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THE TECHNOLOGICAL BIAS AGAINST PRODUCTION WORKERS IN UNITED STATES MANUFACTURING 1949 – 1996

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Working Paper No. 05/30
November 2005

The Technological Bias Against Production Workers in United States Manufacturing 1949 – 1996.

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Abstract: This paper presents quantitative estimates of the effects of technological change on the composition of production and non-production workers in manufacturing in the United States for the period 1950 – 1995. The paper separates the effects of relative wage change, biased technological change and changes in sectoral composition and estimates the effect of upward pressure on relative pay exerted by biased technological change.

Keywords: Skill change, United Kingdom, technological change, sectoral composition.

JEL classification: J40, O52.

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1. Introduction.

From the end of the 1970's to the beginning of the 1990's there was a general in earnings inequality in the USA. The earnings differentials between high and low paid workers widened and there was an increase in income dispersion within almost any group in the labour market. This reversed a tendency towards equality over the previous fifty years. The similarity of increased inequality to trends in other countries suggested the need for general explanations. Standard explanations rely on changes in the balance of supply and demand in favour of workers with higher skills and ability and more generally towards non-production, white-collar workers. The most widely discussed explanations of the changing balance are structural shifts between sectors, and particularly the changing balance between the service and manufacturing sectors, perhaps linked to trade, and 'skill-biased' technical change (Freeman 1995).

One aspect of the growth in inequality has been the increase in the relative pay of non-production workers and this is often interpreted as an indication of the shift towards 'skill'. Although there is too much diversity within each of these broad groups to identify non-production work with skill and production work with lack of skill, the changing fortunes of these two groups throw light on the nature of biased technological change and the degree to which it can explain changing pay differentials. In this paper we consider the way biased technological change altered the balance between these two groups in American manufacturing and the way this may or may not have been related to their relative pay. This aspect of biased technological change was introduced by Berman, Bound and Griliches [1994] and has been further analysed in an international context by Machin and Van Reenen [1998] , Berman, Bound and Machin [1998] and Acemoglu [2002].

The present paper continues in the spirit of Goldin and Katz [1998] and other economic historians who emphasise the long-standing nature of technological bias. Early developments in the factory system were biased against highly skilled independent manual workers and the production methods of Henry Ford similarly motivated at least in part to reduce dependence on the 'labour aristocracy' of skilled, unionised manual workers. Habakkuk (1967) analysed the differences in technological bias between America and Britain in the nineteenth century, arguing that labour scarcity in the US was a strong stimulus to mechanisation which reduced dependence on skilled production workers. In this paper we consider the employment of production and non-production workers in twenty manufacturing industries from 1949 to 1996.

The distinctive features of the paper are:

- It explicitly measures the technological bias and the way it has changed.
- The time period considered, 1949 – 1996, is much longer than that in most discussions.
- Because we have explicit measures of the technological bias over a long time period we are able to assess whether there was an acceleration in this bias at the beginning of the 1980's
- It explicitly considers whether the increasing bias towards non-production workers has been sufficient to account for the changes in their relative pay.

The main conclusions are that the increasing bias against production workers is not a recent phenomenon and can be traced at least as far back as 1949. Although there is some evidence that the bias may have accelerated recently, there have been other periods when it was quite pronounced. Despite the long-standing bias, there has been no corresponding long-standing

increase in the relative pay of non-production workers and the bias can only be part of the explanation for growing inequality.

2. The Increasing Bias Against Production Workers in US Manufacturing 1949 – 1996.

This paper is based on data from the Annual Census of Manufactures for production and non-production workers from 1949 to 1996. Analysis is conducted at the 2-digit level where consistency of industrial classification is stable over this long period. Although a finer level of disaggregation would be desirable, the picture which emerges is consistent and informative. The data is sufficient to show the way the ratio of production to non-production workers has varied, to calculate a measure of the way the underlying technological bias between these two groups has changed and to derive measures of the contribution of this changing technological bias to the changing relative employment of the two groups.

The relative employment of production workers.

A simple measure of the bias against production workers is to take the ratio of production to non-production workers. Three-year centred averages for these are given in Table 1 at five-year intervals from 1950 to 1995. In the earlier part of this period all industries show a decline in the relative employment of production workers.

Table 1 also shows that there is considerable heterogeneity across industries in the ratios of production to non-production workers and in the way the ratios have changed over time. There are also clear variations in the pace of change between different time periods within industries. The textile industry was clearly most intensive in the use of manual workers at the beginning of our period, it experienced a dramatic fall in the relative use of production

workers up to 1970 since when the decline has continued but at a pace similar to that in other industries. Although the ratios of manuals to non-manuals is more equal across industries at the end of our period than at the beginning, there is still considerable variation, with ‘Leather and Fur’ showing a ratio more than five times that in ‘Instrument Engineering’. Since 1970 all industries show the increasing bias against manuals but it is not obvious that this trend has been greater after 1979 than before. The general implication of Table 1 is that the representation of technological bias and its change should allow for considerable technological differences across industries and in rates of change both between industries and within industries between different time periods.

Measures of Skill Bias.

Although the ratios of non-production to production workers show the way employment has swung against manuals, they are not explicit measures of technological bias. The ratios reflect the combined effects of relative pay as well as underlying technology, and changes in the ratios are the result of changes in both of these. To disentangle the effects of relative pay and genuine technological bias we take a CES representation of the technology of each industry in each year and calculate the technological parameters which affect the ratio of non-production to production workers.

