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Enabling the Visible Hand

Ian Keay   Marina Adshade
Queen's University   Dalhousie University

Department of Economics
Queen's University
94 University Avenue
Kingston, Ontario, Canada
K7L 3N6

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Marina Adshade[1]
Department of Economics
Dalhousie University
Halifax, NS
marina.adshade@dal.ca

AND

Ian Keay
Department of Economics
Queen's University
Kingston, ON
ikeay@econ.queensu.ca

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Abstract

In this paper we use data from more than 2,500 industry-years, reported by the Ohio Division of Labor Statistics, to track changes in employment and weekly wages among male and female production workers and clerical workers between 1914-1937. We find that among Ohio's manufacturing establishments female employment and real wages were rising throughout this period, particularly within clerical occupations. Increases in women's share of the total manufacturing workforce were nearly monotonic between 1914-1937, while after having been, at best, stagnant until the mid-1920s, women's relative wages increased through the last half of the 1920s and into the 1930s. After matching our employment and wage data with information from the Census of Manufactures for the state of Ohio, we estimate translog production functions which indicate that Ohio manufacturers were adopting new organizational structures and technologies that were biased in favor of female clerical labor. This non-neutrality in technological and organizational change (like the employment and wage patterns) was driven primarily by larger firms that had relatively complex production processes. A simple counterfactual exercise indicates that the adoption of non-neutral technological and organizational change over this period can explain much of the observed increase in demand and remuneration for educated female manufacturing workers. This conclusion emphasizes the role women played channeling early twentieth century organizational and technological change, in effect enabling Chandler's "visible hand".

1 Introduction

> "The ninth and last division groups all the clerical occupations, the writing of letters, the keeping of books and records. When there were not so many large scale establishments, and the carpenter kept his own books, and the shoemaker both made shoes and kept the record of it, this was an unimportant division, because it was merely part of many occupations; but as business has become more concentrated, this record keeping and letter writing end of the work has become more and more an occupation in itself, and I find clerical occupations increasing by leaps and bounds."
> (Ohio Council on Women in Industry, *Ohio's Women Workers*, 1921.)

In 1914 the rubber tire industry in Ohio consisted of 46 establishments, each hiring an average of 622 workers, with just 11% of those employees categorized as clerical workers. By 1937 the number of establishments manufacturing tires in Ohio had fallen to 22, the average number of workers per firm had grown to 2,380, and the proportion of those employees in clerical jobs had risen to more than 15%. In just over two decades the number of establishments had been reduced by more than half, the average number of workers per establishment had increased nearly four-fold, while the number of clerical workers had increased six-fold.[1] This movement toward a more concentrated rubber tire industry in Ohio is representative of the changes that were occurring in a growing proportion of U.S. manufacturing industries during the first 40 years of the twentieth century. These changes were made possible by the adoption of new technologies and new organizational structures that were characterized by increasingly complex production and administrative processes. Firms began to adopt a greater division of labor in administration, and legions of clerical workers, particularly literate and numerate female clerical workers, were employed to undertake the tasks of record keeping and communication which accompanied these increases in the scale and complexity of production.

Recently there has been a revival in the debate surrounding the exact nature of the relationship between rising education levels, increasing female labor force participation, and technological and organizational change during the late nineteenth and early twentieth centuries. Some authors have suggested that the adoption of new technologies in the form of durable goods used by women in home production reduced women's reservation wages, in effect "pushing" them from the home into waged employment in the face of low and falling wage rates. This view implies the presence of an increasing supply of female workers on the labor market, with no labor demand response. In contrast, others have emphasized demand forces that "pulled" women into waged employment. Two variants of this view of women's role in the industrialization process have developed. The first proposes an exogenous discontinuity in the adoption of "information technologies" that increased the demand for female labor - driving up relative wages, encouraging school attendance, and eventually inducing

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[1]These figures can be calculated from Ohio Division of Labor Statistics (1914 and 1937).

an increase in the supply of literate and numerate females in the waged workforce. The second variant of the pull hypothesis characterizes the adoption of new technologies and organizational structures that increased the demand for female clerical labor as endogenous, or induced, rather than exogenous. The inducement, according to this view, was an initial, exogenous increase in the supply of literate and numerate female workers. Therefore, while both versions of the pull hypothesis are founded on the presence of technological changes that increased the demand for educated female workers, they differ in their proposed chronology: Did an increase in the supply of literate and numerate women seeking waged employment precede or follow these technological changes? Both pull hypotheses portray women as "agents of change" who were responsible for enabling the technological and organizational transformation that Chandler (1977) has famously described as the operation of a "visible hand" guiding early twentieth century U.S. manufacturers.

In this paper we consider a very detailed set of wage and employment distributions published by the Ohio Division of Labor Statistics, which allow us to compile employment figures and weekly wages by gender and occupation type (production and clerical) for approximately 2,500 manufacturing industries between 1914-1937. For the years 1914, 1923, 1929, 1931, 1933, 1935, and 1937 we have matched a total of 801 industries included in both the Ohio Division of Labor Statistics and the Census of Manufactures for the state of Ohio. With the resultant combined data set we have estimated translog production functions. The parameters from these functions allow us to identify the extent to which Ohio manufacturers were adopting non-neutral technologies and organizational structures that increased the demand for female clerical labor. In the compilation of all of our empirical evidence we have divided industries into two groups - large scale, complex, integrated producers (Group L), and smaller scale, less complex, unintegrated producers (Group S) - based on their degree of industrial concentration in 1947.

Our main findings include: (i) female employment among Ohio's manufacturing establishments, particularly female clerical employment, increased substantially through the 1914-1937 period; (ii) women's real wages also rose rapidly over this period, although the gender gap in relative wages was (at best) stagnant until the mid-1920s, before rising through the remainder of the 1920s and into the 1930s; (iii) technological change (broadly defined) among Ohio's manufacturing industries was biased towards the increasingly intensive use of female clerical labor between 1914-1937; (iv) the larger, more integrated and more complex industries experienced the greatest increases in female employment, the most dramatic "U" shaped pattern in women's relative wages, and the strongest tendency towards technological change that was biased in favor of female clerical labor; and finally; (v) the increase in demand for female clerical labor that was driven by non-neutral technological and organizational change was responsible for much of the observed increase in gender and occupation

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specific real wages. We suggest that these findings are supportive of the view that, during the first 40 years of the twentieth century, induced technological and organizational change among U.S. manufacturers led to increases in the demand for literate and numerate female workers. These demand increases offset the downward pressure on gender and occupation specific wages that was a result of women's movement from home production into waged employment.

The next section of the paper distinguishes between the alternate views of women's role in late nineteenth and early twentieth century U.S. industrialization, on the basis of their characterization of the relationship between education, organizational change, technological change, and female labor force participation. In Section 3 we briefly review the compilation and construction of our data set, and we present empirical evidence related to female employment and women's weekly wages among Ohio's manufacturing establishments between 1914-1937. In the fourth section we discuss the estimation of group specific translog production functions, we review the econometric results, and we report on the outcome of a simple counterfactual exercise using these results. The final section summarizes and offers our conclusions.

2   Education, Organizational Change, and Technological Change

Since the early years of the nineteenth century the United States has had unusually high elementary and secondary school enrollment, high school graduation, literacy, and numeracy rates relative to its international competitors.[2] By 1900 78.3% of the U.S. population between the ages of 5-17 was enrolled in some educational institution. This national average enrollment rate had risen to 80.6% in 1914, 87.3% in 1924, and 94.2% in 1940. In contrast, high school graduation rates, although still high by international standards, remained quite low until the inter-war period: only 6.3% of 17 year old Americans had graduated from high school in 1900, 12.8% in 1915, and 24.4% in 1925. By 1940 the U.S. high school graduation rate had increased to a historically unprecedented 49.0%.[3] Claudia Goldin's (1988) exhaustive study of U.S. education patterns illustrates that Ohio's experience with high school enrollment and graduation was representative of the U.S. as a whole during the early twentieth century. According to Goldin (1988, Figure 4 and 5), in the northeast census district, which includes Ohio, high school enrollment rates increased from 24.0% in 1910 to 81.0% in 1940, and high school graduation rates rose from 12.5% to 54% over these years, with female graduation rates consistently exceeding male graduation rates in this region by between 4-8%. Clearly, the population of the United States (and Ohio), particularly the female population, was well educated,

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[2]For a detailed comparison of international education inputs and outcomes see Cipolla (1969), Pg. 62-99.

[3]For information on U.S. school enrollment and high school graduation rates see Series H419 and H599 in U.S. Historical Statistics.

and largely literate and numerate throughout the first four decades of the twentieth century.

Coincident with the expansion in the pool of educated workers on the U.S. labor market was a substantive reorganization of the production methods employed by manufacturing firms in an increasing number of industries. The rise of "big business" and the movement to vertically integrated industries was accommodated by the reorganization of production, on both the factory floor and in administrative offices. The principles of "scientific management", heralded by thinkers such as Frederick Taylor early in the twentieth century, promoted the specialization of tasks within manufacturing establishments.[4] Prior to this organizational shift, firms were often administered by one or two managers, usually the owners of the firm, and the coordination of the labor force - including hiring and the distribution of wages - the purchasing of materials, and the supervision of the production process was often left to factory foremen. One of the founding principles of scientific management was the creation of an accounting system that allowed managers to divide the tasks of the foreman into specialized tasks performed by many functional foremen. These foremen could then be closely monitored by the managers themselves. The new accounting procedures produced a large amount of record keeping that was well beyond the scope of the functional foreman's responsibility. As the level of output produced by individual firms grew, more and more of the responsibility for keeping these records had to be passed on to literate and numerate clerical workers.

In addition to their role as book keepers, the growth in the scale and complexity of firm structures led to a greater need for communication between units. This communication was made possible by the employment of still more educated - and overwhelmingly female - typists, stenographers, and switchboard operators. Chandler (1977) describes the integration of these new, relatively educated workers into the reorganized U.S. manufacturing workforce during the early twentieth century. He argues that by internalizing transactions that had previously been guided by the "invisible hand" of the market, the new human capital intensive producers were relying much more heavily on the "visible hand" of managerial and clerical labor.

Although those who have analyzed changes in late nineteenth and early twentieth century U.S. organizational structures have used measures of industry concentration, scale, complexity, employment patterns, and merger activity to establish key transition periods, we propose using legislative activity to independently establish the chronology of the shift to larger scale, more integrated, and more complex production in the U.S..[5] As large firms came to dominate, public pressure, beginning as early as 1900, led to increased legislation at the state level for independently audited annual reports and improved record keeping. In 1902 the U.S. Industrial Commission recommended the

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[4]For a detailed discussion of Taylor's role in the reorganization of U.S. production techniques see Nelson (1980).

[5]See Atack (1977), Chandler (1969) and (1977), Michaels (2006), and Nelson (1995).

introduction of federal legislation requiring that large corporations publish verifiable reports of profits and losses. The Taft Commission in 1911 implemented changes in state government budgeting practises that eventually led to the Budgeting and Accounting Act of 1921. This Act dramatically increased the need for detailed and accurate record keeping for both governments and businesses. The introduction of a corporate income tax in 1909, personal income taxes in 1913, and an excess profits tax in 1918 meant that corporations were required to adopt standard cost accounting measures that could be upheld by an independent audit. More stringent reporting requirements, stockholder pressure for accountability, and banking reform required a further expansion in the role played by clerical labor in U.S. manufacturing.[6] All of this legislative activity suggests that, although organizational change was constantly occurring, the discontinuity associated with the shift towards large scale, highly complex and integrated manufacturing firms occurred just as U.S. school enrollment and high school graduation rates began their rapid rise.

