The Polarization of the U.S. Labor Market

By David H. Autor, Lawrence F. Katz, and Melissa S. Kearney*

Much research (surveyed in Katz and Autor, 1999) documents a substantial widening of the U.S. wage structure since the late 1970s, driven by increases in educational wage differentials and residual wage inequality. The growth in wage inequality was most rapid during the 1980s, and involved a spreading out of the entire wage distribution. Rapid secular growth in the demand for skills, partly from skill-biased technical change (SBTC), combined with a slowdown in the growth of the relative supply of college workers helps explain these wage changes. Eroding labor market institutions—the minimum wage and unions—further contributed to rising wage inequality.

Recent work emphasizes a slowing of wage inequality growth over the last 15 years (David Card and John DiNardo, 2002; Thomas Lemieux, forthcoming). This "revisionist" literature views the 1980s surge in wage inequality as an "episodic" event caused by institutional forces and argues that "modest" inequality growth in the 1990s is inconsistent with a key role for SBTC.

We reconsider this revisionist view, focusing on a marked change in the evolution of the U.S. wage structure over the past 15 years and divergent trends in upper- and lower-tail wage inequality. We first document that wage inequality in the top half of the distribution has exhibited an unchecked secular rise for 25 years, but it has ceased growing since the late 1980s (and for some measures narrowed) in the bottom half of the distribution. We next demonstrate that employment growth differed sharply in the 1990s versus the 1980s, with more rapid growth of employment in jobs at the bottom and top relative to the middle of the skill distribution. Borrowing terminology from Maarten Goos and Alan Manning (2003), we characterize this pattern as a "polarization" of the U.S. labor market, with employment polarizing into high-wage and low-wage jobs at the expense of middle-skill jobs. We then show how a model of computerization in which computers complement nonroutine cognitive tasks, substitute for routine tasks, and have little impact on nonroutine manual tasks, can rationalize this polarization pattern.

I. Divergent Upper- and Lower-Tail Wage Inequality

Figure 1 displays the evolution of the 90-50 and 50-10 log-hourly wage differentials for all workers (males and females) from 1973 to 2004 using (hours-weighted) wage data from the Current Population Survey (CPS) May samples (for 1973–1978) and Merged Outgoing Rotation Group samples (for 1979–2004).[1] It shows sub-

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[1] Our sample selection and data processing steps for CPS wage data are the same as those described in the Data Appendix of Autor et al. (2005b), extended to cover wage data for 2004.

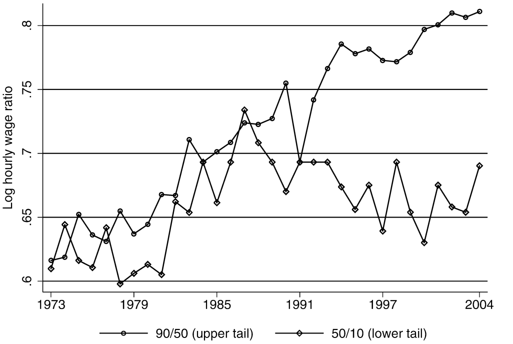

FIGURE 1. MALE AND FEMALE LOG HOURLY 90/50 AND 50/10 EARNINGS RATIOS

Source: Current Population Survey May and Monthly Files, 1973–2004.

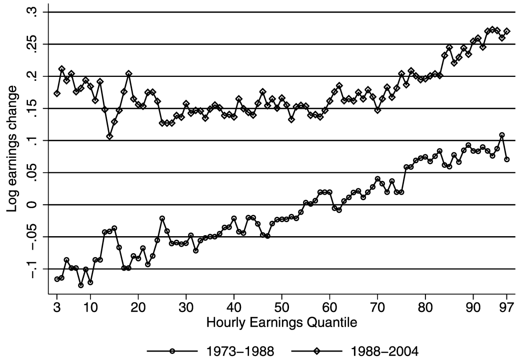

FIGURE 2. CHANGES IN MALE AND FEMALE LOG REAL HOURLY EARNINGS BY PERCENTILE, 1973–1988 AND 1988–2004

Source: See Figure 1.