Table1 **Ratio Non-production to Production Workers: 3 Year Centred Averages.**

	1950	*1955*	*1960*	*1965*	*1970*	*1975*	*1980*	*1985*	*1990*	*1995*
All Ind	0.22	0.27	0.32	0.31	0.34	0.35	0.38	0.44	0.45	0.42
Food Pdc	0.37	0.45	0.49	0.50	0.46	0.44	0.41	0.43	0.39	0.36
Tob Man	0.09	0.12	0.14	0.13	0.14	0.17	0.24	0.35	0.38	0.40
Text mill	0.09	0.10	0.12	0.12	0.13	0.15	0.15	0.16	0.16	0.17
Apparel	0.13	0.12	0.14	0.13	0.14	0.15	0.16	0.18	0.18	0.19
Lumber	0.08	0.11	0.12	0.13	0.14	0.16	0.19	0.20	0.20	0.21
Furn+Fixt	0.15	0.19	0.20	0.19	0.20	0.21	0.23	0.24	0.26	0.24
Paper	0.25	0.22	0.25	0.26	0.27	0.29	0.30	0.31	0.30	0.30
PntngPub	0.62	0.62	0.62	0.64	0.65	0.70	0.76	0.83	0.88	0.90
Chemicals	0.40	0.47	0.54	0.56	0.58	0.63	0.66	0.73	0.76	0.73
PetrolClPd	0.27	0.35	0.38	0.41	0.45	0.44	0.49	0.53	0.53	0.54
Rubber	0.22	0.25	0.27	0.26	0.27	0.28	0.29	0.29	0.30	0.27
Leather	0.11	0.11	0.13	0.12	0.13	0.15	0.16	0.18	0.19	0.19
StoneClGl	0.16	0.19	0.23	0.26	0.26	0.26	0.27	0.29	0.30	0.29
PmryMet	0.16	0.19	0.22	0.22	0.24	0.26	0.27	0.30	0.30	0.27
FabMetPd	0.22	0.24	0.30	0.28	0.29	0.31	0.32	0.34	0.36	0.33
Machnry	0.28	0.31	0.40	0.38	0.44	0.45	0.50	0.61	0.59	0.54
ElectMach	0.28	0.32	0.41	0.41	0.47	0.46	0.50	0.63	0.58	0.55
TransEq	0.22	0.29	0.39	0.36	0.38	0.39	0.44	0.49	0.54	0.44
Instrmnts	0.33	0.40	0.52	0.46	0.54	0.59	0.65	0.73	0.98	0.93
MiscMan	0.20	0.26	0.42	0.23	0.44	0.30	0.33	0.38	0.39	0.41

We assume that output in each industry *i* may be represented by the production function:

$$Y_i = \left[a_i H_i^{\delta} + b_i L_i^{\delta}\right]^{\frac{1}{\delta}} f_i(K_i) \tag{1}$$

Non-production workers, H, are combined in CES manner with production workers, L, which are separable from other inputs *K*. This assumption is commonly made, and although restrictive, is parsimonious in parameters and permits calculation of explicit measures of technological bias. Each sector *i* has its own set of parameters which can vary over time, allowing full heterogeneity of production relations, although all are constrained to be CES.

Assuming cost minimisation in competitive conditions:

$$\frac{H_i}{L_i} = \left[\frac{w_{Hi}}{w_{Li}}\right]^{1/(\delta-1)} \left[\frac{a_i}{b_i}\right]^{-1/(\delta-1)} \tag{2}$$

Changes in relative factor intensities depend on changes in relative pay and changes in technology. Changes in factor ratios only indicate changes in technological bias if relative pay stays constant. Relative pay has changed considerably over the long period considered here, however, both within and between industries. These changes interact with changes in technological bias to affect employment ratios. An increase in relative employment understates the magnitude of a shift in technological bias if it takes place against an increase in relative pay and overstates it if it is supported by changes in relative pay. Technological shifts may be isolated by inverting equation (2) to give:

$$\frac{a_i}{b_i} = \left[\frac{w_{Hi}}{w_{Li}}\right]\left[\frac{H_i}{L_i}\right]^{(1-\delta)} \tag{3}$$

The ratio a_i / b_i is an explicit measure of the technological bias in industry *i*, varying across industries and over time within each industry. For any value of the elasticity of substitution it may be calculated from relative pay and relative factor employments. These ratios have been calculated for each of the 20 industries in Table 1 for each year, but effects are given for changes over five year intervals. There is however an identification issue. The calculations require a value for the elasticity of substitution and the calculated values of the bias parameters are not independent of this. There appears to be no commonly agreed value for the elasticity of substitution but most authors assume values between 1.2 and 1.6. Accordingly, effects have been calculated for both of these values and although details vary, the general pattern of results is robust across these values. It is possible that the elasticity of substitution varies over time within industries, but the results from different combinations should be bracketed by the values used here.

3. Increasing Skill Bias.

The general pattern of change in the bias parameters is not affected by the assumed value of the elasticity of substitution. Table 2 gives values of a/b at regular intervals for each industry for a substitution elasticity of 1.2. The calculated values for the bias parameters show considerable variation across industries as well as over time. Some industries are consistently more biased than others and there is clearly heterogeneity of industry production relationships even when they are all constrained to belong to the class of CES functions. The ratio (a/b) has risen over time in all industries except for the production of paper, showing there has been steady skill-biased technological change against production workers. In some industries such as ‘Chemicals’ and the ‘Machinery and Equipment’ industries the bias increased in the 1950’s as rapidly as at any time since, but there is also a noticeable acceleration in the bias in these industries in the early 1980’s. The biased technological change in the printing industry began to accelerate in the 1970’s and continued at a higher rate than in many other industries until

1990. In other industries such as ‘Machinery’, ‘Electrical Machinery’ and ‘Instruments’, where there has been a marked increase in bias, much of this occurred before 1980. Although rates of change within and between industries vary, the increasing bias against production workers has been generally continuous and pervasive over this forty-five year period.

Although the increasing bias is pronounced, the overall quantitative impact of the bias needs to be separated from changes in relative wages and weighted by the relative importance of the industries in which it occurs. At the economy level, a large change in bias in an industry employing few people may have little impact on overall employment and relative pay. In the next two sections we address these questions. The next section assesses the impact of the increasing bias on relative employment and section 5 considers movements in relative pay.

Table 2. **Bias Ratios a_i/b_i 3 year centred averages. Elas sub = 1.2**

	1950	*1955*	*1960*	*1965*	*1970*	*1975*	*1980*	*1985*	*1990*	*1995*
Food Pdc	0.64	0.75	0.78	0.77	0.73	0.69	0.66	0.70	0.69	0.67
Tob Man	0.29	0.36	0.33	0.32	0.34	0.37	0.46	0.56	0.60	0.60
Text mill	0.27	0.29	0.32	0.33	0.36	0.40	0.38	0.41	0.42	0.46
Apparel	0.40	0.39	0.40	0.40	0.42	0.45	0.46	0.52	0.54	0.56
Lumber	0.25	0.30	0.31	0.29	0.34	0.38	0.42	0.43	0.44	0.47
Furn+Fixt	0.43	0.45	0.47	0.46	0.50	0.52	0.54	0.57	0.62	0.61
Paper	0.54	0.44	0.47	0.47	0.49	0.51	0.52	0.51	0.54	0.55
PntngPub	0.78	0.78	0.79	0.81	0.84	0.91	1.00	1.11	1.25	1.31
Chemicals	0.69	0.79	0.87	0.88	0.92	0.96	0.97	1.20	1.15	1.15
PetrolClPd	0.44	0.54	0.57	0.60	0.67	0.64	0.70	0.71	0.74	0.73
Rubber	0.41	0.44	0.53	0.52	0.54	0.58	0.61	0.62	0.65	0.63
Leather	0.33	0.33	0.37	0.37	0.40	0.43	0.47	0.52	0.60	0.59
StoneClGl	0.35	0.38	0.45	0.46	0.46	0.47	0.48	0.49	0.52	0.54
PmryMet	0.31	0.35	0.42	0.38	0.42	0.42	0.43	0.48	0.51	0.49
FabMetPd	0.46	0.49	0.56	0.53	0.53	0.56	0.58	0.61	0.65	0.66
Machnry	0.50	0.54	0.67	0.62	0.72	0.74	0.81	0.99	0.99	0.96
ElectMach	0.53	0.60	0.76	0.78	0.87	0.87	0.92	1.14	1.16	1.22
TransEq	0.38	0.49	0.64	0.60	0.63	0.65	0.67	0.74	0.81	0.69
Instrmnts	0.62	0.70	0.92	0.86	1.00	1.12	1.17	1.26	1.65	1.72
MiscMan	0.50	0.58	0.88	0.59	0.61	0.71	0.74	0.79	0.86	0.91