Often these organizational changes in U.S. manufacturing are discussed simultaneously with the technological changes that accompanied and facilitated them. A substantial number of authors have studied the impact of technological change, and even biases in technological change, on early twentieth century U.S. manufacturers.[7] However, few have studied the specific technologies that were most closely associated with the increasing importance of clerical workers, particularly female clerical workers, after 1900.[8] The new technologies that accompanied the "second industrial revolution" were not confined to factory production. Electrification, for example, certainly facilitated the concentration of production into factories, but it also freed women's time in the home, and made many of the most common clerical appliances considerably more efficient. Like the change in organizational structures that was occurring at this time, the adoption of these new technologies - including typewriters, adding machines, cash registers, and switch-boards, as well as refrigerators, vacuums, and washing machines - was coincident with the movement of women out of home production and into the waged workforce. The work that has been done on the adoption of the early twentieth century technological innovations most commonly used by women has focused on the diffusion of household durable goods - Vanek (1970) and Day (1992), for example. The diffusion of office technology, and its relation to the female workers who used it, is still poorly understood. Researchers, such as Yates (1989), have relied on specific case studies and anecdotal evidence to

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[6]Strom (1992) discusses the link between legislative activity and the expansion of U.S. firm size and organizational complexity during the first 30 years of the twentieth century.

[7]For some examples see Habakkuk (1962), Cain and Paterson (1986), Woolf (1984), or Wylie (1988).

[8]Historians have commented extensively on the movement of women into waged labor, but they have been largely silent on issues related to technological change. A concise summary of the historical contributions can be found in the introductory chapter of Dublin (1979). For more specific examples see Baker (1964), Tilly, Scott and Cohen (1976), or Yeager (1999).

chart the transformation of the office workplace from one of pen and paper to one in which new technologies and educated workers constituted the primary factors of production. Aside from information about the dates on which patents were awarded, which tell us nothing about the chronology of adoption, and some limited information on the spread of telephone networks and the production of typewriters - both of which seem to have increased substantially after World War 1[9] - we have access to very little in the way of a quantitative assessment of the pace of adoption for office technologies for any period earlier than the 1970s.[10] However, the evidence that is available confirms that although U.S. office environments were largely capital free in 1900, they rapidly evolved into both physical and human capital intensive work places over the next four decades.

There does not seem to be much question that during the early twentieth century there was some connection between rising education rates, increases in female participation in waged employment, technological changes in home production durable goods, office equipment and manufacturing processes, and changes in the organizational structure of U.S. manufacturing firms. There is, however, some uncertainty about exactly how these coincident social, economic, technological and organizational changes were related to each other - which of these changes were exogenous, which were endogenous, and what was the chronology of the transformation?

Greenwood, Seshadri and Yorukoglu (2005) argue that substantial growth in the waged employment of American women at the beginning of the twentieth century was a result of an exogenous technological discontinuity in the household durable goods sector. Their formal model depicts female labor force participation rates that rise steadily over the twentieth century as prices for home durable goods, and women's reservation wages decline. Their model suggests that women, particularly young women from relatively large families who might well have been considered surplus labor in home production, were "pushed" into waged employment.[11] According to this view, during the first 40 years of the twentieth century female labor supply forces swamped any emerging demand response from employers. If this push hypothesis is an accurate depiction of the forces that led women to enter the waged workforce during the early twentieth century, then we would expect to find neutral technological changes within the manufacturing sector, at least with respect to female labor, and persistently falling wages for women, at least relative to their male counterparts.

Two alternatives to the view that women were pushed from home production into waged em-

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[9]See Series P279 and R2-R5 in U.S. Historical Statistics.

[10]Michaels (2006) summarizes much of the available quantitative evidence on what he refers to as the late nineteenth and early twentieth century "I.T. revolution".

[11]Some problems with both the cross sectional and time series implications of the Greenwood et al. model will not be discussed in detail in this paper. For example, the adoption rates for common household durable goods lagged far behind the most dramatic increases in female labor force participation rates (in some cases by more than a decade), and the innovations and subsequent reductions in the prices for home durable goods described by Greenwood et al. were not unique to the U.S., yet the dramatic increase in female labor force participation was unique to the U.S..

ployment have been proposed. Both of these alternatives may be considered variants on a "pull" hypothesis due to their concentration on employers' demand responses to women's labor supply decisions.

Like Greenwood et al., Goldin and Katz (1995), and Michaels (2006) also focus on an exogenous technological discontinuity as the trigger for the movement of women into the waged workforce. However, Goldin and Katz, and Michaels are more interested in the early twentieth century changes in office and production technology, rather than the subsequent changes in home durable technologies. According to the Goldin and Katz, and Michaels view, electrification, continuous production techniques, and the adoption of more efficient communication and information storage devices all required the employment of increasing numbers of literate and numerate clerical workers. Michaels' formal model illustrates how the early twentieth century adoption of these new technologies increased the demand for educated employees, which in turn induced the increases in high school graduation rates identified by Goldin (1998), and eventually led to increases in clerical and female labor force participation. Women, therefore, are said to have been pulled into waged employment in pursuit of rising wages. From an empirical perspective, if we accept that producers make their adoption decisions with respect to technology based on *expected* changes in input market conditions, then this version of the pull hypothesis should be associated with biased technological change that encouraged an increasingly intensive use of clerks, particularly female clerks, and as a result we should also find a distinct "inverted U" shaped pattern in women's wages. The rising portion of the "inverted U" pattern should result from the initial technological discontinuity, that drives up women's wages (at least relative to their male counterparts), while the eventual supply response should drive these employment returns back down.

The second version of the pull hypothesis, proposed by Rotella (1981) and Adshade (2005), has empirical implications that are very similar to those inherent in the Goldin and Katz, and Michaels view, but the trigger for the movement of women into waged employment is said to have been an exogenous discontinuity in women's education decisions, rather than an exogenous technological discontinuity in manufacturing or household durable production.[12] Rotella (1981, pg. 57), suggests that, "... the availability of an abundant supply of cheap female labor provided an incentive to adopt mechanized and routinized production techniques... In this way supply conditions interacted with demand forces to stimulate innovation and diffusion of just those productive techniques that increased employment of women in clerical occupations." In effect, Rotella argues

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[12]Historians such as Dublin (1979), Baker (1964), Davis (1982), and Fine (1990) have proposed a chronological pattern of events in the U.S. labor market that is very close to that implied by the Rotella and Adshade view - rising literacy and numeracy, falling relative wages for women, technological change directed towards using these workers, and finally rising relative wages in response to these induced technological changes.

that the availability of an increasing supply of well educated female workers induced firms to adopt new technologies that eventually increased the demand for their labor - leading to an increase in their wages, at least relative to men. Although women are again depicted as being "pulled" into waged employment as a result of an increase in the demand for their services, this view proposes that it was the women's own education decisions that were the exogenous trigger, and the firms' technological and organizational adoption decisions were endogenous.

Rotella does not explicitly link the "mechanized and routinized production techniques" she discusses to the organizational changes that were simultaneously occurring in the U.S., nor does she offer any theoretical model that might allow us to systematically analyze the process she describes. To address these issues Adshade (2005) has developed a more formal approach that focuses on firms' responses to the growing pool of educated women in the U.S. labor market at the turn of the twentieth century. In Adshade's model firms' organizational structures become more complex in response to the increasing availability of educated female workers, and simultaneously their technology adoption decisions become strongly biased towards the use of these workers. Because men held a comparative advantage in manual labor, Adshade argues that the new clerical positions that were created through the firms' technological and organizational decisions were occupied predominantly by educated women.

Similar to the Goldin and Katz, and Michaels view, the Rotella and Adshade variant of the pull hypothesis also implies technological changes that were biased towards an increasingly intensive use of female clerical labor. Of course, Rotella and Adshade suggest that these biased technological changes were a response to previous increases in women's labor supply, rather than a response to expected increases in women's labor supply, but both variants imply the same empirically identifiable characteristic: non-neutral technological change. Because Adshade emphasizes the role played by organizational as well as technological change, the second version of the pull hypothesis also implies that the non-neutral technological changes should be more pronounced among larger, more integrated, and more complex industries. Another difference between the two pull hypotheses that may allow us to empirically distinguish between the technological change-inducing-education view, and the education-inducing-technological and organizational change view, is the unique relative wage patterns implied by each. More specifically, as we pointed out above, if technological change increased the demand for educated female workers and induced them to complete high school and enter waged employment, then female relative to male wages should follow an "inverted U" shaped pattern between 1900-1940. However, if women's education decisions increased the supply of women in the waged workforce and induced technological and organizational changes among manufacturing establishments, then female relative to male wages should follow a "U" shaped pattern between

1900-1940. Both of these relative wage patterns are distinctly different from the persistently falling relative wages implied by the push hypothesis. We now turn to our evidence on female employment and wage patterns.

3 Female Employment and Weekly Wages

3.1 The Ohio Division of Labor Statistics Data

In 1877 the state of Ohio created the Ohio Division of Labor Statistics which published an annual report with employment figures and annual average weekly wages, by occupation from 1878-1912.[13] Starting in 1886 wage and employment figures for men and women were reported separately. In 1912 the state passed a law requiring all firms with five or more workers (revised to three or more workers in 1924) to report monthly employment figures and weekly wages by occupation type: waged (production) workers; bookkeepers; stenographers and typists; and; salesmen. The results from these surveys were tabulated and published in the Division's annual reports for the years 1914, 1915, 1923-1937. Although the results were tabulated and used within the Division, the data for the years 1916-1922 were never published. The Division also collected data on hours worked per week, but this data was only published for 1914. The result is a remarkably detailed data set with weekly wage and employment distributions reported by gender, age (over and under 18), occupation type, and industry (defined at roughly the four-digit S.I.C. code level of aggregation).

The Division's annual reports published weekly wage and employment distributions in very narrowly defined intervals. For example, the 1914 annual report lists the number of workers in each industry, by gender, age, and occupation type who earned: "Under $4"; "Over $4 but Under $5"; "Over $5 but Under $6"; . . . ; "Over $35". We have used the Division's wage distributions to estimate gender, occupation, and age specific mean log wages for each manufacturing industry included in the report using a standard Tobit model (adjusted to accommodate the open ended upper interval). This estimation approach requires an assumption of log normality for each wage distribution. For industry-years in which workers' wages were only reported in one interval, the mean of the interval was used. In the rare cases where the workers' wages were only reported in the upper interval, the lower bound of that interval was used.

From the Ohio Division of Labor Statistics annual reports from 1914, 1915, 1923-1937 we have compiled information on industry specific employment and mean weekly wages for male produc-

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[13]It seems safe to argue that Ohio's manufacturing sector in the early twentieth century was quite representative of U.S. manufacturing as a whole. In Ohio we find manufacturing in both large urban centers and sparsely populated rural settings, we find a wide range of firm and industry sizes, we find resource intensive and technology intensive producers, and Ohio was a substantial contributor to total U.S. industrial output at this time - ranking third in 1919, 1927, and 1939 with respect to manufacturing value added and the diversity of manufacturing activity - behind New York and Pennsylvania, but slightly ahead of Illinois.

tion workers (L1), female production workers (L2), male clerical workers (L3), and female clerical workers (L4), over the age of 18, working in the manufacturing sector. In total we have 2,566 industry-year observations. These observations are distributed fairly evenly across the 14 years in our sample, with approximately 200 industries in each year.

