Technical Change and Polarization of the Labor Market: Evidence for Brazil, Colombia and Mexico

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Technical Change and Polarization of the Labor Market: Evidence for Colombia, Brazil and Mexico*

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Abstract

We use occupations descriptions for Colombia, Brazil, and Mexico, to build computer-use related tasks intensities, and link then to series of cross sections of data of each country in order to empirically assess to what extent the observed empirical regularities, and the reallocation of workers across occupations that require different tasks intensities, are consistent with the SBTC or polarization models (TBTC). We find an increase of both wages and workers at the extremes of the wage or skills occupations distribution, the less routinaire/computerizabe, particularly pronounced in the period since personal computers began to be introduced in the region. This finding, along with other empirical regularities, provides support for some of the main implications of the polarization model in the cases of Colombia and Mexico.

JEL Codes: J3, D3, O3
Keywords: Relative Wages, Income Distribution, Technical Change

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1 Introduction

Several studies in the case of developed economies have assigned a role to technical change on the evolution of earnings inequality, either through skill-replacing (unskill-biased) or unskill-replacing (skill-biased) technologies.[1]. Today there is wide consensus that technical change was skill-biased during most of the twenty century in both developed and developing economies.[2] Increases in relative demand of skilled versus unskilled workers has been found for several Latin-American countries, including Brazil, Colombia and Mexico.[3]

The study of the evolution of income inequality in Colombia until the 1980s was mostly linked to the access to education and the evolution of its returns. Londoño (1990) for example, highlighted the huge returns to education in the urban Colombia of the 1960s, a decade with the highest income inequality reported in his study, and attributed the decrease in earnings inequality that took place until the 1980s to the expansion of access to education, the straightforward implication of a standard supply and demand framework, but unconditional to variations in the technologies employed in the production processes.[4] It was only until the late 1990s and 2000s that the role of technical change on earnings inequality, initially motivated by the study of the effect of the opening of the economy that took place in the early nineties, began to be widely considered by several authors which largely analyzed the evolution of earnings inequality following various approaches, but usually including the one proposed by Katz and Murphy (1992).[5] Although most of those studies found evidence of international trade affecting relative wages, they did not find strong evidence to claim that trade had been the major force affecting them, and most agreed in attributing a major role in the observed increase in the skill premium during the nineties to skill-biased technical change, SBTC.

Nonetheless, various empirical regularities of the Colombia labor market observed over the longer period of time that includes most of the 2000s, reveals several characteristics that are hard to be predicted by the standard model of SBTC, and that actually might be better matched by that introducing the task dimension into the production function, like Autor, Levy and Murnane (2003) (ALM hereafter) did, and that derived into the models of polarization (or Task Biased Technical Change, TBTC) in the labor market developed and used by Autor, Katz and Kearney (2006) (AKK hereafter), and Goos and Manning (2007), among others. First, SBTC predicts an increase in earnings inequality all through the income distribution, with workers increasing their earnings the more educated they were before the technical change took place. Nonetheless, and just as it has occurred in the US, in the Colombian labor market we observe that earnings of workers in the middle of the income distribution have decreased more than those of workers at the lower end of it. Secondly, although the increase in earnings inequality observed among skilled workers matches the SBTC model, the evolution towards a stable or even lower income inequality, among the unskilled workers, is at odds with it.

In this article, we use household survey data for Colombia and ,Brazil and census data for Mexico, to assess whether the TBTC (or Polarization) model could contribute to explain key stylized facts of the labor market in these countries. We present evidence of aggressive implementation of computer technology in Latin American countries, and important reductions in the cost of computer capital in Colombia since the late 1990s. In particular, we test whether there is a positive covariance between increases in wages at the extremes of the wage distribution, and increases in employment at the extremes of the distribution of occupations' average skills or wages. We begin presenting evidence that the tasks more likely to affect workers' earnings

[1] Acemoglu (2002, 2007) review the broad evidence contained in the literature, and argue that skill-replacing technologies were endogenously developed in nineteen century Britain, while unskilled-replacing technologies were as well endogenously developed through most of the twenty century, since in each of these two periods, it was more profitable for potential innovator firms to focus on the unskilled and skilled markets respectively.