4. The Quantitative Significance of the Bias.

The overall employment of production and non-production workers is determined by the technological bias in each industry, relative pay in each industry and the size of each industry. Over the long period considered here all of these factors have changed. This section assesses the contributions of each. Ideally the analysis would be economy wide and allow for the changing balance between manufacturing and the service sector. The service sector is generally more intensive in the employment of non-production workers and the overall balance of employment will shift towards them as the service sector expands with consequent effects on relative pay. Similar considerations apply to the different industries in manufacturing. Table 1 shows that some are relatively more intensive in the employment of production workers than others and the changing relative balance between industries within manufacturing will alter the overall balance between them. We have data only for manufacturing and can consider only the changing balance between industries within manufacturing.

We decompose the change in employment of manual and non-manual workers in the manufacturing sector into 3 factors:

- the effect of biased technological changes
- the effect of relative wage changes
- the effect of industry composition changes

For a standard size of manufacturing sector of 1000 we calculate the size of each of the separate effects. This is done for each of the nine sub periods shown in Tables 3 to 9.

The individual effects are isolated by answering the hypothetical questions:

- What would employment of a skill group have been at the end of a decade, compared to the actual employment, if the biased technical change had occurred but there had been no changes in relative pay or the relative importance of each industry?
- What would employment in different groups have been at the end of a decade compared to the actual employment, if relative wages changed as they did but there had been no biased technical change and there had been no changes in the relative importance of each industry?
- What would employment in different groups have been at the end of a decade compared to the actual employment, if the sectoral composition had changed as it did but there had been no biased technical change and no changes in relative wages?

The decomposition may be expressed as:

$$
\begin{aligned}
\left[(e_L, e_H)_t - (e_L, e_H)_0\right] = \; & e_0\left[(p_L, p_H)_{W_0,(a/b)_t} - (p_L, p_H)_{W_0,(a/b)_0}\right] \\
+ \; & e_0\left[(p_L, p_H)_{W_t,(a/b)_t} - (p_L, p_H)_{W_0,(a/b)_t}\right] \\
+ \; & \left[e_t - e_0\right](p_L, p_H)_{W_t,(a/b)_t}
\end{aligned}
\tag{4}
$$

Here:

t denotes the end of a five year period

0 denotes the beginning of a five year period

e_L denotes employment of production workers

e_H denotes employment of non-production workers

$(p_L, p_H)_{W_0,(a/b)_t}$ is an industry matrix giving employment proportions of production and non-production workers, evaluated at base year relative wages and terminal year technology.

e_0 is an industry employment vector, total =1000,of base year total employment weights for evaluating the relative wage and technological change effects.

The first term on the right is the changed technological bias effect.

The second term is the changed relative wage effect.

The last term is the effect of changed industry composition.

Tables 3,4 and 5 give the contributions of each of these effects for each five-year period. The tables are constructed for a standard economy of one thousand workers and give the effects for each industry and for the whole economy. The effects for the whole economy are the sum of the individual industry effects. The tables give changes as proportions relative to the number of production or non-production workers in the standard economy at the beginning of the period. Hence, an apparently large effect in terms of numbers may convert to a small proportionate effect. Over time the number of production workers has declined so that identical changes in numbers over two periods may convert into different proportionate effects. Similarly, any increase in one group of workers in a period is matched by an equal but opposite change in the numbers in the other group, but these will generally convert to different proportionate effects as numbers employed in the groups are different.

These tables show that almost all industries in all periods have become increasingly biased against production workers. Despite this prevalence it is also noticeable that the degree of bias and its rate of increase varies across industries.

All periods show significant effects from biased technological change, and that of the three effects, biased technological change is by far the most important. The magnitude of the effect has however, varied. The largest proportionate effect on the increase in non-production workers occurred between 1955 and 1960 but it is also clear that the effects of biased change accelerated in the period between 1980 and 1985 compared to the earlier period.

The greater effect of the bias after 1980 is clear once the effects of relative wage change are removed. In this period the relative pay of non-production workers rose and masks the full magnitude of the underlying bias in their favour. This clear acceleration however, is concentrated in ‘Primary Metals’, ‘Non Electrical’ and ‘Electrical Machinery’, ‘Transport Equipment’ and ‘Instruments’, with the largest effect in ‘Electrical Machinery’, where the bias increased employment of non-production workers by 17.5%. Many other industries experienced more change in bias in the previous period, and even those industries where the bias was most pronounced after 1980 had experienced a greater increase between 1955 and 1960.