We have further divided the full sample of four-digit manufacturing industries into two groups - Group S (small/unintegrated) and Group L (large/integrated/complex) - in an effort to investigate the relationship between female employment and firm organization. In 1958 the U.S. Senate had a Committee on the Judiciary, which in turn had a subcommittee on Anti-Trust and Monopoly Formation. This subcommittee published information on manufacturing industry concentration ratios starting in 1947. Industry concentration ratios were defined as the proportion of total output produced by the four largest firms in each four-digit S.I.C. industry. We have placed industries for which the 1947 concentration ratio was below 33% in Group S, and industries with concentration ratios greater than 33% in Group L. Our industry grouping conforms very closely to Chandler's (1969, Chart 1) categorization of integrated and unintegrated two-digit S.I.C. manufacturing industries for 1939, and Michaels' (2006, Appendix Table A1) categorization of two-digit S.I.C. industries on the basis of their production "complexity" for 1940. In addition, our industry grouping also conforms closely to a categorization based solely on average establishment size. For example, in 1937 the average number of employees per establishment among our Group L industries was 143.0, while the Group S industries averaged only 46.0 workers per establishment.[14]

The summary statistics in Table 1 are averages over all industry-years covered by the Ohio Division of Labor Statistics data (as well as the 1914 and 1937 end points in the time series) for all manufacturing establishments, the Group L industries, and the Group S industries. Table 1 includes the total number of industry-years, average production males per industry-year, average production females per industry-year, average clerical males per industry-year, average clerical females per industry-year, average weekly wages for each of these four labor-types, and the standard deviations for these means. We can see that between 1914-1937 the average Ohio manufacturing industry employed just less than 10,500 male production workers (88.7 per establishment), approximately 2,080 female production workers (19.4 per establishment), 700 male clerks (5.4 per establishment), and over 530 female clerks (4.0 per establishment). Between 1914 and 1937 the average number of female clerical employees nearly doubled, while the average number of male production workers increased much more modestly - by only 11%. On average between 1914-1937 the mean weekly wage among Ohio manufacturing industries for male production workers was $24.16. This represented

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[14]As a test of our industry grouping we have recalculated all of our group specific empirical results using Chandler's (1969, Chart 1) categorization of two-digit S.I.C. manufacturing industries by decade between 1909-1939. Our qualitative conclusions are unaffected by the choice of categorization method.

Table 1: Summary Statistics - Ohio Manufacturing (1914-1937)

	All Manufacturing	Group L Industries	Group S Industries
L1: 1914-1937	10494.5	15117.3	4582.5
	(51733.9)	(68002.8)	(11168.7)
1914	8846.1	12481.7	4371.5
	(39754.5)	(52655.8)	(9829.4)
1937	9822.8	13635.3	4932.8
	(52369.6)	(68673.5)	(13869.5)
WL1: 1914-1937	24.16	24.50	23.75
	(6.250)	(6.632)	(5.705)
1914	13.87	13.97	13.75
	(1.638)	(1.519)	(1.777)
1937	26.26	26.74	25.66
	(4.840)	(5.489)	(3.815)
L2: 1914-1937	2081.9	2426.6	1641.1
	(9854.8)	(12613.2)	(4193.4)
1914	1455.4	1553.3	1335.0
	(6546.1)	(8360.6)	(3179.2)
1937	1950.5	2189.8	1643.5
	(9941.6)	(12764.2)	(4165.8)
WL2: 1914-1937	14.30	14.35	14.23
	(3.980)	(4.074)	(3.862)
1914	7.55	7.61	7.49
	(1.520)	(1.813)	(1.089)
1937	16.43	16.74	16.06
	(3.362)	(3.966)	(2.415)
L3: 1914-1937	704.4	982.5	348.7
	(3464.6)	(4530.5)	(942.6))
1914	449.9	616.0	245.4
	(2048.4)	(2700.3)	(602.8)
1937	708.5	973.2	369.2
	(3790.2)	(4950.3)	(1130.9)
WL3: 1914-1937	33.62	34.17	32.85
	(8.025)	(8.413)	(7.392)
1914	18.12	18.15	18.07
	(1.349)	(1.157)	(1.580)
1937	33.99	34.65	33.14
	(5.500)	(6.391)	(3.967)
L4: 1914-1937	533.2	679.9	345.7
	(2546.6)	(3313.5)	(824.5)
1914	273.4	339.3	192.4
	(1182.5)	(1557.3)	(374.5)
1937	511.1	634.6	352.7
	(2628.1)	(3417.2)	(896.7)
WL4: 1914-1937	19.92	20.09	19.68
	(3.905)	(3.843)	(3.980)
1914	11.17	11.36	10.93
	(1.190)	(1.271)	(1.044)
1937	20.46	20.52	2037
	(2.733)	(3.028)	(2.311)
Industry-Years: 1914-1937	2566	1440	1126
1914	145	80	65
1937	210	118	92

Note: Group L=large, integrated, complex industries, Group S=small, unintegrated industries, L1=production males, L2=production females, L3=clerical males, L4=clerical females, WL_X=average weekly nominal wages for worker-type L_X, standard deviations provided in parentheses.

a 78% weekly wage premium over female production workers and a 27% weekly wage premium over female clerical workers, but a 24% shortfall relative to male clerical workers. The average Group L industry employed nearly twice as many female clerks as the average Group S industry during our period of study (680 women versus 345 women), and female clerks were paid slightly more in the average Group L industry ($20.09 per week versus $19.68 per week). To delve more deeply into the chronological and cross-sectional patterns that are masked by the industry-year averages reported in Table 1, we now turn to a consideration of the gender and occupation specific employment and wage patterns experienced by Ohio's manufacturing workers during the first 40 years of the twentieth century.

3.2   Employment Patterns

From the Ohio Division of Labor Statistics annual reports we have summed total female employment in each available year between 1914-1937 for all industries listed, for the larger, more integrated and more complex Group L industries, and for the smaller, less integrated Group S industries. In Figure 1a we illustrate total female employment for each of these three groups of manufacturing establishments. It seems clear that the number of women participating in the waged manufacturing workforce in Ohio increased dramatically over these years - nearly doubling from 95,570 female workers in 1914, to 186,191 female workers in 1937. The average percentage increase in total female employment for all Ohio manufacturing establishments was just slightly less than 2.5% per year.[15] The more complex Group L industries' female workforce expanded from just 1.3% larger than the Group S industries' female workforce in 1914, to 49.8% larger in 1925, and 46.0% larger in 1937. As we will see for all of the employment and wage figures discussed in this section, the macroeconomic volatility associated with the Great Depression had a substantial impact on female employment among Ohio manufacturers, with the total number of women in the workforce falling sharply in 1930, 1931 and 1932, only to recover and just surpass the pre-Depression peak at the very end of our sample period. Of course, looking at female employment patterns in isolation tells us nothing about women's labor market experiences relative to their male counterparts. It may be that the strong increases in female participation that appear in Figure 1a simply reflect a dramatic expansion in the demand for all labor-types among Ohio manufacturers, and women's labor force participation rates were not particularly noteworthy. To emphasize the rising importance of female workers, and the relatively large increases in female labor supplies, we must compare gender and occupation specific employment patterns, rather than simply focusing on aggregate female employment.

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[15] All of the average annual rates of change discussed in this section have been calculated by regressing a constant and a linear time trend against the natural logarithm of each series illustrated in Figures 1a-2d. All reported rates of change are statistically significant with at least 95% confidence, unless otherwise reported.

As a first step, we have calculated the share of the total manufacturing workforce that was female in each available year between 1914-1937. From Figure 1b we can see that across all industries there was a slight increase in women's relative employment levels over this period. In 1914 17.7% of the Ohio manufacturing workforce was female. This participation rate rose to 19.4% in 1925, and again to 20.5% in 1937. Women's contribution to the Ohio manufacturing workforce increased at an average annual rate of 1.0% over the entire period, with the largest annual increases coming in 1931 and 1932. It is also interesting to note that among the larger, more integrated, and more complex industries there was a considerably larger increase in female labor force participation between 1914-1937, with the share of women in the total workforce rising from 11.8% in 1914, to 15.1% in 1925, and 16.1% in 1937. The average annual increase in female participation among the Group L industries between 1914-1937 was 1.5%, and with the exception of only 1929, 1933 and 1934 the increases in women's labor force participation among the complex industries were monotonic over the period. In contrast, average growth in female participation among the smaller, less integrated Group S industries was much slower - just 0.2% per year between 1914-1937.[16]

From Figure 1c we can see that if we look at the occupational composition of the Ohio manufacturing workforce between 1914-1937, rather than the gender composition depicted in Figure 1b, we can identify another substantive change in the characteristics of this group of employees - an increase in the proportion of clerical workers. 6.6% of the total Ohio manufacturing workforce held a clerical position in 1914, 8.5% were clerks in 1925, and 9.4% were clerks in 1937. On average over the entire period clerical workers' contribution to total manufacturing employment increased by more than 1.5% per year, with a very sharp increase in 1930 and an equally sharp drop in 1933.[17] Similar to the employment patterns for women, the Group L industries increased their employment of clerical workers slightly more rapidly than the Group S industries. On average over the 1914-1937 period the Group L industries increased the share of clerical workers in their total workforce by 1.6% per year, while the Group S industries increased their share of clerical workers by just 1.4% per year.

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[16]It is surprising to find that the Group S industries employed proportionately more women and more clerks than the Group L industries. We suggest that this may be due to the type of establishments included in the Group S industries, which were considerably smaller than the Group L industries - less than one third as many employees on average - and it seems likely that many of the Group S industries may have been primarily family operated firms in which all members of the family were listed as employees. If this was the case, than there would be a bias towards over-enumeration of female and clerical labor in the Group S industries. If we had access to data on hours worked, then this issue could be addressed. It seems likely that the Group L industries were using considerably more female and clerical labor hours relative to the Group S industries. The collection and analysis of women's work hours is ongoing.

[17]The jump in the proportion of clerical workers in 1930 appears to have been due to a decline in production employment in this year, rather than an increase in clerical employment. Similarly, the decline in the proportion of clerks in the total workforce in 1933 was due to an expansion in the number of production workers, with virtually no change in the number of clerks.

The series included in Figure 1d depict the proportion of female clerks in the total Ohio manufacturing workforce between 1914-1937. As such, these series illustrate changes in both the gender and occupational composition of the aggregate workforce. Ohio's female clerks increased their labor force participation rates even more rapidly than all female workers or all clerical workers over this period. Female clerks accounted for 2.5% of the total manufacturing workforce in 1914, 3.7% in 1925, and 3.9% in 1937. Again, the Group L industries experienced the largest increase in female clerks' labor force contributions, with average growth rates equal to 2.2% per year - from 2.1% of the total Group L workforce in 1914, to 3.3% in 1925, and 3.5% in 1937. Unlike female participation in general, female clerks managed to substantially increase their labor force contribution among the Group S industries as well - at an average annual rate of 1.5% over the 1914-1937 period.

Based on the employment evidence depicted in Figures 1a - 1d we suggest that there is support for four qualitative conclusions. First, women were increasingly participating in the waged manufacturing workforce in Ohio between 1914-1937, and their increased participation was nearly monotonic. Second, clerical workers of both genders were becoming an increasingly important component of the manufacturing workforce in Ohio during this period. Third, female clerks were increasing their labor force contributions at an even faster rate than female workers as a whole, or clerical workers as a whole. Finally, the increases in labor force participation by female workers, clerical workers, and female clerks, were largest within the more integrated, large scale, complex industries. These conclusions are not only consistent with the empirical implications of both variants of the pull hypothesis, the rising female participation rates depicted in Figure 1b are also consistent with the empirical implications of the push hypothesis. As a final point, it is reassuring to note that these conclusions bolster confidence in our claim that the employment and wage patterns that characterized the manufacturing sector in Ohio were fairly typical of the patterns that have been identified by both economists and historians for the aggregate U.S. manufacturing sector during the first forty years of the twentieth century.