stantial increases in upper-half (90-50) and lower-half (50-10) wage inequality from 1979 to 1987, expanding the 90-10 wage differential by 21 log points. But the trends in upper-half and lower-half inequality diverge after 1987, with upper-half wage inequality continuing to rise steadily while lower-half inequality growth ceased in the late 1980s (with a *contraction* in the 50-10 differential of four log points from 1987 to 2004). Monotonic rising wage inequality in the 1980s and diverging upper- and lower-tail inequality since the late 1980s are observed for males and females separately, for the weekly wages of full-time workers, and for the CPS March samples (Autor et al., 2005a).

Figure 2 illustrates where in the wage structure the divergence of upper- and lower-tail wage inequality trends have occurred. It plots cumulative log hourly real earnings growth (indexed using the Personal Consumption Expenditures implicit price deflator) by wage percentile for 1973 to 1988 and for 1988 to 2004. The figure shows an almost linear spreading out of the entire wage distribution for 1973 to 1988. In contrast, wage growth has polarized since 1988, with faster wage growth in the bottom quartile than in the middle two quartiles, and with the most rapid rise and a continued spreading out of the distribution in the top quartile.

The divergence of upper- and lower-tail wage inequality since the late 1980s holds for residual wage inequality and is robust to adjustments for labor force composition changes (Autor et al., 2005a). Using tax-return data, Thomas Piketty and Emmanuel Saez (2003) further document the divergence of earnings in the very upper-end of distribution (the top 1 percent) relative to other workers since the 1970s.

We examine how a nuanced view of technological change may contribute to these trends. Following Autor et al. (2003), our framework observes that the first-order impact of computerization is to displace "middle skilled," routine cognitive and manual tasks, such as bookkeeping and repetitive production work. If routine tasks are more complementary to high-skilled abstract tasks than to "nonroutine manual" tasks (such as those of truck drivers), the computerization of routine work can generate labor market polarization. The model predicts that wage polarization should be accompanied by employment polarization.

II. Job Polarization Trends

We examine trends in the "quality," skill content, and task content of U.S. jobs since 1980. We follow Goos and Manning's (2003) analysis of the United Kingdom in exploring how U.S. employment growth by occupation has been related to skill proxied by initial educational levels or wages.

We first sort (3-digit) occupations into percentiles by mean years of schooling in 1980, using data from the 1980 Census Integrated Public Use Microsample (IPUMS). Figure 3 plots

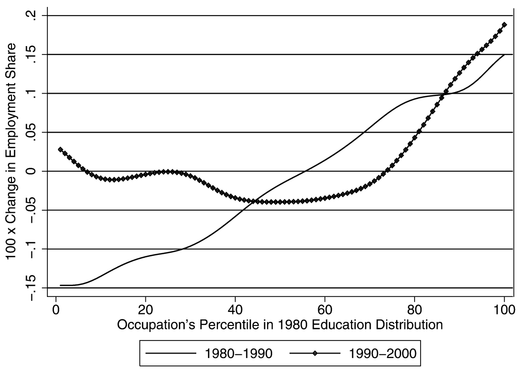

FIGURE 3. SMOOTHED CHANGES IN OCCUPATIONAL EMPLOYMENT SHARES 1980–2000, WITH OCCUPATIONS RANKED BY THEIR 1980 AVERAGE YEARS OF SCHOOLING

Source: Census Integrated Public Use Microsamples 1980, 1990, and 2000.

employment growth, measured as the change in an occupation's share of total hours worked, from 1980 through 1990 and 1990 through 2000, against 1980 occupational skill (education) percentile using employment shares from the 1980 to 2000 IPUMS.[2] For the 1980s, the figure shows declining employment at the bottom of the distribution, and near-monotonic (almost linear) increases in employment moving up the education distribution. In contrast, employment growth in the 1990s polarized with the most rapid increases in high-skill jobs, slowest growth in middle-skill jobs, and modest growth in low-skill jobs.