Table 3 **Proportionate effects of technical change Elas sub = 1.2**

		1950-1955	*1955-1960*	*1960-1965*	*1965-1970*	*1970-1975*	*1975-1980*	*1980-1985*	*1985-1990*	*1990-1995*
All Ind	Nonpdn	0.08	0.14	-0.03	0.05	0.02	0.03	0.10	0.04	0.00
	Pdn	-0.02	-0.04	0.01	-0.02	-0.01	-0.01	-0.04	-0.02	0.00
Food Pdc	Nonpdn	0.14	0.03	-0.01	-0.04	-0.04	-0.04	0.05	-0.01	-0.03
	Pdn	-0.05	-0.01	0.01	0.02	0.02	0.02	-0.02	0.01	0.01
Tob Man	Nonpdn	0.24	-0.29	-0.05	0.09	0.10	0.23	0.20	0.06	0.00
	Pdn	-0.02	0.04	0.01	-0.01	-0.01	-0.04	-0.05	-0.02	0.00
Text mill	Nonpdn	0.11	0.10	0.02	0.11	0.11	-0.04	0.08	0.02	0.09
	Pdn	-0.01	-0.01	0.00	-0.01	-0.01	0.01	-0.01	0.00	-0.01
Apparel	Nonpdn	-0.05	0.02	0.01	0.06	0.08	0.03	0.12	0.04	0.03
	Pdn	0.01	0.00	0.00	-0.01	-0.01	0.00	-0.02	-0.01	-0.01
Lumber	Nonpdn	0.21	0.04	-0.06	0.17	0.13	0.09	0.02	0.03	0.05
	Pdn	-0.02	0.00	0.01	-0.02	-0.02	-0.02	0.00	-0.01	-0.01
Furn+Fixt	Nonpdn	0.04	0.05	-0.03	0.08	0.04	0.04	0.05	0.09	-0.01
	Pdn	-0.01	-0.01	0.01	-0.02	-0.01	-0.01	-0.01	-0.02	0.00
Paper	Nonpdn	-0.37	0.06	0.01	0.03	0.04	0.01	-0.01	0.06	0.01
	Pdn	0.09	-0.01	0.00	-0.01	-0.01	0.00	0.00	-0.02	0.00
PntngPub	Nonpdn	0.00	0.01	0.02	0.02	0.06	0.07	0.07	0.08	0.03
	Pdn	0.00	0.00	-0.01	-0.01	-0.04	-0.05	-0.05	-0.07	-0.03
Chemicals	Nonpdn	0.12	0.07	0.01	0.03	0.03	0.01	0.16	-0.03	0.00
	Pdn	-0.05	-0.04	-0.01	-0.02	-0.02	0.00	-0.10	0.02	0.00
PetrolClPd	Nonpdn	0.20	0.06	0.04	0.09	-0.03	0.08	0.01	0.04	-0.01
	Pdn	-0.05	-0.02	-0.02	-0.04	0.015	-0.03	-0	-0.02	0.006
Rubber	Nonpdn	0.081	0.186	-0.01	0.034	0.077	0.047	0.013	0.045	-0.03
	Pdn	-0.02	-0.05	0.004	-0.01	-0.02	-0.01	-0	-0.01	0.009
Leather	Nonpdn	-0.01	0.125	0.017	0.074	0.077	0.098	0.103	0.165	-0.03
	Pdn	8E-04	-0.01	-0	-0.01	-0.01	-0.01	-0.02	-0.03	0.005
StoneClGl	Nonpdn	0.094	0.185	0.019	-0	0.019	0.028	0.021	0.056	0.03
	Pdn	-0.02	-0.04	-0	2E-04	-0	-0.01	-0.01	-0.02	-0.01
PmryMet	Nonpdn	0.127	0.199	-0.11	0.126	-0	0.02	0.101	0.05	-0.03
	Pdn	-0.02	-0.04	0.025	-0.03	6E-04	-0.01	-0.03	-0.01	0.01
FabMetPd	Nonpdn	0.062	0.138	-0.05	0.005	0.044	0.036	0.044	0.056	0.011
	Pdn	-0.01	-0.03	0.015	-0	-0.01	-0.01	-0.01	-0.02	-0
Machnry	Nonpdn	0.073	0.213	-0.06	0.124	0.023	0.076	0.173	-0	-0.03
	Pdn	-0.02	-0.07	0.022	-0.05	-0.01	-0.03	-0.09	7E-04	0.016
ElectMach	Nonpdn	0.121	0.228	0.026	0.096	-0	0.045	0.175	0.013	0.043
	Pdn	-0.03	-0.07	-0.01	-0.04	0.002	-0.02	-0.09	-0.01	-0.02
TransEq	Nonpdn	0.286	0.277	-0.06	0.055	0.016	0.035	0.077	0.073	-0.11
	Pdn	-0.06	-0.08	0.025	-0.02	-0.01	-0.01	-0.03	-0.04	0.061
Instrmnts	Nonpdn	0.105	0.256	-0.06	0.132	0.085	0.034	0.057	0.191	0.022
	Pdn	-0.03	-0.1	0.031	-0.06	-0.05	-0.02	-0.04	-0.14	-0.02
MiscMan	Nonpdn	0.157	0.471	-0.3	0.028	-0.08	0.042	0.055	0.081	0.047
	Pdn	-0.03	-0.12	0.127	-0.01	0.034	-0.01	-0.02	-0.03	-0.02

Table 4 gives the effects of relative wage change for an assumed elasticity of substitution of 1.2. The effect is not only much smaller than the effects of technical change but almost uniformly negligible in importance. The changes in relative pay after 1980 have had little effect on relative employment. Although a higher elasticity of substitution leads to a larger effect for relative pay, technological bias remains dominant. The effects of sectoral change in Table 5 show very small effects so that shifts between sectors within manufacturing have had little influence on overall relative employment of these two groups of workers.

