\text{predicted})+\text{abs}(\text{predicted})}$. This gives us the % of actual growth rate that is unexplained.

[20] The results shown in Table 7 are along the lines of those in Dasgupta and Osang [6]. However, that paper does not consider the effects of international capital flows.

considered a large economy with potential market power. For these sectors the user cost of capital is likely to be determined in domestic markets rather than being set on world markets as assumed in our model.

The analysis presented in this paper lends itself to several extensions. The model could be easily applied to data for other countries, just as 'mandated-wage regression' analysis of U.S. industries was later applied to wage inequality issues in countries such as the UK and Sweden. Another extension would be to include service sector industries in the empirical analysis, as U.S services sectors have witnessed significant capital inflows since the early '80s as well.

Appendix A

To calculate the predicted skill premium in equation (33), we need values for ε_{ij}. Since $\varepsilon_{ij} = E^i_{p_j} - E^i_{Np_j}$,we can use equations (3) for $E^k_{i_j}$. Since $\widehat{a_{ij}} = \widehat{V_{ij}} - \widehat{Q_j}$, we can use equation (3) and (13)-(15) to write the following:

$$\widehat{V_{ij}} - \widehat{Q_j} = E^k_{K_j}\widehat{r_j} + E^p_{K_j}\widehat{w_P} + E^{NP}_{K_j}\widehat{w_{NP}} - \widehat{b_{ij}}\ \forall i \quad (40)$$

Moving the $\widehat{Q_j}$ term to term to the right, holding technology constant, i.e., $\widehat{b_{ij}} = 0$, and indexing factor returns to labor by sector j, we get:

$$\widehat{V_{ij}} = E^k_{K_j}\widehat{r_j} + E^p_{K_j}\widehat{w_{Pj}} + E^{NP}_{K_j}\widehat{w_{NP}} + \widehat{Q_j}\ \forall i \quad (41)$$

The $E^k_{i_j}$ on the RHS of this equation are factor demand elasticities. Following the labor demand literature, summarized in Hamermesh [16], we estimate these elasticities with the following model[21]:

$$LnV_{ij} = \sum_i \beta_i Lnw_i + \gamma_j LnQ_j + \varrho_j \quad (42)$$

where ϱ_j is the error term. As noted in the literature (see Roberts and Skoufias [30]) equation (42) must be estimated in long time-differences to avoid the potential errors-in-variables problem. Accordingly, we estimate (42) using 10-year time differences. We consider two different specifications. In the first specification, we use cross-sectional data and estimate the elasticities for each year from 1968-94. In the second specification, we use a panel data approach and estimate the above equation with time and industry dummies. For both specifications, we impose two constraints: $\sum_i \beta_i = 0$ and $\gamma_j = 1$. Since the second specifications yields implausible results for some own price elasticities, we use the first specification. Averaging the yearly estimates from the first specification yields the following values for the demand elasticities[22]:

$$\begin{bmatrix} E^K_K & E^K_P & E^K_{NP} \\ E^p_K & E^p_P & E^p_{NP} \\ E^{NP}_K & E^{NP}_P & E^N_{NP} \end{bmatrix} = \begin{bmatrix} -.700 & .005 & -.091 \\ .521 & -.111 & .554 \\ .179 & .107 & -.463 \end{bmatrix} \quad (43)$$

As predicted by theory, all own price elasticities re negative. However, the symmetry condition does not hold. We did not impose this restriction in our elasticity estimations since it has been noted in the

[21] In the context of international trade and wage inequality, Slaughter [33] has estimated constant-output factor demand elasticities using the same dataset that we use. However, he does not report these manufacturing-wide elasticity estimates in his paper.

[22] Using time averaged instead of yearly estimates entails a trade-off. It allows us to use a larger dataset to calculate (27), i.e., we avoid losing the years 1958-67. The cost is that we need to assume that the actual elasticites we are trying to estimate are time-invariant, i.e., $E^k_{i,t} = E^k_t$.

literature that such restrictions do not necessarily improve the efficiency of the estimates.

Appendix B

Here we describe the construction of the variables used in our analysis.

w_{NP} : Non-production labor wages = *PAY* - *PRODW*

V_{NP} : Non-production employment = *EMP* -*PRODE*

r: User cost of capital for jth industry = *(VADD-PAY)/CAP*

r : Nominal interest rate on corporate bonds (Moody's Baa, from ERP, 2011.)

$\widehat{V_P}$: Growth rate of total production employment = growth rate of $\sum_j$ PRODE

$\widehat{V_{NPJ}}$: Growth rate of non-production employment in *j*th industry

λ_{Pj}: Share of jth industry in total production labor force = *PRODE/ PRODE*

λ_{NPj}: equal to 1 by definition

θ_{Pj} : Revenue share of production labor for jth industry = *PRODW/VSHIP*

θ_{NPj} : Revenue share of non-production labor for jth industry = w_{NP} /*VSHIP*

θ_{Mj}: Materials revenue-share for jth industry = *MATCOST/VSHIP*

$\theta_{\mathrm{Kj}} = 1 - \theta_{\mathrm{P}j} - \theta_{\mathrm{NP}j} - \theta_{\mathrm{M}j}$

$\widehat{Q_J}$: growth rate of real value-added

$\widehat{a_{\mathrm{Pj}}}$: growth rate of production labor-input coefficient for industry j =(P $\widehat{\mathrm{RODE}_J}$)-$\widehat{Q_J}$

$\widehat{a_{\mathrm{NPj}}}$: growth rate of non-production labor-input coefficient for industry j =($\widehat{\mathrm{VNP}}$j) - $\widehat{Q_J}$

$\widehat{a_{\mathrm{Kj}}}$: growth rate of capital-input coefficient for industry *j* =($\widehat{\mathrm{CAP}_\mathrm{j}}$) - $\widehat{Q_J}$

Π_j: Total factor productivity growth in jth industry =$\sum_i \Theta_{ij} \widehat{b_{\iota J}}$.

Π_j : Measure of factor-specific technological change for i-th factor = $\sum_j \lambda_{ij} \widehat{b_{\iota J}}$

$\widehat{PM_J}$: growth rate of PIMAT for industry *j*

$\mu_j \hat{P}$: adjustment term for intermediate inputs = product of an m*m matrix with materials revenue-share θ_{Mj} on its main diagonal with the m*1 vector of $\widehat{PM_J}$

$\widehat{p_J}$: growth rate of PISHIP for industry $j - \mu_j \hat{p}$

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