This pattern of job growth (and possible labor demand shifts) corresponds well with the wage structure changes shown in Figure 2. In a comparison of the 1980s to the 1990s, we find that employment growth is more rapid in the 1990s below the fortieth and above the eightieth percentiles of the occupational skill distribution and declines in the middle.

We have tested the robustness of these patterns with an alternative skill definition—median hourly wage in an occupation in 1980. This skill measure also indicates that employment growth was roughly monotonic in skill during the 1980s and then polarized in the 1990s. Daron Acemoglu (1999) reports similar U.S. job polarization from the mid-1980s to early 1990s using more aggregated industry-occupation cells, and Goos and Manning (2003) document job growth polarization for Britain, another country with a large increase in wage inequality.

A third methodology for measuring employment structure trends involves changes in employment by job task content. Autor et al. (2003) take this approach using data on task content from the *Dictionary of Occupational Titles* aggregated to Census occupations. We extend their analysis of employment growth in industry-gender-education cells using CPS data through 2002. We find that employment growth was most rapid in the 1990s for cells intensive in nonroutine cognitive tasks (those most complementary with computerization), was declining at an increasing rate in the 1990s for cells intensive in routine cognitive and manual tasks (those most substitutable for computers), and ceased declining in the 1990s for (typically low-wage) jobs intensive in nonroutine manual tasks.

These patterns of employment growth by education, wages, and task intensity suggest that labor demand shifts have favored low- and high-wage workers relative to middle-wage workers over the last 15 years. This contrasts with the labor demand shifts of the 1980s, which appear to have been monotonically rising in skill.

III. A Model and Interpretation

Our framework, building on Autor et al. (2003), considers how a decline in the real price of computing power may lead to a polarization of work. The model is based on four observations that are well supported by the existing evidence. First, computer capital—denoted by K and measured in efficiency units—is a close substitute for human labor in routine cognitive and manual tasks, such as clerical work and repetitive production tasks. Second, routine task input—embodied in either computer capital or human labor—is a complement to workers

[2] We employ a consistent set of occupation codes for census years 1980, 1990, and 2000 developed by Peter B. Meyer and Anastasiya M. Osborne (2005). We use a locally weighted smoothing regression (bandwidth 0.8 with 100 observations) to fit the relationship between decadal growth in occupational employment share and occupations' initial percentile in the 1980 skill distribution, measured by mean years of schooling. Figure 3 plots the fitted values from these regressions.

engaged in abstract reasoning tasks such as problem solving and coordination. Third, there exists a panoply of nonroutine manual tasks for which computers currently neither directly substitute nor strongly complement, such as the tasks performed by truck drivers, waiters, and janitors. We refer to these categories of tasks as abstract (A), routine (R), and manual (M); and we consider them to correspond roughly to high-, intermediate-, and low-skilled occupations. Lastly, we observe that workers' ability to engage in specific tasks is contingent on their education. We assume that there are two types of workers: college workers, who can perform abstract tasks; and high school workers who can substitute between routine and manual tasks.

The exogenous driving force in our model is the precipitous decline in the price of computing power in recent decades. Computerization—the falling real price of computers—lowers the price of routine task input and increases demand for routine tasks. We sketch the formal model here and refer the reader to an online Theory Appendix available at www.e-aer.org/data/may06_app_p06006.pdf.

Output, priced at unity, is produced using the aggregate Cobb-Douglas production function $Y = A^{\alpha}R^{\beta}M^{\gamma}$ with α, β, $\gamma \in (0, 1)$, $\alpha + \beta + \gamma = 1$, and where A, R, and M denote the three tasks above. Abstract and manual tasks are performed by workers who supply labor inputs, L_A and L_M. Routine tasks can be performed either by workers who supply L_R or by computer capital, K, measured in efficiency units, which is a perfect substitute for L_R. Computer capital is supplied perfectly elastically to routine tasks at price ρ, which is falling at an exogenous rate.