Table 4 **Proportionate effects of wage change Elas sub = 1.2**

		1950-1955	*1955-1960*	*1960-1965*	*1965-1970*	*1970-1975*	*1975-1980*	*1980-1985*	*1985-1990*	*1990-1995*
All Ind	Nonpdn	0.022	8E-04	0.01	0.001	-0.01	0.003	-0.02	-0.01	-0.04
	Pdn	-0.02	-0	-0.01	-0	0.007	-0	0.018	0.013	0.038
Food Pdc	Nonpdn	0.02	-0.02	0.024	-0	0.008	-0	-0.02	-0.02	-0.02
	Pdn	-0.02	-0.01	-0.02	0.005	-0.01	0.004	0.017	0.022	0.017
Tob Man	Nonpdn	0.07	-0.07	-0.01	0.002	0.064	0.01	0.166	-0	0.068
	Pdn	-0.07	-0.05	0.01	-0	-0.06	-0.01	-0.17	2E-04	-0.07
Text mill	Nonpdn	-0.06	0.062	0.017	8E-05	-0.02	0.01	-0.03	-0.01	5E-04
	Pdn	0.062	-0.01	-0.02	-0	0.022	-0.01	0.035	0.007	-0
Apparel	Nonpdn	-0.05	0.054	-0.05	0.002	-0.05	0.005	-0.02	-0.01	0.043
	Pdn	0.054	-0.01	0.051	-0	0.051	-0.01	0.02	0.005	-0.04
Lumber	Nonpdn	0.082	-0.08	0.134	-0.02	0.018	0.01	0.013	-0	-0.04
	Pdn	-0.08	-0.01	-0.13	0.016	-0.02	-0.01	-0.01	0.004	0.039
Furn+Fixt	Nonpdn	0.144	-0.14	0.015	-0.01	-0.02	0.003	0.003	-0.01	-0.05
	Pdn	-0.14	0.004	-0.01	0.007	0.016	-0	-0	0.009	0.046
Paper	Nonpdn	0.256	-0.26	0.036	-0	0.008	0.008	0.035	-0.02	-0.04
	Pdn	-0.26	-0.01	-0.04	0.001	-0.01	-0.01	-0.03	0.021	0.039
PntngPub	Nonpdn	-0	0.004	0.002	-0.01	-0.02	-0.02	-0.02	-0.05	-0.03
	Pdn	0.004	0.002	-0	0.009	0.015	0.018	0.021	0.052	0.032
Chemicals	Nonpdn	-0	0.005	0.006	-0	0.018	0.01	-0.1	0.036	-0.03
	Pdn	0.005	-0.01	-0.01	0.002	-0.02	-0.01	0.097	-0.04	0.027
PetrolClPd	Nonpdn	0.018	-0.02	0.003	-0.01	0.016	0.002	0.039	-0.02	0.02
	Pdn	-0.02	-0	-0	0.006	-0.02	-0	-0.04	0.015	-0.02
Rubber	Nonpdn	0.012	-0.01	-0.04	0.003	-0.08	-0	-0.02	-0.01	-0.08
	Pdn	-0.01	0.028	0.04	-0	0.083	0.004	0.016	0.014	0.078
Leather	Nonpdn	4E-05	-0	-0.04	8E-04	0.003	-0	-0	-0.01	0.016
	Pdn	-0	0.002	0.041	-0	-0	0.003	0.002	0.007	-0.02
StoneClGl	Nonpdn	0.04	-0.04	0.114	-0	0.002	-0	0.024	-0.01	-0.04
	Pdn	-0.04	7E-04	-0.11	0.004	-0	0.003	-0.02	0.006	0.038
PmryMet	Nonpdn	0.023	-0.02	0.092	-0	0.062	0.003	-0.03	-0.01	-0.02
	Pdn	-0.02	0.008	-0.09	0.005	-0.06	-0	0.028	0.008	0.023
FabMetPd	Nonpdn	0.023	-0.02	-0	0.009	0.008	-0.01	0.019	-0.01	-0.08
	Pdn	-0.02	-0.01	0.005	-0.01	-0.01	0.011	-0.02	0.008	0.078
Machnry	Nonpdn	0.015	-0.02	0.023	-0.01	-0.01	-0	-0.06	-0.01	-0.04
	Pdn	-0.02	0.004	-0.02	0.005	0.009	0.002	0.063	0.011	0.039
ElectMach	Nonpdn	0.007	-0.01	-0.04	0.007	-0.02	0.005	-0.02	-0.04	-0.07
	Pdn	-0.01	0.016	0.041	-0.01	0.016	-0.01	0.022	0.042	0.073
TransEq	Nonpdn	-0.01	0.012	0.005	-0	0.009	0.018	-0	-0.01	-0.02
	Pdn	0.012	0.013	-0	0.004	-0.01	-0.02	0.002	0.007	0.017
Instrmnts	Nonpdn	0.046	-0.05	-0.02	-0.01	-0.03	0.018	0.033	-0.02	-0.15
	Pdn	-0.05	0.025	0.022	0.008	0.031	-0.02	-0.03	0.022	0.153
MiscMan	Nonpdn	0.07	-0.07	-0.08	0.081	-0.12	0.009	0.061	-0.02	-0.01
	Pdn	-0.07	0.005	0.079	-0.08	0.124	-0.01	-0.06	0.016	0.007

Table 5 **Proportionate effects of sectoral change**

		1950-1955	*1955-1960*	*1960-1965*	*1965-1970*	*1970-1975*	*1975-1980*	*1980-1985*	*1985-1990*	*1990-1995*
All Ind	Nonpdn	0.026	0.003	0.008	0.003	0.004	0.006	0.02	0.005	-0.01
	Pdn	-0.08	-0.04	0.041	-0.02	-0.03	-0.01	-0.12	-0.02	-0.01
Food Pdc	Nonpdn	0.024	0.017	-0.11	-0.03	-0.04	-0.03	0.015	0.014	0.033
	Pdn	-0.13	-0.01	0.02	0.016	0.035	0.014	-0.04	-0	0.016
Tob Man	Nonpdn	0.213	-0.05	-0.1	-0.01	-0.05	-0.03	-0.15	-0.03	-0.29
	Pdn	-0.33	0.054	0.033	-0.01	-0.06	-0.02	-0.18	-0.01	0.023
Text mill	Nonpdn	-0.23	-0.01	-0.07	-0	-0.06	-0.02	-0.1	-0.01	-0.03
	Pdn	-0.13	-0.01	-0.01	-0.01	-0.12	0.008	-0.09	-0.01	-0.07
Apparel	Nonpdn	-0.02	0.002	0.012	-0.01	-0.05	-0.01	-0.09	-0.01	-0.06
	Pdn	0.028	0.002	-0.03	-0.01	-0.1	-0	-0.13	-0.01	-0.02
Lumber	Nonpdn	-0.2	-0.01	-0.1	-0.01	0.168	0.004	-0.02	0.015	0.194
	Pdn	-0.18	-0	0.095	-0.02	-0.12	-0.01	-0.03	-0.01	-0.11
Furn+Fixt	Nonpdn	-0.02	0.003	0.06	0.006	-0.03	0.006	0.119	0.014	0.056
	Pdn	0.004	-0.01	0.033	-0.02	-0.05	-0.01	-0.05	-0.03	0.002
Paper	Nonpdn	-0.2	0.013	-0	0.003	-0.06	-0.01	0.034	0.011	0.01
	Pdn	0.436	-0.01	-0	-0.01	-0.04	-0	0.026	-0.02	-0.03
PntngPub	Nonpdn	-0.02	0.067	0.015	0.03	0.01	0.059	0.248	0.129	0.018
	Pdn	-0	-0.01	-0.02	-0.02	-0.07	-0.06	-0.09	-0.1	-0.06
Chemicals	Nonpdn	0.034	-0.01	0.023	0.029	-0.02	-0.01	0.008	0.027	-0.02
	Pdn	-0.12	-0.03	-0.01	-0.02	-0.03	-0	-0.21	0.032	-0.01
PetrolClPd	Nonpdn	-0.27	-0.02	-0.2	-0.02	0.008	-0	-0.08	-0.06	-0.02
	Pdn	-0.19	-0.01	-0.04	-0.03	0.033	-0.02	0.006	-0.02	0.016
Rubber	Nonpdn	-0.02	0.141	0.359	0.062	0.208	-0.04	0.387	0.05	0.233
	Pdn	-0.08	-0.05	0.009	-0.02	-0.13	-0.02	-0.02	-0.02	0.023
Leather	Nonpdn	-0.12	-0	-0.13	-0.02	-0.14	-0.01	-0.25	-0.02	-0.13
	Pdn	0.007	-0.01	-0.03	-0.01	-0.06	-0.01	-0.08	-0.01	0.021
StoneClGl	Nonpdn	-0.06	0.031	-0.06	-0.02	0.028	-0.01	-0.07	-0.01	0.009
	Pdn	-0.08	-0.03	0.011	-0	-0.02	-0.01	-0.01	-0.02	-0.04
PmryMet	Nonpdn	-0.01	-0.01	0.016	-0.01	-0.08	-0.02	-0.27	-0.01	-0.02
	Pdn	-0.12	-0.04	0.148	-0.03	0.023	-0	-0.11	-0.01	0.014
FabMetPd	Nonpdn	-0	0.006	0.03	0.022	0.134	0.004	-0.01	-0.01	0.034
	Pdn	-0.05	-0.03	0.058	0.001	-0.04	-0.02	-0.05	-0.02	-0.04
Machnry	Nonpdn	0.025	-0.04	0.11	0.024	0.118	0.062	-0.17	-0.03	0.041
	Pdn	-0.07	-0.07	0.067	-0.05	-0.03	-0.04	-0.29	-0	0.02
ElectMach	Nonpdn	0.209	0.141	0.248	0.032	-0.13	0.062	0.168	-0.15	0.028
	Pdn	-0.12	-0.09	-0.06	-0.05	5E-04	-0.02	-0.22	-0.02	-0.07
TransEq	Nonpdn	0.311	-0.04	0.047	-0.02	-0.04	0.004	0.065	0.002	-0.14
	Pdn	-0.29	-0.1	0.074	-0.02	-0.01	-0.01	-0.08	-0.03	0.142
Instrmnts	Nonpdn	0.126	0.1	-0.09	0.077	0.339	0.083	0.18	0.731	-0.4
	Pdn	-0.09	-0.12	0.078	-0.07	-0.1	-0.02	-0.1	-0.21	-0.13
MiscMan	Nonpdn	0.337	-0.06	-0.28	-0	-0.02	-0.01	-0.18	0.037	0.037
	Pdn	-0.13	-0.15	0.35	0.01	0.006	-0.01	-0.05	-0.03	-0.04