3.3   Weekly Wage Patterns

From the wage distributions included in the Ohio Division of Labor Statistics annual reports we have estimated gender, occupation and industry specific nominal mean wages for each available year between 1914-1937. We have generated weighted average weekly wages for all manufacturing and our two industry groups using total employment figures as weights. After deflating the nominal weekly wages by a consumer price index (U.S. Historical Statistics, Series E135) we report women's average weekly real wages for all Ohio manufacturers, the Group L industries, and the Group S

industries in Figure 2a. It is apparent that there was a strong upward trend in women's real wages over this period, with all Ohio manufacturers paying women an average of $8.17 per week in 1914, $9.89 per week in 1925, and $12.59 per week in 1937[18] - an average annual increase of just over 1.6% in excess of inflation. The Group L industries paid an average of $0.78 more per week than the smaller, unintegrated industries in Group S over the period. Another noteworthy feature of the real wage series depicted in Figure 2a is the very rapid real wage growth experienced by female workers in Ohio manufacturing in 1930, followed by the equally dramatic drop in their real wages in 1932. This volatility was driven by changes in the consumer price index, as women's nominal weekly wages fell monotonically between 1929-1932, from $18.78 in 1929 to $14.85 in 1932, but the C.P.I. fell even faster in both 1930 and 1931, before leveling off in 1932. There is little more we can say with confidence about women's remuneration experiences based on Figure 2a without additional controls for other influences on manufacturing wages in Ohio during this period. It may be that strong demand for manufactured goods produced in Ohio drove up all workers wages, such that women may have actually experienced weak labor demand relative to men, despite their rising real wages.

The series included in Figure 2b illustrate women's average weekly wages relative to men's average weekly wages for all Ohio manufacturers, the Group L industries, and the Group S industries. The comparison of female relative to male wages allows us to control for industry-wide wage effects that were not specific to women. In particular, changes in relative wages indicate changes in the scarcity of female labor in excess of any changes in the scarcity of manufacturing labor in general. Between 1914-1925 it appears that there was virtually no change in female relative to male wages in Ohio: the average annual change in the gender wage gap during the first 11 years of our sample was a statistically insignificant -0.09% for all manufacturing, -0.3% for the Group L industries, and 0.5% for the Group S industries. In contrast, over the last 11 years of our sample (1926-1937) women experienced quite strong growth in their average weekly wages compared to their male counterparts. On average among all manufacturers, women earned only 59.6% of the male weekly wage in 1925, but by 1937 they were earning 64.5% as much as men - an average increase in relative wages of 0.89% per year. The post-1925 average annual increase in women's relative wages in the Group L industries was just slightly greater, at 0.91%. Even women in the unintegrated Group S industries experienced a 0.8% average annual increase in their relative wages after 1925.

One particularly striking feature of all three of the series included in Figure 2b is the very rapid rise in women's wages relative to men's wages in 1933. In stark contrast to men's average nominal weekly wage, which fell from $23.72 in 1932 to $22.34 in 1933, women's average nominal weekly

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[18]All real wage figures are in 1900 constant dollars.

wage actually rose from \$14.85 in 1932 to \$15.06 in 1933. As a result, between 1932 and 1933 female relative to male weekly wages in Ohio rose from 62.6% to 67.4% for all manufacturers, 63.4% to 67.2% for the Group L producers, and 60.6% to 67.9% for the Group S producers. The volatility in this one year is another example of the impact of the macroeconomic fluctuations associated with the Great Depression. To avoid drawing qualitative conclusions that have been adversely biased by this volatility, it would be ideal if we had access to information on gender, age, occupation, and industry specific employment and weekly wages that would allow an assessment of "peak-to-peak" changes. Unfortunately, our primary data source - the Ohio Division of Labor Statistics - stopped publication of their annual reports in 1937, prior to the full recovery of the aggregate economy. Information on wages and employment by gender or occupation is not widely available from other sources for this era. However, the 1940 U.S. Bureau of Labor Statistics Handbook (B.L.S. Bulletin # 694) includes a report by the Bureau of Women's Labor Statistics, which has information on male and female average hourly earnings for two-digit manufacturing industries in 1937 and 1940, and gender and industry specific weekly earnings for 1940, all based on figures collected from the 12 largest industrial states (including Ohio). Although the information in the B.L.S. Handbook is not directly comparable to the information in the Ohio Division of Labor Statistics annual reports, we have made an adjustment to try to account for the compositional differences using the one overlapping year (1937) in both sources, and we have used the adjusted figures to extend the female relative to male weekly wage series in Figure 2b to include the additional information from 1940. By including a measure of the gender wage gap in 1940 we can consider changes from peak-to-peak (1929-1940) and we can have more confidence that our qualitative conclusions are not wildly distorted by the volatile movements in nominal weekly wages associated with the decent into, and recovery from the Depression.

Controlling for the dramatic increase in female relative to male weekly wages in 1933, and extending the relative wage series depicted in Figure 2b to include 1940 are important adjustments if we are to distinguish between the hypotheses which seek to explain the increases in women's participation in the waged workforce at the beginning of the twentieth century. It seems fairly safe to suggest that the relative wage series in Figure 2b do not support the Greenwood et al. claim that women were pushed from home production into waged employment due to a discontinuity in home durable goods technology. There is no evidence of persistently falling female relative to male wages that could be associated with an increasing supply of female workers, and no demand response.

Drawing a distinction between the two variants of the pull hypothesis is not quite so straight forward. If the Goldin and Katz, and Michaels technological change-induces-education variant of the pull hypothesis is correct, then we should find an "inverted U" pattern in the series depicted in

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Figure 2b. If the Rotella and Adshade education-induces-technological and organizational change variant of the pull hypothesis is correct, then we should find a "U" shaped pattern in the series depicted in Figure 2b.

In addition to a visual inspection of the series in Figure 2b, our initial consideration of the rates of change in the gender wage gap before and after 1925 suggests, at best, stagnant relative wages for women prior to 1925, and rising relative wages after 1925. This difference in linear trends holds even if we exclude the rapid increase in women's relative wages in 1933 and/or extend the series to 1940. We may provide some statistical rigor to support our initial assessment in two ways. First, a standard Chow test confirms a statistically significant discontinuity in the rate of change in women's relative to men's weekly wages among all Ohio manufacturers, the Group L industries and the Group S industries in 1925 - from a negative trend to a positive trend for all manufacturing and the Group L industries. Second, if we estimate a quadratic time trend through the series included in Figure 2b (a constant, year, and year squared regressed on the natural logarithm of the gender wage gap), we find that the first derivative of the quadratic trend is negative for all Ohio manufacturing and the Group L industries up to the early 1920s, then positive thereafter. There is no statistically significant change in the sign of the first derivative of the quadratic trend for the Group S industries. The qualitative results from the Chow tests and the quadratic time trend tests are unaffected by the exclusion of 1933 and/or the inclusion of 1940. Visual inspection of the female relative male wage series depicted in Figure 2b, consideration of the linear time trends before and after 1925, Chow test results, and the estimation of quadratic time trends all suggest that between 1914-1940 women employed by Ohio manufacturers experienced stagnant, or slightly falling relative wages until the mid-1920s, but rising relative wages over the remainder of our sample period. At least for the larger, more integrated and more complex industries in Group L, the pattern in female relative to male weekly wages seems to conform more closely to the "U" shape implied by the Rotella and Adshade variant on the pull hypothesis.

Insert Figure 2a - 2d

In Figure 2c weekly wages paid to clerical workers, regardless of gender, relative to weekly wages paid to production workers, again regardless of gender, for all Ohio manufacturers, the Group L industries and the Group S industries are depicted for the years 1914-1937. Similar to the gender specific relative wage patterns in Figure 2b, we see stagnant, or slightly falling weekly wages for clerical workers relative to production workers up until the mid-1920s. However, unlike the gender wage gap, the clerical wage gap increases sharply in 1930, 1931 and 1932, before falling through the remainder of the sample, ending in 1937 at almost the same level as 1929: a 9% weekly

wage advantage for clerks among all Ohio manufacturers, an 8% advantage among the Group L industries, and a 10% advantage among the Group S industries. None of the series included in Figure 2c have statistically significant linear time trends after 1925, and only the Group S industries have a statistically significant "U" shaped quadratic time trend over the full 1914-1937 period.

Although we would very much like to report information on clerical relative to production wages for some years following the full recovery from the Depression, this is not possible with the Ohio Division of Labor Statistics data. The only available occupation specific wage data available for this era is reported by Goldin and Katz (1995) for the state of Iowa in 1929 and 1939. Their figures show virtually no change in clerical relative to production workers' annual earnings for men or women over this period.[19] This suggests that at least over the last years of the 1930s the occupation wage gap stabilized. Despite the possibility that relative wages may have been settling into a period of greater stability at the very end of our sample, the sharp expansion and subsequent contraction in clerical wages relative to production wages during the 1930s makes any generalizations about the chronological patterns in these series difficult to support. It does not, however, appear that clerks wages were persistently and substantively falling relative to production workers' wages between 1914-1937, as we would expect to find if supply forces were the dominant determinants of clerical participation in the waged workforce.

The final set of relative wage series we consider are included in Figure 2d. These include average weekly wages for female clerks relative to male production workers for all Ohio manufacturing, the Group L industries and the Group S industries over the years 1914-1937. A familiar pattern is again apparent - slightly falling relative wages for female clerks until the mid-1920s, slowly rising relative wages from the mid-1920s until the late 1920s, then another rapid increase from 1930-1933, followed by another dramatic drop from 1934-1937. Among all Ohio manufacturers the average female clerk earned 23% less than the average male production worker in 1914, 23.5% less in 1925, only 13% less in 1933, but 24% less by 1937. As with the occupation specific series depicted in Figure 2c, we have no comparable gender and occupation specific relative wage information for the years immediately after 1937. For all Ohio manufacturing and for the Group L industries there was a statistically significant negative linear time trend in women's clerical wages relative to men's production wages between 1914-1925, but there was no significant linear trend in any of the series included in Figure 2d after 1925. The quadratic time trend for all Ohio manufacturing and for the Group L industries was statistically significant and falling until the early 1920s, before rising

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[19]For 1929 Goldin and Katz (1995, Table 5) identify a 13% annual earning premium for male clerks over male production workers in Iowa manufacturing and a 53% advantage for female clerks. These differences in annual earnings increase to 15% and 56%, respectively, in 1939. These occupation premia conform very closely to those reported by Michaels (2006, Table A2) for all U.S. manufacturing in 1939.

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thereafter, but there was no significant quadratic trend for the Group S industries. Again, the evidence from our gender and occupation specific relative wage series is not definitive, although it seems quite safe to reject the possibility that female clerks' relative wages were falling persistently and substantively throughout this period.

The relative wage patterns in Ohio manufacturing between 1914-1937 suggest that women, clerks, and female clerks were not experiencing consistently falling wages, as we would expect in the presence of an increasing supply of these workers and no demand response from employers. It also appears that women's average weekly wages were following a rough "U" shaped pattern relative to men's average weekly wages, at least among the larger, more integrated and more complex Group L producers. However, it is difficult to identify this same pattern in clerical relative to production weekly wages, or female clerks relative to male production workers relative weekly wages. At the same time, it is worth emphasizing that we cannot identify an "inverted U" pattern in any of the relative weekly wage series discussed in this subsection. The fluctuations in the gender and/or occupation specific employment and relative wage series associated with the Depression years make more robust conclusions difficult to support, but if we confine our attention to the (approximately) "peak" years of 1914, 1925 and 1937 (1940 where available), then it seems that we can confidently identify strong employment growth for women, clerks, and clerical women across all three years, and we can identify a small drop in relative wages for women, clerks, and clerical women between 1914-1925, followed by a small increase in the relative wages earned by each of these groups of workers between 1926-1937. Can technological changes among Ohio's manufacturing industries explain the demand conditions that allowed women to match their male counterparts' real wage gains, despite considerably more rapid increases in their labor force participation rates? It is to this question that we now turn.