There are many workers with educational supplies assumed exogenous. Each college worker is endowed with one efficiency unit of abstract skill, which she supplies inelastically to abstract tasks. Each high school worker, i, is endowed with one efficiency unit of manual skill and η_i efficiency units of routine skill, where η is distributed continuously on the unit interval with positive mass at all points $\eta \in [0, 1]$. High school workers do not possess abstract skills.

The supply of high school labor to routine and manual tasks is determined by self-selection. Let w_m and w_r equal the wages paid to manual and routine tasks. Each high school worker, i, chooses to supply either one efficiency unit of labor to manual tasks if $\eta_i < w_m/w_r$ or supplies η_i efficiency units of labor to routine tasks otherwise. Thus labor supply to manual (routine) tasks is weakly upward (downward) sloping in w_m/w_r.

Equilibrium occurs when: (a) the economy operates on the demand curve of the aggregate production function; (b) each factor is paid its marginal product; and (c) the labor market clears so that no worker wishes to reallocate labor input among tasks.

Because computer capital is a perfect substitute for routine labor, $w_r = \rho$, a decline in ρ reduces w_r one for one. We are interested in the effect of a decline in ρ on: (a) the equilibrium quantity of routine task input; (b) the allocation of labor between routine and manual tasks; (c) the wage paid to each task; and (d) the observed wage in each job type—which, for routine tasks, may differ from the wage paid per efficiency unit of routine task input.

Since own-factor demand curves are downward sloping, a decline in ρ raises demand for routine tasks. This demand can be supplied by either additional computer capital or routine labor input. Due to worker self-selection, the additional demand will be supplied by computer capital. The reason is that manual and routine tasks are q-complements—a rise in routine input (spurred by the fall in ρ) raises the marginal productivity of manual task input.

When ρ (and thereby w_r) falls, some workers—those with relatively low η—self-select from routine to manual tasks. This additional labor supply works against the beneficial effects of computerization on the manual wage. It is possible for *both* w_m and w_r to fall when ρ declines, but the wage of manual relative to routine tasks (w_m/w_r) unambiguously rises.

We distinguish between the wage of routine tasks measured in *efficiency units* and the observed wages of workers in routine tasks, which are affected by composition. As workers self-select out of routine tasks, the remaining routine workers have above-average routine skills, meaning the *observed* routine wage can rise or fall (overall and relative to w_m) as ρ declines.

As with manual workers, workers in abstract tasks benefit from a rise in routine task input due to q-complementarity. For abstract tasks, however, there is no countervailing labor supply response to buffer the positive impact of computerization on the abstract wage. Consequently, computerization unambiguously raises w_a, absolutely and relative to w_r and w_m. A more realistic production function would reinforce this pattern through greater complementarity of computerization with abstract tasks than manual tasks.

Does this framework generate a polarization of work? The key observation of the model is that computers *do not* appear to substitute directly for the lowest-skilled workers; rather they appear to displace a set of "middle-skilled" routine tasks. Displacing this "middle" generates polarization through three mechanisms. First, it directly lowers the wage of middle-skill tasks. Second, it raises the wage of high-skilled (abstract) tasks through q-complementarity. Finally, it has ambiguous effects on the wages of low-skilled (manual) tasks due to offsetting impacts of q-complementarity and additional labor supply of workers displaced from routine tasks. Thus, computerization always raises "upper-tail" inequality in our model—the wage gap between abstract and routine tasks. But it can either expand or compress "lower-tail" inequality—the wage gap between routine and manual tasks—depending on whether the q-complementarity or labor supply effect dominates.