5. Movements in Relative Pay.

The previous sections dealt with the effects of technological and other changes on the relative demands for production and non-production workers. In this section we look at the changes in relative pay and consider whether technological bias is sufficient to explain them. The conclusion is that changing bias is insufficient as a general explanation.

Long Run Movements in Relative Pay.

Table 6 gives the pay of non-production relative to production workers in each industry at five-year intervals. There is considerable variation across industries. At the beginning and end of the period the highest relativity is about ninety percent higher than the lowest. Although there is some stability in the industry rankings, there are some marked changes. The Tobacco industry has the highest relativity in 1950 but this declines steadily, while the Printing industry has the lowest and rises. Over the whole period and working to two decimal places, the relativity rose in twelve industries, fell in seven and remained unchanged in Chemicals. From 1955 to 1980 however fifteen industries show a narrowing and four a widening of relativities with 'Machinery' remaining constant. The general narrowing of relativities prior to 1980 and subsequent widening first drew attention to the possible role of biased technological change, which generally accelerated after 1980. The movements in relative pay are consistent with this, but it is notable that prior to 1980 the relativities narrowed despite the prevalence and persistence of biased change over the previous thirty years. This suggests that biased change by itself is not sufficient to account for changes in relativities.

Table 6. Relative Pay: Wage of Nonproduction to Production Workers.

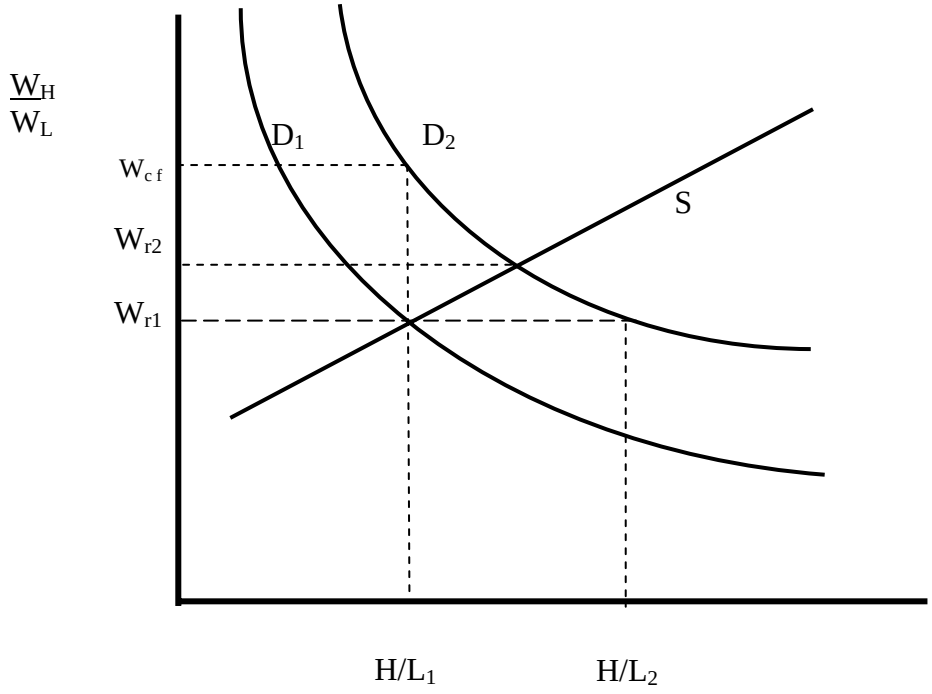
	1950	*1955*	*1960*	*1965*	*1970*	*1975*	*1980*	*1985*	*1990*	*1995*
All Ind	1.654	1.606	1.576	1.558	1.556	1.57	1.544	1.565	1.623	1.686
Food Pdc	1.478	1.447	1.404	1.366	1.385	1.368	1.385	1.423	1.526	1.564
Tob Man	2.184	2.638	1.747	1.771	1.728	1.614	1.514	1.343	1.347	1.273
Text mill	1.952	2.057	1.943	1.914	1.914	1.949	1.81	1.868	1.978	1.977
Apparel	2.183	2.308	2.072	2.16	2.138	2.24	2.164	2.203	2.292	2.194
Lumber	2.029	1.911	1.775	1.57	1.797	1.768	1.671	1.66	1.695	1.731
Furn+Fixt	2.038	1.795	1.835	1.81	1.869	1.895	1.875	1.87	1.933	2.003
Paper	2.169	1.555	1.502	1.456	1.465	1.454	1.408	1.359	1.467	1.526
PntngPub	1.164	1.17	1.174	1.172	1.192	1.215	1.259	1.29	1.394	1.436
Chemicals	1.480	1.488	1.445	1.435	1.442	1.413	1.384	1.55	1.436	1.486
PetrolClPd	1.309	1.287	1.275	1.271	1.299	1.269	1.262	1.207	1.263	1.227
Rubber	1.410	1.394	1.558	1.6	1.589	1.691	1.708	1.73	1.791	1.892
Leather	2.038	2.04	2.084	2.159	2.145	2.138	2.201	2.209	2.416	2.343
StoneClGl	1.572	1.517	1.523	1.402	1.425	1.422	1.443	1.405	1.44	1.502
PmryMet	1.447	1.419	1.478	1.348	1.377	1.295	1.276	1.314	1.384	1.438
FabMetPd	1.630	1.594	1.529	1.537	1.488	1.476	1.525	1.502	1.535	1.647
Machnry	1.431	1.41	1.427	1.391	1.414	1.427	1.434	1.505	1.542	1.609
ElectMach	1.543	1.533	1.6	1.654	1.634	1.659	1.639	1.677	1.831	2.021
TransEq	1.341	1.354	1.401	1.396	1.417	1.403	1.329	1.332	1.356	1.382
Instrmnts	1.577	1.505	1.602	1.635	1.666	1.727	1.676	1.64	1.687	1.816
MiscMan	1.897	1.784	1.806	1.994	1.528	1.958	1.875	1.781	1.902	1.92