4   Biased Technological Changes

4.1   The Census of Manufacturing for the State of Ohio

To understand the role played by technological change in the increasingly intensive use of female and clerical labor during the first 40 years of the twentieth century, we must consider the possibility that manufacturers' adoption of new technologies and organizational structures was not neutral. This implies that technological and organizational change during this era may not have improved the efficiency of all inputs simultaneously and in equal proportions. To facilitate the investigation of biases, or non-neutrality in early twentieth century technological change, we have estimated the parameters from group specific translog production functions. These estimates require more

information about the inputs employed and outputs produced by Ohio's manufacturers than is available from the Ohio Division of Labor Statistics annual reports. We have, therefore, matched our gender, occupation, and industry specific employment and wage data with information from the biennial Census of Manufactures for the state of Ohio. The census data and employment data overlap for seven years during our sample period: 1914, 1923, 1929, 1931, 1933, 1935, and 1937.

We have used the four-digit S.I.C. code industry titles to match industries in the two data sets. Where there was any question about the similarity in industry titles the industry was dropped from our combined sample. Because the census published information aggregated from manufacturing establishments with \$500 or more in gross output, but the Ohio Division of Labor Statistics annual reports published information aggregated from establishments with five or more employees (later three or more employees), even the industries with identical titles may have included different establishments in each data set. Fortunately, it is unlikely that this source of mismatch is a substantive problem. According to Croxton (1935, Pg. 4) the Ohio Division of Labor Statistics employment and wage data accounted for 95.2% of wage earners and 96.4% of all wage payments reported in the Census of Manufactures for the state of Ohio in 1914. To be even more confident in our industry match we dropped any industries for which the number of establishments or the total number of employees differed by more than 25% between the two data sets. We adjusted the number of gender and occupation specific employees in the combined sample to account for any differences in either the number of establishments or total number of employees.

Our combined data set includes 801 matched industry-years distributed fairly evenly across the sample period, with a minimum of 89 industry matches in 1914 and a maximum of 134 industry matches in 1923. For each industry-year we have information on: gross output (the value of gross output deflated by a manufacturing wholesale price index (U.S. Historical Statistics, Series E86)); materials (the value of all materials used deflated by an intermediate materials used in manufacturing wholesale price index (U.S. Historical Statistics, Series E79)); the adjusted gender and occupation employment figures from the Ohio Division of Labor Statistics; the weekly wage rates from the Ohio Division of Labor Statistics; and; a capital proxy (value added less the total payment to all types of labor (assuming a 50 week work year) deflated by a user cost for capital index (a purchase price for capital index multiplied by a nominal interest rate, the G.D.P. deflator, and an assumed 10% depreciation rate)).[20] These data are sufficient for the estimation of translog production functions for all Ohio manufacturing, the Group L industries, and the Group S industries

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[20]Our capital proxy assumes that there was a competitive market for capital in Ohio, and purchase prices, depreciation rates and tax treatments were approximately equal across industries. Other capital proxies, including horsepower figures reported in the Census, have been used in our estimations without any substantive impact on our regressions (other than reducing the number of observations available).

over the year 1914-1937.

4.2 Estimating Translog Production Functions

The translog production function is particularly desirable for our purposes because it is a second order approximation of any arbitrary, twice differentiable production function for a given input combination, and unlike the more common Cobb-Douglas or C.E.S. production functions, it does not impose any restrictions on the elasticities of substitution.[21] The translog specification also accommodates an explicit decomposition of the total impact of technological change - broadly defined to include any increases in output that cannot be attributed to increases in measured input employment[22] - into a neutral component that increases the efficiency of all inputs in equal proportions, and input specific "biased" components that increase the efficiency of individual inputs in isolation. A cost function approach would also be feasible given our purposes and the data we have access to, but because we need not impose any parameter restrictions to guarantee appropriate curvature properties, we prefer our translog production function estimates. As a check on the sensitivity of our conclusions we have estimated constrained generalized Leontief cost functions with our combined data set. Our main qualitative conclusions are unaffected by the choice of cost versus production function estimation.

The translog production function with materials, capital, gender and occupation specific labor inputs, and a technological change parameter takes the form:

$$\ln Q_{it} = \theta + \lambda_X \Sigma_X \ln X_{it} + \beta_{XY} \Sigma_X \Sigma_Y \ln X_{it} \ln Y_{it} + \kappa_Z Z_j + \varepsilon_{it} \tag{1}$$

Where i identifies the four-digit industry code; j identifies the two-digit industry code; t identifies the year; Q_{it} is gross output of industry i in year t; X_{it} and Y_{it} are input vectors including the natural logarithm of capital (K), materials (M), male production workers $(L1)$, female production workers $(L2)$, male clerks $(L3)$, and female clerks $(L4)$; X_{it} and Y_{it} also include a time parameter (t) that captures the effects of technological change on the production function; Z_j is a vector of industry specific fixed effects variables included to control for cross panel heteroscedasticity; and finally; $\theta, \lambda_X, \lambda_t, \beta_{XY}, \beta_{Xt}$ and κ_Z are vectors of parameters to be estimated.

The signs and statistical significance of the translog production function's parameter estimates may be used to directly identify characteristics of the technology employed. For example: $\beta_{XY} > 0$ implies that X and Y are complements in production; $\beta_{XY} < 0$ implies that X and Y are substitutes

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[21]Diewert (1976) describes the desirable features of the translog production function in detail.

[22]This definition of technological change implies that we are not only capturing the effects of changes in technology embodied in physical capital, but we are also capturing the effects of changes in human capital, and changes in organizational structure.

in production; $\beta_{Xt} > 0$ implies that there was a bias in technological change associated with an increasingly intensive use of input X; while $\beta_{Xt} < 0$ implies that there was a bias in technological change associated with a reduction in the intensity with which producers used input X.

In addition to the directly observable technological characteristics, the translog production function parameter estimates may be used in conjunction with the measured inputs to derive input elasticities, cost shares, and returns to scale estimates. From Equation (2) we can see that the first derivative of the translog production function with respect to input $\ln X_{it}$ not only allows us to measure input elasticities of X (%Δ in output for a small %Δ in X) that vary over time and input market conditions, but these elasticities may be summed across inputs to measure aggregate returns to scale, and if we accept the standard neo-classical assumptions, then these input elasticities may also be used to represent shares in total cost for input X.

$$\frac{\delta \ln Q_{it}}{\delta \ln X_{it}} = \lambda_X + 2\beta_{XX} \ln X_{it} + \beta_{XY}\Sigma_Y \ln Y_{it} + \beta_{Xt}t \tag{2}$$

With an unbalanced panel regression technique we have used all 801 industry-year observations to estimate a translog production function for early twentieth century Ohio manufacturers.[23] We have also disaggregated our full sample - using 411 industry-year observations to estimate a translog production function for the Group S industries, and the remaining 390 industry-year observations to estimate a separate translog production function for the Group L industries. The relevant parameter estimates (and their p-values) from all three of these regressions are reported in Table 2.

4.3 The Econometric Results

From Table 2 we can see that the statistical significance of many of the parameter estimates that are of particular interest to us is strong, and the data seem to fit the translog specification quite well. With the full set of parameter estimates we could discuss in great detail the technological characteristics of Ohio manufacturing between 1914-1937 - describing the substitution possibilities among all inputs, all technological change characteristics, and even input specific returns to scale estimates. However, in an effort to maintain our focus on the relationship between technological change and female clerical labor, we will confine our attention to the parameter estimates reported

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[23]The econometric approach adopted in this paper has been taken from Berndt (1991, Chapter 9). A random effects correction for cross panel heteroscedasticity was rejected on the basis of a standard Hausman test. A generalized least squares estimation approach generated very similar results to those reported in Table 2. There is virtually no evidence of autocorrelation among any of the error terms, and a correction for first order autocorrelation has no impact on any of our qualitative conclusions. The estimation of systems of cost share equations rather than the production functions as a whole add virtually no statistical power to our significance tests and we cannot calculate aggregate returns to scale with the share equations alone.

Table 2: Translog Parameter Estimates - Ohio Manufacturing (1914-1937)

	All Manufacturing	Group S Industries	Group L Industries
RTS	0.9977	0.9931***	1.0052**
	(0.223)	(0.005)	(0.049)
β_{L1t}	0.0020***	0.0018***	0.0021***
	(0.000)	(0.005)	(0.001)
β_{L2t}	0.0001	0.0004*	-0.0004
	(0.594)	(0.077)	(0.115)
β_{L3t}	-0.0007	0.0001	-0.0014^*
	(0.222)	(0.929)	(0.082)
β_{L4t}	0.0010*	-0.0002	0.0017**
	(0.096)	(0.837)	(0.050)
β_{Kt}	0.0009*	0.0020***	0.0017***
	(0.099)	(0.003)	(0.009)
β_{Mt}	-0.0029^{***}	-0.0035^{***}	-0.0030^{***}
	(0.000)	(0.000)	(0.000)
β_{L1L4}	0.0077	-0.0196^*	0.0191*
	(0.265)	(0.068)	(0.082)
β_{L2L4}	-0.0043^{**}	-0.0055^{**}	-0.0041
	(0.024)	(0.039)	(0.156)
β_{L3L4}	-0.0001	-0.0077	-0.0089
	(0.986)	(0.324)	(0.323)
β_{L4K}	0.0060	-0.0211^{**}	0.0115
	(0.393)	(0.047)	(0.220)
β_{L4M}	-0.0195^{***}	0.0297**	-0.0246^{***}
	(0.000)	(0.023)	(0.000)

Note: RTS > 1 (< 1) indicates increasing (decreasing) returns to scale. Statistical insignificance of RTS indicates constant returns to scale. $\beta_{Xt} > 0$ (< 0) indicates input X using (saving) biased technical change. $\beta_{XY} > 0$ (< 0) indicates input X and Y are complements (substitutes) in production. P-values are provided in parentheses. * indicates statistical significance with at least 90% confidence. ** indicates statistical significance with at least 95% confidence. *** indicates statistical significance with at least 99% confidence.

in Table 2 - namely, those associated with female clerks (L4).

In the top row of Table 2 we report aggregate returns to scale estimates calculated at the mean of the data. We can see that in general scale effects among Ohio manufacturers were weak. Given the work on returns to scale - or more accurately, the absence thereof - among late nineteenth and early twentieth century U.S. manufacturers by Cain and Paterson (1986), Sokoloff (1984), Atack (1977), and Keay (2003), this is not a surprising result. What is reassuring about these estimates is that we find statistically significant decreasing returns to scale among the Group S industries and statistically significant increasing returns to scale among the Group L industries. These scale estimates suggest that our Group L producers were representative of the more integrated, complex, and larger scale producers that Chandler and Nelson described as embracing organizational change.

In the next six rows of Table 2 we report the parameter estimates that indicate biases, or non-neutrality in technological change. We can see that among all Ohio manufacturers, the Group L industries *and* the Group S industries, the technological choices being made by producers between 1914-1937 led to the increasingly intensive use of male production workers and physical capital, and a reduction in the intensity of materials usage.[24] The smaller, less integrated, and less complex Group S industries were also adopting technology that used female production workers intensively. While the larger, more integrated, and more complex Group L industries were making technological and organizational choices that saved on their use of male clerks, and, from a statistical perspective, quite strongly increased their reliance on female clerks.