We can think of the model as moving between two equilibria as the price of computers declines. Initially computerization displaces workers from routine and into manual tasks, depressing wages in the middle and (potentially) the bottom of the distribution, even as the abstract wage increases. When ρ falls sufficiently, the model exhibits a second equilibrium in which routine tasks are performed exclusively by K. In this equilibrium, only the q-complementarity effect operates; further declines in ρ raise wages in *both* manual and abstract tasks. Thus, the model is consistent with an initially monotone wage impact of computerization followed by a polarization of the wage distribution as jobs "hollow out" to encompass only abstract and manual tasks. A similar impact of international outsourcing could arise from declining international coordination costs associated with information technology advances (Frank Levy and Richard J. Murnane, 2004; Pol Antràs et al., forthcoming).

IV. Conclusions

The major new U.S. wage structure "facts" evident in the last decade are the smooth, secular rise in upper-tail inequality over the last 25 years, coupled with an expansion and then compression of lower-tail inequality. These facts are not easily handled by standard institutional stories. The minimum wage explanation fits only lower-tail inequality trends well to 1987 (Autor et al., 2005b), and does not explain why relative employment in low-wage jobs *fell* as the minimum wage dropped. A "social-norms" explanation of the skewing of the upper reaches of the wage distribution (as suggested by Piketty and Saez, 2003) has some plausibility but needs work to refine clear, testable predictions.

Our analysis offers unambiguous evidence that demand shifts are likely to be a key component of any cogent explanation for the changing U.S. wage structure. We find that quantity and price changes covary positively throughout the earnings distribution both in the 1980s, when the wage structure was spreading monotonically, and in the 1990s, when it was polarizing. We believe that the changing distribution of job task demands, spurred directly by advancing information technology and indirectly by its impact on outsourcing, goes some distance toward interpreting the recent polarization of the wage structure.

REFERENCES

Acemoglu, Daron. "Changes in Unemployment and Wage Inequality: An Alternative Theory and Some Evidence." *American Economic Review*, 1999, *89*(5), pp. 1259–78.

Antràs, Pol; Garicano, Luis and Rossi-Hansberg, Esteban. "Offshoring in a Knowledge Economy." *Quarterly Journal of Economics* (forthcoming).

Autor, David H.; Katz, Lawrence F. and Kearney, Melissa S. "Rising Wage Inequality: The Role of Composition and Prices." National Bureau of Economic Research, Inc., NBER Working Papers: No. 11628, 2005a.

Autor, David H.; Katz, Lawrence F. and Kearney, Melissa S. "Trends in U.S. Wage Inequality: Reassessing the Revisionists." National

Bureau of Economic Research, Inc., NBER Working Papers: No. 11627, 2005b.

Autor, David H.; Levy, Frank and Murnane, Richard J. "The Skill Content of Recent Technological Change: An Empirical Exploration." *Quarterly Journal of Economics*, 2003, *118*(4), pp. 1279–333.

Card, David and DiNardo, John E. "Skill-Biased Technological Change and Rising Wage Inequality: Some Problems and Puzzles." *Journal of Labor Economics*, 2002, *20*(4), pp. 733–83.

Goos, Maarten and Manning, Alan. "Lousy and Lovely Jobs: The Rising Polarization of Work in Britain." London School of Economics, Center for Economic Performance Discussion Papers: No. DP0604, 2003.

Katz, Lawrence F. and Autor, David H. "Changes in the Wage Structure and Earnings Inequality," in Orley Ashenfelter and David Card, *Handbook of labor economics*. Vol. 3A. Amsterdam: Elsevier Science, North-Holland, 1999, pp. 1463–1555.

Lemieux, Thomas. "Increased Residual Wage Inequality: Composition Effects, Noisy Data, or Rising Demand for Skill?" *American Economic Review* (forthcoming).

Levy, Frank and Murnane, Richard J. *The new division of labor: How computers are creating the next job market*. New York: Princeton University Press and Russell Sage Foundation, 2004.