Note: 'All Ind' relative pay is a weighted sum of relative pay in each industry with weights being industry shares in total employment.

Can the Bias Explain Movements in Relative Pay?

To throw further light on the role of based change in movements in relativities, changes in relative pay are regressed on a measure of the excess demand resulting from biased change. The procedure is illustrated in Diagram 1. At the existing relative wage $W_{r1,}$ biased change raises the relative demand for non-production workers from H/L_1 to $H/L_{2.}$ With inelastic short run supply and instantaneous pay adjustment, relative pay would rise to W_{cf} . We do not know what the supply elasticity is however, and to avoid specifying a full structural model of supply and demand we estimate a wage change equation relating relative pay change to two lags in the excess relative demand.

Diagram 1. Demand Shifts and Relative Pay.



The values of $(H/L_2 - H/L_1)$ indicated in Diagram 1 are calculated for each year in each industry and two lagged values are used as explanations of relative pay change as indicated in equation (4).

$$(5) \qquad \left(\frac{W_H}{W_L}\right)_{t+1} - \left(\frac{W_H}{W_L}\right)_t = \beta_1 \, Exdem_{t-1} + \beta_2 \, Exdem_{t-2}$$

The equation is estimated without a constant term. The results of this simple regression, estimated on forty-five annual observations in each industry and for all industries pooled, are given in table 7. Estimates are given for the whole period 1952 to 1996 and for the two sub periods from 1952 to 1979 and 1980 to 1996. This permits a comparison of the periods before and after the widening of pay relativities.

In the pooled regressions both lags in excess demand are highly significant with the coefficient on the second lag being smaller than that on the first, as expected. The overall regressions are highly significant but the explanatory power is not particularly high. It is noticeable that the explanatory power and coefficients are generally lower in the second period, when union power and regulation was less, than in the earlier period, and are sometimes of the wrong sign. For the overall period, in fourteen industries the coefficient on the first lagged excess demand variable is significant at the five percent level and in only 'Printing and Publishing' and 'Petroleum and Coal Products' is it not significant at the ten percent level. In nine industries the second lag is also significant. Generally the coefficient on the second lag is smaller than that on the first, conforming to expectations. The explanatory power of fourteen of the overall equations is significant but their explanatory power is very poor. Comparing results for the two periods, the equation is generally more successful for the earlier period. Coefficients are more significant and although general explanatory power is poor, twelve of the individual industry regressions are significant for the earlier period whereas only six are in the later. The only general conclusion which it seems safe to draw is that although excess demand resulting from biased change has played a role in movements in relative pay this does not by itself account for the movements and that it seems to be less important for the period after 1980 than before.