[2] See the literature review made by Acemoglu (2002), which also includes evidence for developing economies which experienced large increases in their premiums to skills despite both their increases in skills relative supplies, and despite of being implementing processes of trade opennes.

[3] See Sanchez-Paramo and Schady (2003) for evidence of important increases in relative demand of skilled workers for Argentina, Chile, Colombia and Mexico. These authors find a much moderate variation in relative demand for Brazil.

[4] According to Londoño (1990) the wage ratio between workers with complete high school and the non educated was 5.3 in the 1930s and 9.1 in the 1960s, while between workers with complete university and the non educated it was 10.6 in the 1930s and 28.8 in the 1960s, both figures much larger than what they have been since the 1980s.

[5] See for example Núñez and Sánchez (1998a), Cárdenas and Bernal (1999), Robbins (2001), Attanasio, Goldberg, and Pavcnik (2003), Arango, Posada and Uribe (2004) and Santamaria (2004).

in Colombia though the intensive adoption of computer technologies, are performed in those occupations with median wages or skills, which are more intensive in routinary computerizable activities. Then we show evidence that TBTC might have taken place in Colombia and Mexico, but not in Brazil. Polarization in Colombia would have lead to an increase in the supply of unskilled labor to manual tasks relative to routine tasks, and to an increase in the supply of skilled labor to abstract tasks relative to routine tasks. Reductions in the cost of computer capital in the case of Colombia would have led to an increase in the wages of unskilled workers in manual tasks relative to those in routine tasks, and similarly, to an increase in the relative wages of the skilled workers performing abstract tasks relative to those performing routine tasks, which in turn, would have contributed to a reduction of earnings inequality within unskilled workers, and an increase in earnings inequality between skilled workers. These effects nonetheless, were not enough to offset the severe consequences of the economic crisis experienced by the country in the late nineties, which particularly hit the very poorest.

We begin presenting some background that presents a sketch of the SBTC and TBTC models, and then we present the main empirical regularities of the Colombian labor market since 1984 until 2009 and analyze to what extent they could be matched by either model. Then we briefly assess the role of SBTC in Colombia, before presenting our detailed assessment of the polarization model for Colombia, Brazil and Mexico. Since there are empirical regularities that neither the SBTC nor the standard polarization model seem to match, we present a brief discussion to motivate a modified polarization model that seeks to capture some of those unexplained empirical regularities. We finish with the conclusions.

2 Background

There is a wide variety of hypotheses seeking to explain the evolution of earnings inequality among workers, and most of them, have been focused on the evolution of relative wages between skilled and unskilled workers. More recently, it has been proposed a new approach that places its emphasis on the substitutabilities between specific types of task performed by workers of different skills and the technologies involved in the production process. A large part of the literature focused on explaining the evolution of relative earnings between skilled and unskilled workers propose hypotheses based on different forms of Skill Biased Technical Change, SBTC, but their framework is limited to explain earnings differences between just those two groups, skilled and unskilled, while the literature focused on a production function that uses as inputs tasks performed by people of different skills allows to establish earnings differences among a broader group of workers, thus letting explain additional regularities than those explain by the SBTC models. Before assessing what data can tell us about relative wages and demand of skilled workers once we introduce the task dimension, let us sketch the theoretical SBTC model, and the TBTC model developed by AKK, in order to understand what changes should we expect to happen in the labor market due to technical change and computerization. In this section we sketch both approaches and highlight the main implications of each of them.

2.1 Earnings Inequality and the Skill Premium

Literature on skill premium is widely reviewed by Acemoglu (2002), so here we just provide the basic elements of it in order to express our argument later. The standard model in this case considers two types of workers, skilled, H, and unskilled, L. who are inputs in the following CES production function for the aggregate economy: $Y_t = \left[\alpha_t \left(A_{Ht}H_t + B_{Ht}\right)^{\rho} + \left(1-\alpha_t\right)\left(A_{Lt}L_t + B_{Lt}\right)^{\rho}\right]^{1/\rho}$, where A_{Ht} and A_{Lt} represent skilled and unskilled labor augmenting technological change, B_{Ht} and B_{Lt} are skilled-labor-replacing and unskill-replacing technologies respectively, and $\sigma \equiv \frac{1}{1-\rho}$ is the elasticity of substitution between skilled and unskilled workers.[6] Standard optimization assumptions imply the following relationship between relative wages and relative supplies (simplified omitting the terms on the Bs) : $Ln\left(\frac{w_{Ht}}{w_{Lt}}\right) = Ln\left(\frac{\alpha_t}{1-\alpha_t}\right) + \frac{\sigma-1}{\sigma}Ln\left(\frac{A_{Ht}}{A_{Lt}}\right) - \frac{1}{\sigma}Ln\left(\frac{H_t}{L_t}\right)$. In this model, an increase in α_t implies SBTC, and so does an increase in A_{Ht}/A_{Lt} when $\sigma > 1$,