The final five rows in Table 2 include the parameter estimates that indicate input substitution patterns. Among all Ohio manufacturers between 1914-1937 female clerks appear to have been substitutes for female production workers and materials. The female clerks employed by the Group S industries were substitutes for male production workers, female production workers, and physical capital, but complements to materials. In contrast, the Group L industries employed female clerks as complements to male production workers and substitutes for materials.

These input substitution patterns are relevant because in a number of cases they seem to re-enforce the technological biases. Among the non-female clerical inputs, production males, capital, and materials have significant technological change biases. We can see that for each of these three inputs, complementarity with female clerical labor was associated with "using" technological change biases (production males and capital) while substitutability was associated with "saving" technological change biases (materials). In other words, between 1914-1937 Ohio manufacturers tended to adopt technological changes that used female clerks and their complements intensively,

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[24]These technological change biases conform closely to those reported by Cain and Paterson (1986, Table 4) for all U.S. manufacturing between 1850-1920.

while saving on substitutes for female clerical labor.

Producers who adopted technological and organizational changes that were biased in favor of the intensive use of female clerks would have increased their demand for the services of these workers. Can the non-neutrality of technological change among Ohio manufacturers, and more specifically among the Group L producers, account for the wage patterns we identified in Section 3? This question is really asking if the statistically significant results reported in Table 2 are economically significant as well. A simple "back-of-the-envelope" counterfactual exercise can help to answer this question.

4.4   A Simple Counterfactual Exercise

In 1914 the Ohio manufacturing sector employed 13,580 female clerks, and the Group L industries accounted for 8,727 of these workers. By 1937 Ohio manufacturers were employing 35,840 female clerks, and the Group L industries were responsible for the employment of 24,211 of these women. Female clerks' real wages among all manufacturers rose from \$10.90 in 1914 to \$14.54 in 1937, while the real wages earned by female clerks employed by Group L producers rose from \$11.05 to \$14.68 over these same years. At the start of our sample payments to female clerks accounted for just 0.30% of total cost for all Ohio manufacturing and 0.33% of total cost for the Group L industries. By the end of our sample female clerks' share of total cost had risen to 0.98% for all producers and 1.05% for the larger, more complex producers. There was clearly a substantive and persistent increase in the supply of female labor, particularly female clerical labor, seeking waged employment in Ohio between 1914-1937, and these women were enjoying rising absolute and relative real wages.

Using the translog parameter estimates reported in Table 2 and the independent variables included in Equation (2) we may calculate input elasticities, which are equal to total cost shares if the standard neo-classical assumptions hold. By setting β_{L4t} equal to zero in Equation (2), we may calculate the counterfactual change in female clerks' share of total cost if there had been no biased technological changes in their favor between 1914-1937.[25] With this counterfactual cost share we may derive a rough estimate of the contribution non-neutral technological change made to women's remuneration experiences over this period.

We find that in the absence of input using technological change, the counterfactual 1937 share of total cost paid to female clerks employed by all manufacturing establishments falls from 0.98%

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[25]This approach should provide a lower bound on the impact of biased technological change on female clerks' real wages because we have confined our counterfactual imposition of neutral technological change to female clerical labor alone. If we imposed neutrality on all inputs, then the counterfactual reduction in the demand for complements to female clerical labor, and the counterfactual increase in demand for substitutes for female clerical labor would further reduce the demand and remuneration these workers would have received in excess of the reductions we report in this section.

to just 0.67%. The counterfactual decline in female clerks' total cost share among the Group L industries is even larger - from 1.05% to 0.52% in 1937. This implies that 45.4% of the increase in female clerks' total cost share among all manufacturers was due to biased technological change, and 73.4% of the increase in female clerks' total cost share among the Group L producers was due to biased technological change. If we then assume that female clerks inelastically supplied their labor to manufacturing establishments, we can calculate the counterfactual change in real wages that would have produced this decline in total cost shares. In the absence of biased technological change in favor of female clerical labor, female clerks' real wages would have fallen from $10.90 in 1914 to $9.96 in 1937 among all producers, and from $11.05 in 1914 to $7.25 among the Group L producers - a drop from the observed 1937 real wages in these two groups of more than 31.5% and 50.6%, respectively. With technological changes favoring female clerical labor, their average weekly wages relative to male production workers were roughly equal in 1914 and 1937. However, without favorable technological change biases, the counterfactual average weekly wages of female clerks relative to male production workers would have fallen from approximately 0.75 in 1914 to 0.49 for all Ohio manufacturing and 0.35 for the complex Group L industries. Based on these counterfactual calculations it appears that the increase in demand for female clerical labor that stemmed from non-neutral technological and organizational changes between 1914-1937 made a substantial contribution to the maintenance of women's absolute and relative wage performance, in spite of the increasing supply of these workers.

5   Some Conclusions

If supply forces were the dominant determinant of American women's increasing participation in waged employment during the first 40 years of the twentieth century, as proposed by the Greenwood et al. push hypothesis, then we should expect to find increasing female labor force participation with no emphasis on female clerical employment, persistently falling relative wages for women, and neutral technological change among Ohio's manufacturing establishments between 1914-1937. If technological change increased the demand for educated female labor in the U.S. workforce, which then induced women to graduate from high school and seek waged employment, we should expect to find increasing female labor force participation, particularly among clerical occupations, rising relative wages for women preceding falling relative wages, and biases in technological change in expectation of an increasing supply of educated female workers. However, if the presence of a growing pool of educated female workers induced firms to adopt technologies and organizational structures that increased the demand for these workers, then we should again expect to find increasing fe-

male labor force participation, particularly among clerical occupations in larger, more integrated, and more complex industries, falling relative wages for women preceding rising relative wages, and biases in technological change in response to the increased supply of educated female workers.

The evidence presented in this paper reveals that among Ohio's manufacturing establishments between 1914-1937 female labor force participation was increasing rapidly, with the most dramatic increases in women's employment shares concentrated in clerical occupations and in the largest, most complex industries. Women's real wages were also rising over this period among Ohio's manufacturing industries, although relative to their male counterparts these increases were largely confined to the Group L industries, and they were most striking during the decade between the mid-1920s and mid-1930s. The increasing demand for female labor, particularly female clerks, was founded at least in part on technological change, which was biased towards the increasingly intensive use of female clerical workers among the larger, more complex Group L producers. These technological change biases accounted for a substantial portion of the observed increase in female real wages among Ohio manufacturers between 1914-1937, and without these demand shifts female relative to male average weekly wages would have fallen substantially, rather than increasing slightly, as we observe in the Ohio Division of Labor Statistics data.

Based on these findings we suggest that there was a substantive demand response that accompanied the movement of women into the waged workforce during the first 40 years of the twentieth century. It seems that technological and organizational change must have driven much of the increase in demand for educated female workers during this era. It is more difficult to draw confident conclusions about the chronology of the demand response that pulled women into manufacturing employment. However, for Ohio manufacturing establishments it does appear that there were stagnant, or slightly falling wages for women relative to men up to the mid-1920s, after which women's relative wages began to rise. Unfortunately the volatility introduced by the decent into, and recovery from the Great Depression, make it harder to make this distinction between a "U" shaped versus an "inverted U" shaped pattern in female clerks' wages relative to male production workers' wages. The available evidence does seem to indicate that supply forces - increasing numbers of educated female workers entering the labor force - were dominant until the mid-1920s, after which demand forces - driven by technological changes biased towards the intensive use of female clerks - overcame the increasing supply of these female workers and began to drive up their wages relative to their male counterparts. This conclusion, therefore, provides some tentative empirical support for the Rotella-Adshade variant of the pull hypothesis.