Table 7		Wage Adjustment Equation 5.		
		Exdem $_{t-1}$	Exdem $_{t-2}$	Equation Fit
		Coeff Sig Prob	Coeff Sig Prob	$\bar{R}^2$ Sig Prob *F*
All Ind	1952-'96	0.601 (0.000)	0.345 (0.000)	0.108 (0.000)
	1952-'79	0.766 (0.000)	0.438 (0.000)	0.136 (0.000)
	1980-'95	0.441 (0.000)	0.253 (0.003)	0.075 (0.000)
Food Pdc	1952-'96	1.133 (0.001)	0.728 (0.020)	0.189 (0.004)
	1952-'79	1.435 (0.006)	1.015 (0.029)	0.202 (0.020)
	1980-'95	0.724 (0.101)	0.349 (0.379)	0.066 (0.244)
Tob Man	1952-'96	1.061 (0.000)	-0.092 (0.667)	0.383 (0.000)
	1952-'79	0.812 (0.013)	-0.182 (0.464)	0.281 (0.005)
	1980-'95	1.198 (0.006)	-0.080 (0.855)	0.399 (0.399)
Text mill	1952-'96	0.618 (0.036)	0.380 (0.188)	0.069 (0.081)
	1952-'79	0.775 (0.192)	-0.242 (0.607)	0.047 (0.204)
	1980-'95	0.437 (0.039)	1.109 (0.000)	0.617 (0.001)
Apparel	1952-'96	0.059 (0.893)	-0.002 (0.997)	-0.046 (0.987)
	1952-'79	0.276 (0.460)	0.154 (0.825)	0.009 (0.895)
	1980-'95	-0.246 (0.719)	-0.253 (0.727)	-0.130 (0.912
Lumber	1952-'96	0.802 (0.000)	0.450 (0.025)	0.259 (0.001)
	1952-'79	1.129 (0.000)	0.515 (0.045)	0.364 (0.001)
	1980-'95	0.468 (0.124)	0.538 (0.115)	0.135 (0.142)
Furn+Fixt	1952-'96	0.679 (0.016)	0.245 (0.229)	0.088 (0.052)
	1952-'79	1.064 (0.011)	1.001 (0.021)	0.088 (0.018)
	1980-'95	0.411 (0.261)	-0.014 (0.948)	-0.008 (0.416)
Paper	1952-'96	0.343 (0.029)	0.184 (0.306)	0.065 (0.089)
	1952-'79	0.948 (0.000)	0.798 (0.004)	0.355 (0.001)
	1980-'95	0.089 (0.666)	-0.079 (0.750)	-0.101 (0.768)
PntngPub	1952-'96	0.324 (0.192)	-0.149 (0.556)	0.028 (0.206)
	1952-'79	-0.045 (0.927)	0.141 (0.744)	-0.070 (0.923)
	1980-'95	0.399 (0.138)	-0.279 (0.202)	0.253 (0.051)
Chemicals	1952-'96	0.403 (0.069)	0.188 (0.464)	0.033 (0.182)
	1952-'79	0.421 (0.149)	0.180 (0.497)	0.009 (0.341)
	1980-'95	0.386 (0.304)	0.231 (0.672)	-0.056 (0.573)
PetrolClPd	1952-'96	0.503 (0.147)	0.262 (0.471)	0.004 (0.345)
	1952-'79	0.429 (0.371)	-0.023 (0.964)	-0.030 (0.559)
	1980-'95	0.585 (0.282)	0.919 (0.281)	-0.021 (0.455)
Rubber	1952-'96	0.329 (0.068)	0.123 (0.518)	0.040 (0.156)
	1952-'79	0.472 (0.024)	0.232 (0.361)	0.127 (0.065)
	1980-'95	0.097 (0.797)	-0.024 (0.942)	-0.128 (0.911)
Leather	1952-'96	1.009 (0.020)	1.207 (0.011)	0.138 (0.016)
	1952-'79	1.323 (0.050)	0.848 (0.168)	0.088 (0.115)
	1980-'95	0.645 (0.358)	1.532 (0.060)	0.121 (0.160)
StoneClGl	1952-'96	0.531 (0.012)	0.394 (0.032)	0.108 (0.032)
	1952-'79	0.656 (0.013)	0.454 (0.093)	0.154 (0.043)
	1980-'95	0.266 (0.489)	0.189 (0.537)	-0.099 (0.761)
PmryMet	1952-'96	0.676 (0.031)	0.523 (0.145)	0.064 (0.061)
	1952-'79	1.189 (0.012)	0.862 (0.056)	0.177 (0.030)
	1980-'95	0.067 (0.884)	-0.244 (0.692)	-0.105 (0.792)

Table 7 contd.

FabMetPd 1952-‘96	0.490 (0.000)	0.307 (0.054)	0.286 (0.000)
1952-‘79	0.637 (0.000)	0.469 (0.022)	0.420 (0.000)
1980-‘95	0.378 (0.065)	0.217 (0.418)	0.113 (0.170)
Machnry 1952-‘96	0.652 (0.000)	0.294 (0.053)	0.256 (0.001)
1952-‘79	1.082 (0.000)	0.391 (0.054)	0.481 (0.000)
1980-‘95	0.253 (0.243)	0.399 (0.074)	0.121 (0.159)
ElectMach 1952-‘96	0.827 (0.000)	0.644 (0.004)	0.237 (0.001)
1952-‘79	1.293 (0.000)	1.236 (0.000)	0.545 (0.000)
1980-‘95	0.427 (0.196)	0.031 (0.928)	0.082 (0.215)
TransEq 1952-‘96	0.989 (0.003)	0.870 (0.004)	0.186 (0.005)
1952-‘79	0.597 (0.107)	0.286 (0.372)	0.027 (0.265)
1980-‘95	1.787 (0.005)	1.892 (0.002)	0.473 (0.004)
Instrmnts 1952-‘96	0.728 (0.000)	0.545 (0.014)	0.241 (0.001)
1952-‘79	0.631 (0.009)	0.492 (0.148)	0.177 (0.030)
1980-‘95	0.852 (0.022)	0.619 (0.081)	0.224 (0.066)
MiscMan 1952-‘96	0.477 (0.071)	0.168 (0.426)	0.032 (0.189)
1952-‘79	0.787 (0.048)	0.409 (0.256)	0.086 (0.119)
1980-‘95	0.031 (0.934)	-0.062 (0.819)	-0.133 (0.060)

6. Conclusion.

There has clearly been biased technological change in most industries for most of the forty-five years considered here. Although the relative pay of non-production workers rose in many of these industries there are several where relative pay at the end of the period is much the same as the beginning. Although there is no simple relation between biased change and changes in relative pay, the regression results from equation 5 suggest that the upward pressure caused by biased change has some role to play. Changes in relative supply should clearly be part of the story. In the long run the general adaptability of workers and changes in training and educational systems alter these relative supplies. A possible explanation for the fall in relative pay of non-production workers in many industries in the period before 1980 is an improvement in the level of general education. The increasing participation rates of women over this period also increased the supply of non-production workers. It is possible that the relative supply of non-production workers expanded more rapidly than relative demand in the earlier period and the reversal of the trend may be due to the acceleration in biased change from the late 1970's, leading to relative demand outstripping relative supply. It is also possible that the structure of demands for skills within the non-production and production groups changed. Within production work, the spread of pre-assembled parts and more automated production may have reduced the demand for skill, while among non-production workers there may well have been a marked shift towards higher skills in the 1980's. Whereas the shift towards non-production work in the earlier period was towards skills which could easily be provided by the existing educational system, the later shift required more fundamental changes. The disaggregation of production and non- production workers into further skill groups, as emphasised by Coleccia and Papaconstantinou [1996] would be desirable but data limitations prevent this.

It is often suggested that the bias against production workers is associated with the adoption of computers and associated equipment. This may well be the case, but this paper shows that the bias was prevalent long before computers could have had any impact. It has also been suggested by Bresnahan [1999] that computers have weakened the demand for low-level non-production skills, reducing demand and pay for these skills, while other changes have raised demand and pay for higher level cognitive non-production skills, where supply lags behind demand. Such counteracting forces may be responsible for the apparent weakening of the force exerted by excess demand on relative pay in the period after 1980. Technological change in this period may have increased demand and relative pay for higher skilled and lowered them for less skilled non-production workers. These would be masked at the level of aggregation used here. More complex interactions between skill supply, biased change and relative pay have been discussed in Acemoglu [2002]. Although biased technological change does not explain movements in relative pay in any simple way at the level of skill disaggregation permitted by data used here, it has been a pervasive and powerful force, stronger in some industries than others and which did generally accelerate in the early 1980's.

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