Meyers, Peter B. and Osborne, Anastasiya M. "Proposed Category System for 1960–2000 Census Occupations." U.S. Bureau of Labor Statistics, Working Paper Series: No. 383, 2005.

Piketty, Thomas and Saez, Emmanuel. "Income Inequality in the United States, 1913–1998." *Quarterly Journal of Economics*, 2003, *118*(1), pp. 1–39.

The Polarization of the U.S. Labor Market: Theory Appendix

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1 Motivation

Motivating ideas:

1. Workplace tasks may be usually subdivided into three broad groups:

   (a) Abstract problem-solving and managerial tasks. These tasks are not well structured and require non-routine cognitive skills.

   (b) Routine tasks. These may either be cognitive or physical tasks that they follow closely prescribed sets of rules and procedures and are executed in a well-controlled environment.

   (c) Manual tasks. These tasks (which ALM call non-routine manual) do not require abstract problem solving or managerial skills but are nevertheless difficult to automate because they require some flexibility in a less than fully predictable environment. Examples include: truck drivers, security guards, unskilled medical personnel, janitors and house-cleaners, high speed check-keyers, construction workers, many in-person servers.

2. Routine tasks are complementary to Abstract tasks and perhaps also to Manual tasks (though probably less so).

3. Routine tasks are readily substituted with computer capital. The continually falling price of computer capital drives this substitution.

4. The falling price of computer capital generates an incentive for workers engaged in Routine tasks to switch to other tasks.

5. It is more difficult for workers displaced from Routine tasks to shift 'up' to Abstract tasks than it is for them to shift 'down' to Manual tasks.

2 Model

2.1 Production

Aggregate output in this economy (priced at unity) is given by the Cobb-Douglas production function

$$Y = A^{\alpha} R^{\beta} M^{\gamma},$$

where A, R and M are Abstract, Routine and Manual tasks, with exponents $\alpha, \beta, \gamma \in (0, 1)$ respectively, and $\alpha + \beta + \gamma = 1$. Abstract and manual tasks can *only* be performed by workers who supply labor inputs, L_A and L_M. Routine tasks can be performed *either* by workers who supply L_R or by computer capital, K, measured in efficiency units, which is a perfect substitute for L_R.

2.2 Factor supplies

Computer capital is supplied perfectly elastically to Routine tasks at price ρ per efficiency unit. The secularly declining price of computer capital is the exogenous driving force in this model.

There is a large number of income-maximizing workers in this economy, each endowed with a vector of three skills, $S_i = (a_i, r_i, m_i)$, where lower-case letters denote an individual's skill endowment for the three production tasks.

Workers are of two types. A fraction $\theta \in (0,1)$ are High School (H) workers and the remaining $1-\theta$ are College (C) workers. For simplicity, all college workers are assumed identical. Each is endowed with one efficiency unit of Abstract skill: $S^C(a,r,m) = (1,0,0)$.[1] The labor supply of each college worker is $L^C = (1,0,0)$.

All high school workers are equally skilled in Manual tasks but differ in their ability in Routine tasks. We write the skill endowment of high school worker i as $S_i^H(a,r,m_i) = (0,\eta_i,1)$, where η is a continuous variable distributed on the unit interval with positive probability mass at all points $\eta \in (0,1)$. The labor supply of High School worker i is $L_i^H(a,r,m) = (0,\lambda_i\eta_i,(1-\lambda_i))$ where $\lambda_i \in [0,1]$. Each High School worker chooses λ_i to maximize earnings.

2.3 Equilibrium concept

Equilibrium in this model occurs when:

1. Productive efficiency is achieved—that is, the economy operates on the demand curve of the aggregate production function for each factor.