[6] Note that this model implicitly assumes perfect substitution across age groups with the same level of education. For a model that relaxes this assumption see Card and Lemieux (2001).

that is, when skilled and unskilled workers are gross substitutes, so that an increase in A_{Ht}/A_{Lt} will be unskill-replacing.[7]

Under what Acemoglu (2002) calls the *steady-demand hypothesis*, the structure of demand for skills has evolved according to $Ln\left(\frac{A_{Ht}}{A_{Lt}}\right) = \gamma_0 + \gamma_1 t$, where t is time, what supposes that SBTC has progressed constantly, and implies that, once we simplify omitting the term that is a function of α_t, the previous relationship becomes

$$Ln\left(\frac{w_{Ht}}{w_{Lt}}\right) = \frac{\sigma - 1}{\sigma}\gamma_0 + \frac{\sigma - 1}{\sigma}\gamma_1 t - \frac{1}{\sigma}Ln\left(\frac{H_t}{L_t}\right) \tag{1}$$

which is the equation commonly estimated to explain the relation between relative wages and quantities. Whenever it is found a positive covariation between these variables during a determined period of time, it is taken as evidence of SBTC.

A related model by Krusell et al. (2000), use a set up that allows capital being a complement of skill labor and a substitute of unskilled labor. Using their model they can explaining the empirical result obtained for the United States under the steady-demand hypothesis, since the new terms they include in (1) are nearly perfectly related to the time trend used by Katz and Murphy (1992) to simulate labor demand, what Krussell et al. to conclude that Katz and Murphy's time trend is a good proxy for capital-skill complementarity in the analyzed period.

Acemoglu (1998), Kiley (1999), and Acemoglu (2007) endogenize the skill bias in technology by making it a function of profit incentives in a similar way as some models of endogenous economic growth do. Although those models present an illuminating story of how skill based technology evolves, which can even be consistent with the timing of innovations, they still consider only two labor inputs, and thus, end up explaining similar empirical regularities as the steady-demand model does.

Trying to explain one of the empirical caveats SBTC models present, namely their not being able to predict the reduction of earnings among the unskilled workers, Acemoglu (1999) presents a model that can have either a pooling or a separating equilibrium. When the economy moves from the pooling to the separating equilibrium, the unskilled move from middle wage occupations to low wage occupations, and the skilled from middle to high wage occupations. Neither this model or that by Krussell et al. (2000), is able to explain the positive covariation between earnings and quantities at the lower end of the income distribution reported by Autor, Katz and Kearney (2006, 2008), since in their model skill premium increases both because earnings of the skilled increase, and those of the unskilled decrease, due to technological change. Although in AKK the earnings of all unskilled workers might as well fall, those at the lower end of the distribution might actually increase. Lack of predicting an increase in the share of workers performing unskilled tasks is another criticism to the SBTC model. Actually, a quality of the polarization model we will describe next, is its possibility to predict the positive covariation between wages and quantities at the lower end of the earnings distribution.

With the exception of models like that by Card and Lemieux (2001), which considers imperfect substitutability among workers of different ages and the same education, models based on (1) can only explain earnings differences between two groups, what prevent them from being able to explain more complex empirical regularities like a potential polarization of earnings, under which both groups of workers, at the lower and upper ends of the distribution, increase their earnings relative to those at the middle of it. That is one of the goals seek to explain by the models we analyze next.