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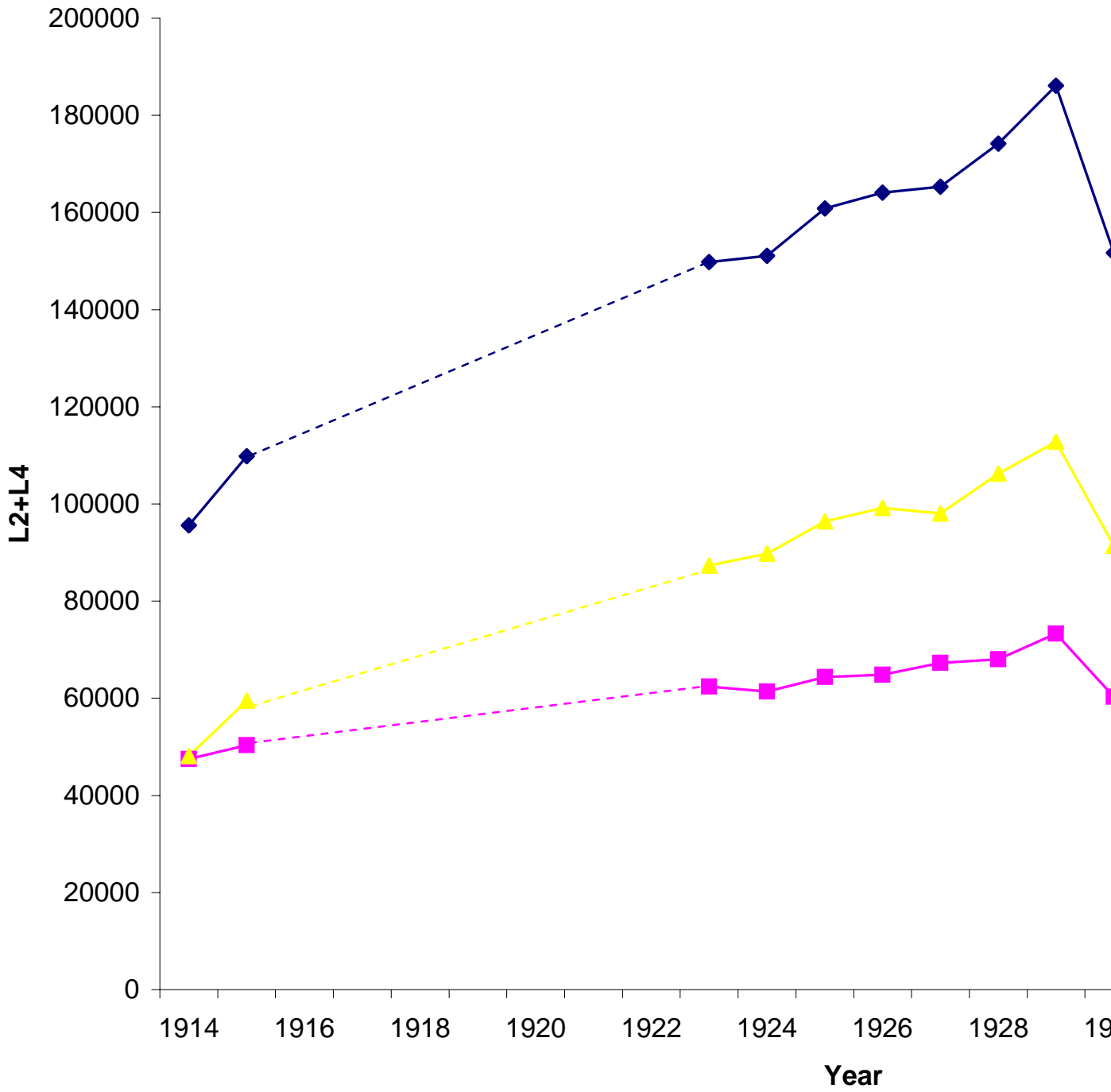
Figure 1a: Total Female Employment - Ohio
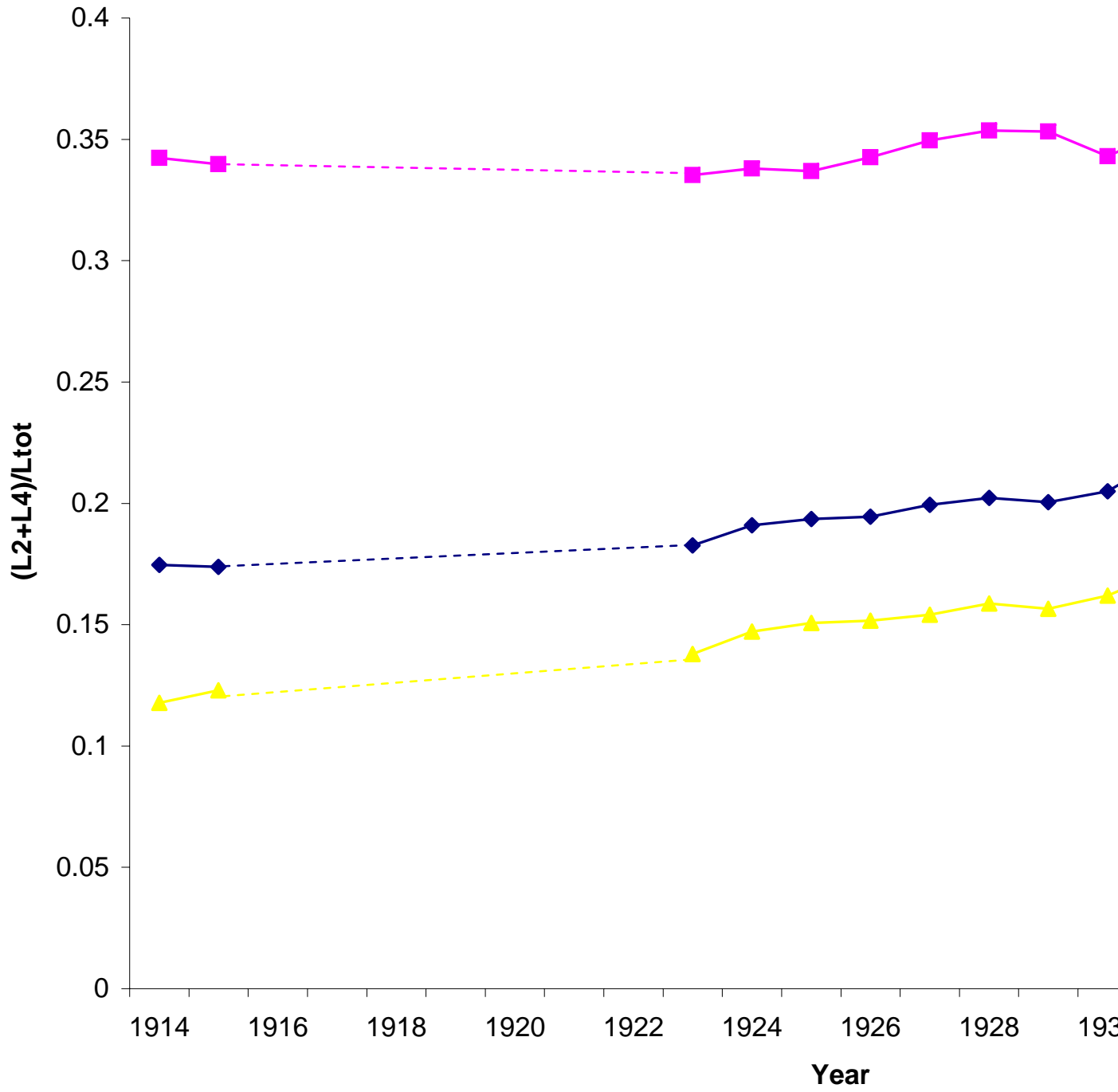
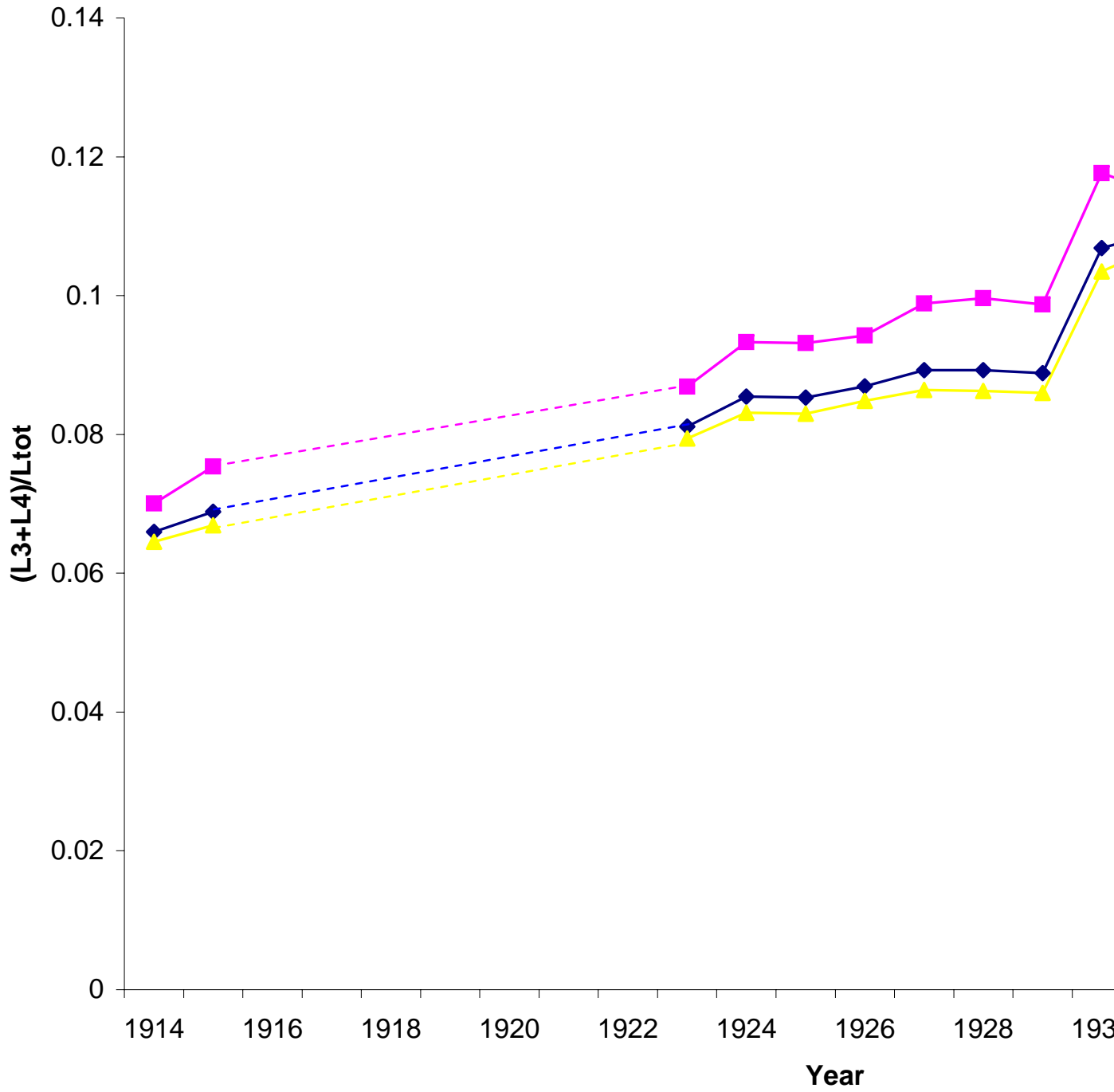Figure 1b: Female Employees as % Total Workforc

Figure 1c: Clerical Employees as % Total Workforce

Figure 1d: Female Clerical Employees as % Total Work[...]
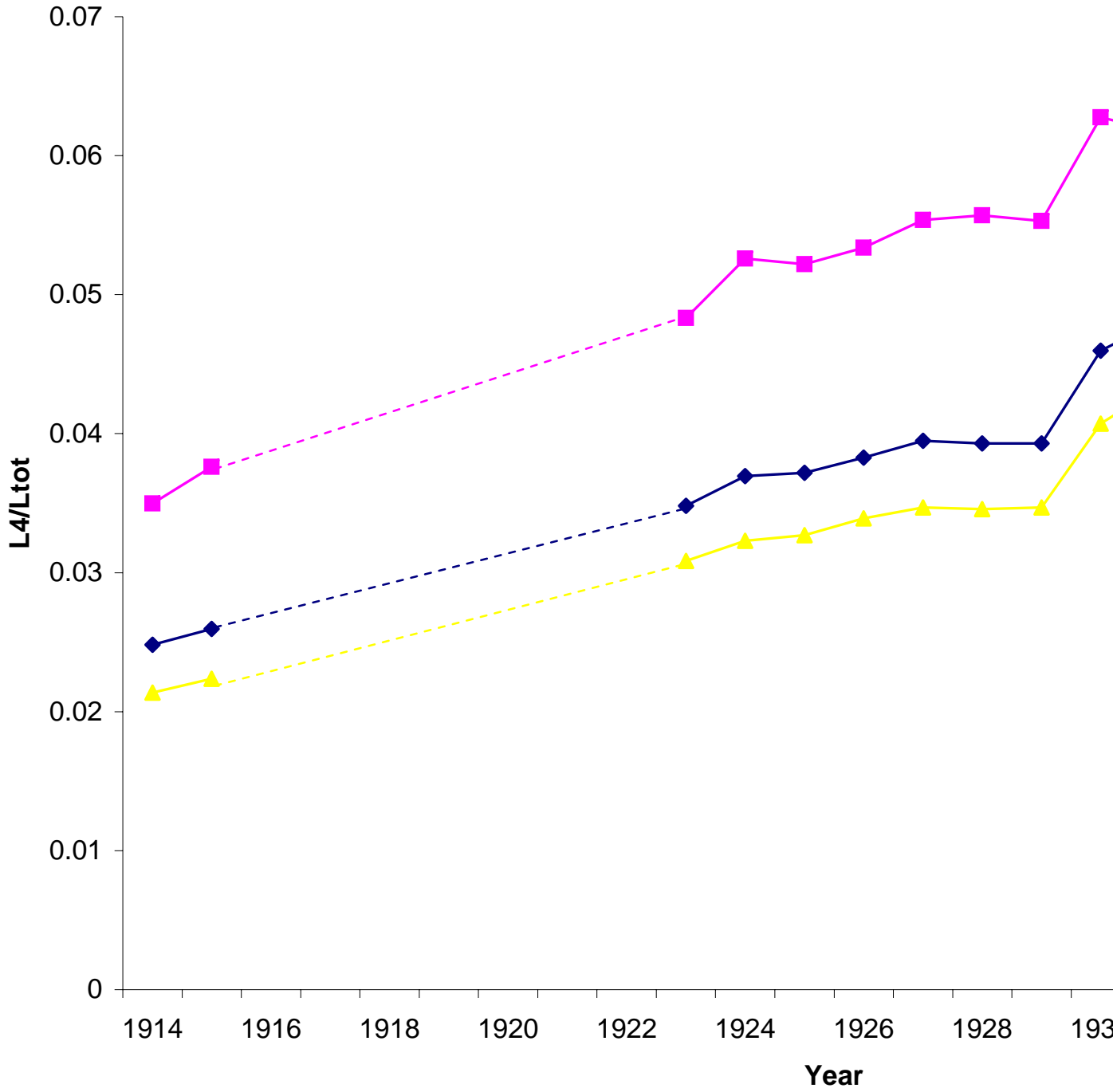
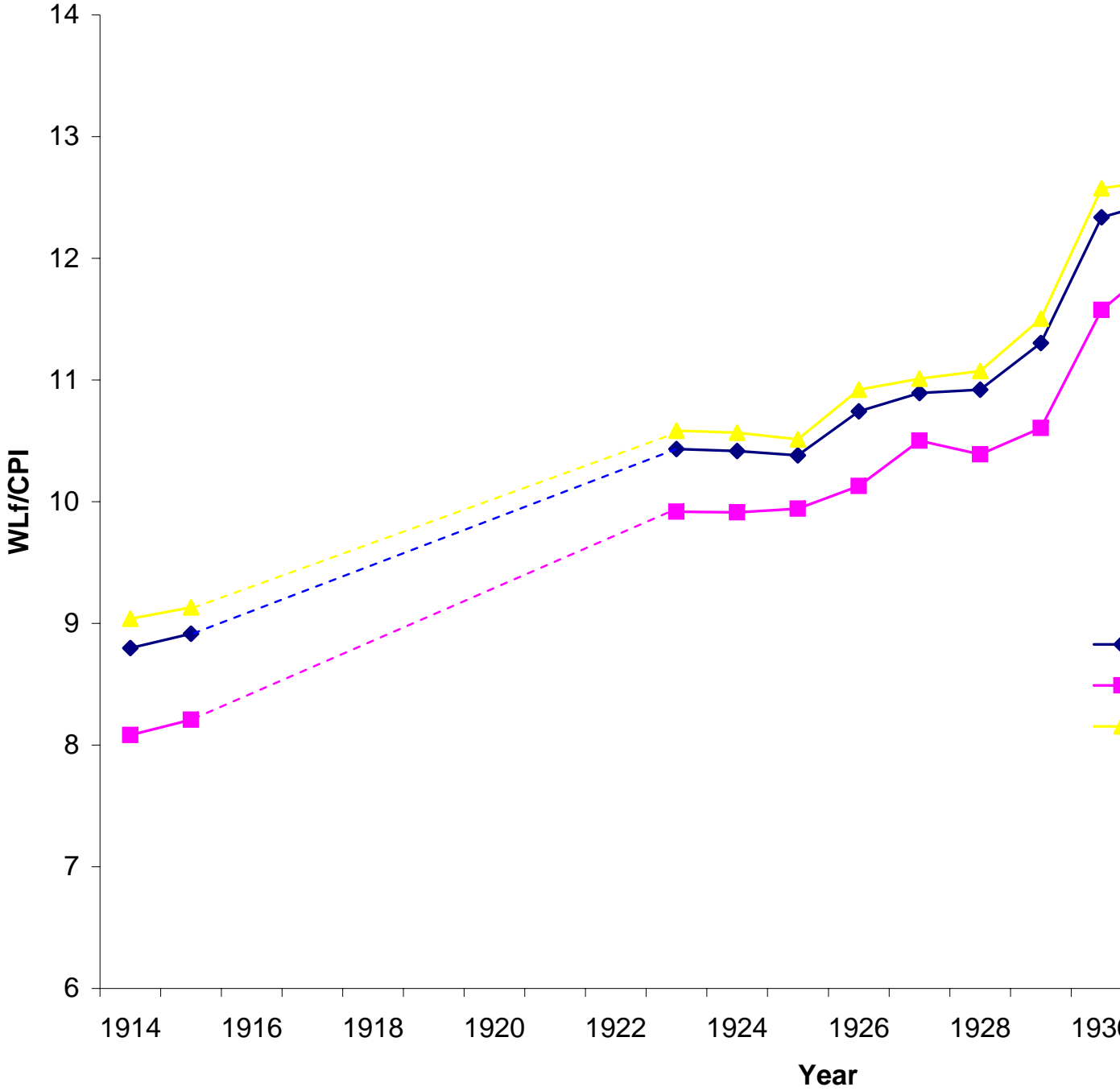Figure 2a: Female Real Wages (1900$) - Ohio