2. All factors are paid their marginal products.

3. The labor market clears; no worker wishes to reallocate labor input among tasks.

2.4 Productive efficiency

The wage of each factor is given by:

$$\begin{aligned} w_a &= \frac{\partial Y}{\partial A} = \alpha A^{\alpha-1} R^{\beta} M^{\gamma}, \\ w_r &= \frac{\partial Y}{\partial R} = \beta A^{\alpha} R^{\beta-1} M^{\gamma}, \\ w_m &= \frac{\partial Y}{\partial M} = \gamma A^{\alpha} R^{\beta} M^{\gamma-1}. \end{aligned}$$

[1] It would be a very minor matter to instead assume that $L_C(a,r,m) = (1,1,1)$ with $w_a > w_r, w_m$ for all relevant cases. This would ensure that college-workers always supply Abstract labor—and of course this tendency would only be reinforced by a falling price of computer capital.

2.5 Self-selection of workers to tasks

The supply of College labor to Abstract tasks is inelastic.

The supply of High School labor to Routine and Manual tasks is determined by self-selection. Each High School worker i chooses to supply one efficiency unit of labor to Manual tasks if $\eta_i < w_m/w_r$, and supplies η_i efficiency units of labor to Routine tasks otherwise. We can write the labor supply functions to Manual and Routine tasks as $L_M(w_m/w_r) = \theta \sum_i 1[\eta_i < w_m/w_r]$ and $L_R(w_m/w_r) = \theta \sum_i \eta_i \cdot 1[\eta_i \geq w_m/w_r]$, where $1[\cdot]$ is the indicator function. Observe that $L'_M(\cdot) \geq 0$ and $L'_R(\cdot) \leq 0$.

2.6 Equilibrium and comparative statics

Since computer capital is a perfect substitute for routine labor input, it is immediate that $w_r = \rho$ and hence a decline in ρ reduces w_r one for one.[2]

We are interested in the effect of a decline in ρ on:

1. The equilibrium quantity of Routine task input
2. The allocation of labor between Routine and Manual tasks
3. The wage paid to each task
4. The observed wage in each job type (which in may differ from the wage per efficiency unit in Routine tasks)

A decline in ρ raises demand for Routine tasks, since own-factor demand curves are downward sloping ($R'(\rho) < 0$). This demand can be supplied by either additional computer capital or Routine labor input. Due to worker self-selection, the additional demand will be supplied by computer capital.

To see this, let η^* equal the Manual skill level of the marginal worker, such that $\eta^* = w_m/w_r$. Rewriting η^* using the marginal productivity conditions:

$$\eta^* = \frac{w_m}{w_r} = \frac{\gamma R}{\beta L_M(\eta^*)}.$$

Differentiating with respect to $-\rho$ (a decline in the price of K) gives

$$-\frac{\partial \eta^*}{\partial \rho} = \frac{\gamma}{\beta}\left[\frac{\partial \eta^*}{\partial \rho} \cdot \frac{R L'_M(\eta^*)}{L_M(\eta^*)^2} - \frac{\partial R/\partial \rho}{L_M(\eta^*)}\right] = -\frac{\gamma L_M(\eta^*) \cdot \partial R/\partial \rho}{\beta L_M(\eta^*)^2 + \gamma R L'_M(\eta^*)} > 0. \tag{1}$$

A decline in ρ raises the relative Manual/Routine wage.

[2] Technically, ρ only binds w_r from above. In an earlier period, when computer capital was far more expensive, it's plausible that $w_r < \rho$. For the period under study, we assume that this constraint binds.

Summing up these wage implications:

$$
\begin{aligned}
-\frac{\partial w_r}{\partial_\rho} &= -1, \\
-\frac{\partial w_m}{\partial \rho} &= -\gamma A^\alpha \left[\underbrace{\beta L_M{}^{\gamma-1} R^{\beta-1} \frac{\partial R}{\partial \rho}}_{(-)} + \underbrace{(\gamma-1) R^\beta L_M (\eta^*)^{\gamma-2} L_M' (\eta^*) \frac{\partial \eta^*}{\partial \rho}}_{(+/0)} \right] \lesseqgtr 0, \\
-\frac{\partial w_a}{\partial \rho} &= -\alpha A^{\alpha-1} \left[\underbrace{\beta R^{\beta-1} \frac{\partial R}{\partial \rho}}_{(-)} + \underbrace{\gamma L_M (\eta^*)^{\gamma-1} L_M' (\eta^*) \frac{\partial \eta^*}{\partial \rho}}_{(-)} \right] > 0.
\end{aligned}
$$