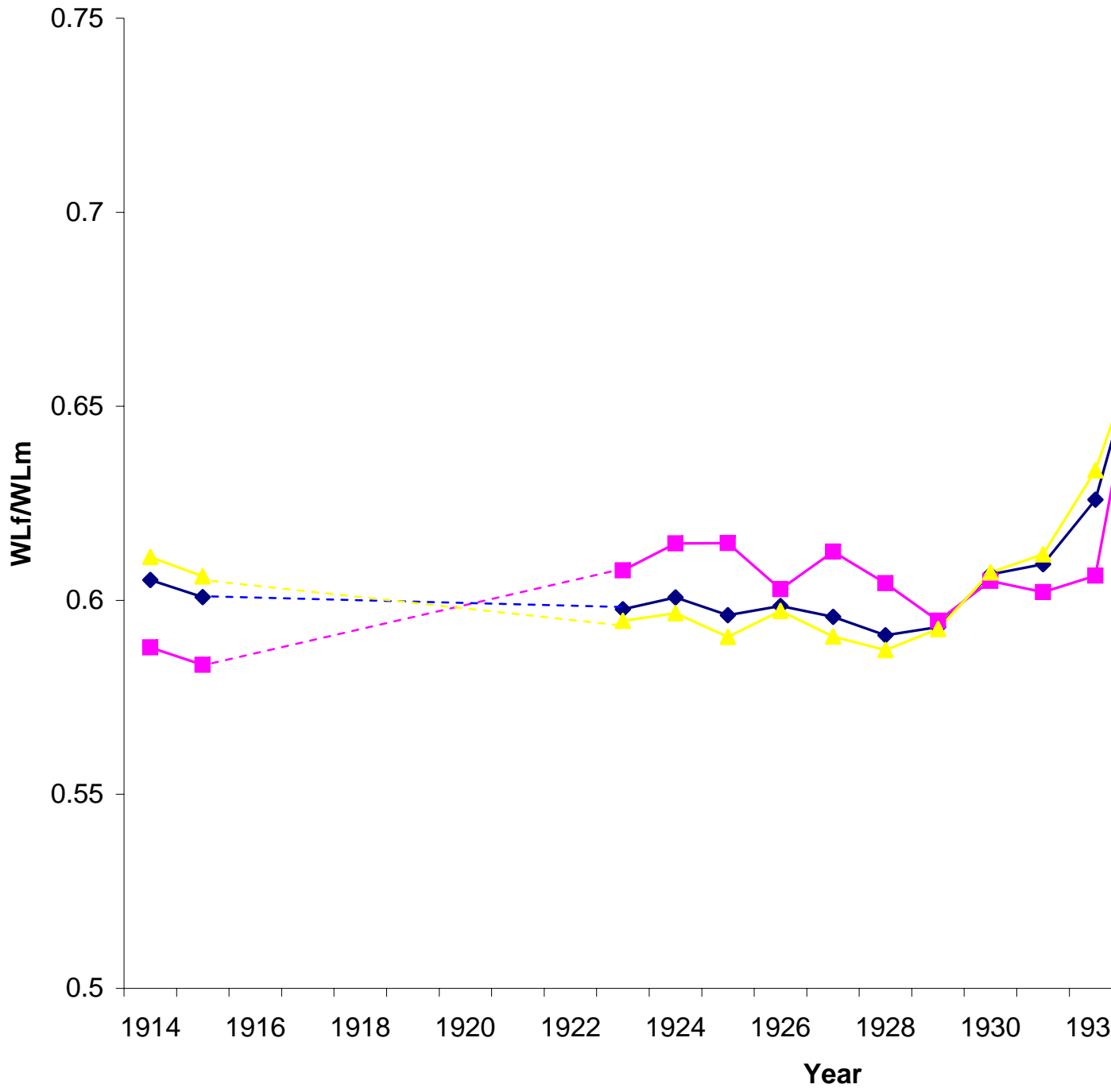**Figure 2b: Female Wages Relative to Male Wages**
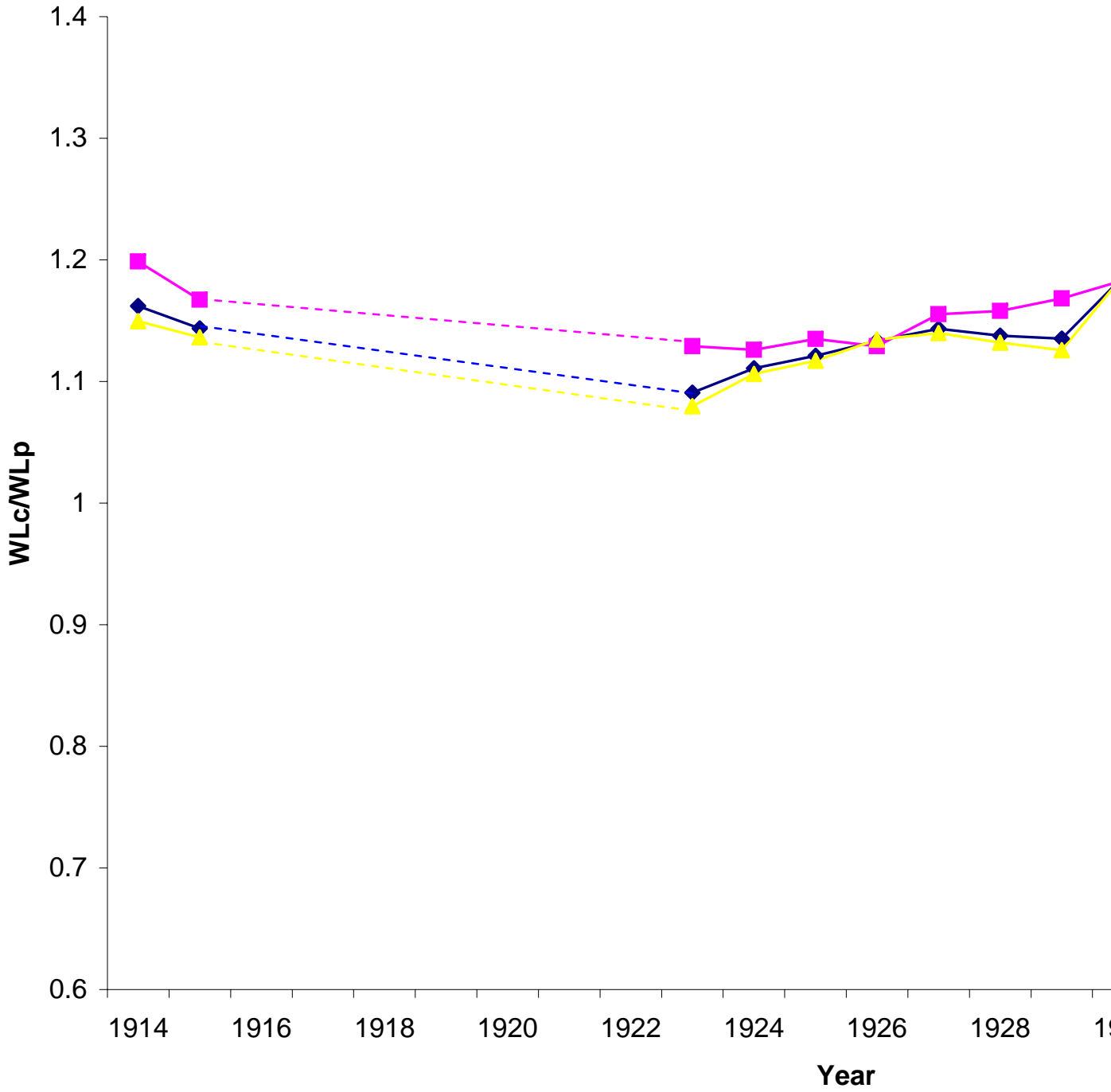
Figure 2c: Clerical Wages Relative to Production Wag

Figure 2d: Female Clerical Wages Relative to Male Producti