A decline in the price of computer capital lowers the wage of Routine labor input, raises the wage of Abstract labor input through two channels of q-complementarity—increased use of Routine task input and increased labor supply to Manual task input—and has ambiguous implications for the wage of Manual task input (due to the countervailing effects of q-complementarity between Routine and Manual tasks and increased labor supply to Manual tasks).

Though, as established above, a decline in ρ yields a larger proportionate fall in the wage of Routine than Manual tasks ($-\partial (w_m/w_r)/\partial \rho > 0$), the *observed* log wage differential between workers in Routine and Manual jobs may *rise* despite the fall in w_r/w_m. The reason is that a decline in w_r leads to marginal workers with lower values of η to exit Routine jobs, inducing a *positive* compositional shift in the pool of workers in Routine occupations ($-\partial E[\eta|\eta > \eta^*]/\partial \rho > 0$).

Summarizing:

1. A decline in the price of computer capital causes an increase in demand for Routine task input.

2. This increase is entirely supplied by computer capital as the price decline causes a corresponding reduction in labor supply to Routine tasks and an increase in labor supply to Manual tasks.

3. The reduction in the price of computer capital has the following implications for wages levels measured in *efficiency units:*

$$-\frac{\partial w_r}{\partial_\rho} < 0, -\frac{\partial w_m}{\partial \rho} \lesseqgtr 0, -\frac{\partial w_r/w_m}{\partial \rho} < 0, -\frac{\partial w_a}{\partial \rho} > 0.$$

4. The reduction in the price of computer capital has the following implications for *observed* wage levels:

$$-\frac{\partial \hat{w}_r}{\partial_\rho} \lesseqgtr 0, -\frac{\partial \hat{w}_m}{\partial \rho} \lesseqgtr 0, -\frac{\partial w_r/w_m}{\partial \rho} \lesseqgtr 0, -\frac{\partial \hat{w}_a}{\partial \rho} > 0,$$

   where 'hats' over wage variables denote observed values that do not adjust for changes in occupational skill composition (e.g., $\partial E[\eta|\eta > \eta^*]/\partial \rho$).[3]

[3] For Manual and Abstract tasks, compositional shifts are nil by assumption.

Remark 1: The model does not pin down the ranking of wages in Abstract, Routine and Manual tasks; these levels depend on labor supplies and ρ. For workers who switch from Routine to Manual tasks as ρ falls, the manual wage must be higher than the Routine wage ($w_m > \eta_i w_r$). But for inframarginal Routine workers, it must be the case that the Routine wage is higher than the Manual wage. This observation has an important empirical implication: if there are *any* workers remaining in the Routine job, their *observed* wage (i.e., not accounting for composition) must be higher than the wage in the Manual job since there is no skill heterogeneity in Manual tasks. Hence, even in cases where $w_r < w_m$, it will be true that $\hat{w}_r > \hat{w}_m$ provided that $L_R(w_m/w_r) > 0$.

Remark 2: In an equilibrium in which H workers supply both Routine tasks and Manual tasks, K is a direct substitute for some H workers and a complement to others. In this setting, a decline in ρ causes a 'widening' of wage inequality by lowering w_m relative to w_a (moreover, w_m may fall in absolute terms). In an equilibrium with ρ sufficiently low such that no workers remain in Routine tasks ($w_m/w_r > 1$), further declines in ρ unambiguously benefit both High School and College workers and hence do not augment inequality. (Given the Cobb-Douglas form, both groups benefit equally, so this has no effect on w_a/w_m.)