2.2 Earnings Inequality and Polarization in the Labor Market

In this section we briefly present the key characteristics and implications of the theoretical model developed by AKK, which incorporates the key implications of that developed by ALM, and formally models the concept of polarization in the labor market, introduced by Goos and Manning (2007). The model moves beyond the

[7] See for example Freeman (1976), Katz and Murphy (1992), Autor, Katz and Krueger (1998), Johnson and Stafford (1998), Murphy, Riddell and Romer (1998), Autor, Katz and Kearney (2008), and the surveys by Gordon and Dew-Becker (2008) and Acemoglu (2002), on which this section builds heavely, and the references quoted therein.

standard two types of skills approach, towards what Acemoglu (2002) argued it was need, multidimensional skills. In words of Gordon and Dew-Becker (2008), "three- or five-dimensional breakdown of skills".

In the model, there are three tasks. First, the routine task, like clerical work and repetitive production tasks, can be performed by either computer capital or human labor, which are assumed to be perfect substitutes to perform routine tasks. The abstract task which involves analysis, direction and coordination and complex activities. Finally, the manual task as those performed by barbers, truck drivers, etc. Both abstract and manual tasks are non-routinary. The introduction of computers affects the demand of labor supplied to routinary tasks, and the decline in the cost of computing adoption further affects the assignment of labor across tasks.[8]

2.2.1 Firms

Aggregate production is given by the Cobb-Douglas production function

$$Y = A^{\alpha} R^{\beta} M^{(1-\alpha-\beta)} \tag{2}$$

where A, R, and M are abstract, routine and manual tasks, and α, $\beta \in (0,1)$. Abstract and Manual tasks can only be performed by workers who supply labor inputs L_A and L_M, while Routine tasks can be performed by workers supplying L_R or by computer capital, X, the exogenous driving force in this model, which is supplied perfectly elastically.

The firm maximizes profits subject to (2) and the fact that labor supplied to perform Routine tasks, and capital, are perfect substitutes. That is, $R = L_R + X$, where L_R is the amount of labor demanded by the firm to perform Routine tasks. Perfect substitution of these inputs imply that their prices are equal, that is, $W_R = P$, where W_R and P are the prices of labor demanded for Routinary tasks and computer capital respectively.

2.2.2 Workers

There are N workers endowed with three skills, $S = \{a, r, m\}$, each denoting the individual's endowment to perform abstract, routine and manual tasks respectively. Individuals can either be High School workers, H, or College workers, C, and there are a fraction θ and $1-\theta$ of workers in each of these groups respectively. College workers are assumed to be endowed with one efficiency unit of abstract skill, and each supplies one unit of labor. High School workers can either supply one efficiency unit of manual task or r efficiency units of routine task, where $r \in (0,1)$ and it is assumed that r has a known probability density function, $r\tilde{}f(r)$. Each High School worker chooses occupation to maximize earnings. In particular, they would choose the routinary task if $W_R \cdot r > W_M \cdot M = W_M$, that is, if $r > W_M/W_R = W_M/P = \eta^*$. Aggregate efficiency units supplied to the routine task are then

$$L_R(\eta^*) = \theta N \cdot [1 - F(\eta^*)] \cdot E(r|r > \eta^*) \tag{3}$$

and the aggregate efficiency units supplied to the manual task are

$$L_M(\eta^*) = \theta N \cdot F(\eta^*) \cdot E(M|r > \eta^*) = \theta N \cdot F(\eta^*) \tag{4}$$

On the other hand, labor supply to the abstract task becomes

$$L_A(\eta) = (1-\theta) N \tag{5}$$

[8] The specific role of computers on wages has also been studied by Krueger (1993), DiNardo and Pischke (1997), Autor, Levy and Murnane (2000), Brynjolfsson and Hitt (2002), Spitz (2004), Borghans and ter Weel (2007), and Nresnahan, Spitz (2008) among others.

2.3 Implications of the SBTC and TBTC Models

Maybe the key difference between the SBTC and the TBTC models is the later disaggregates labor in more than just the two types considered by the SBTC model, and considers intuitive ways of substitutabilities and complementarities between them and computer capital.

Some of the key implications of AKK model are that a decline in the price of computer capital, P, causes an increase in the demand for computer capital, X, an increase in the demand for routine task input, R, and a reduction in labor supplied to the routine task, L_R. This in turn, implies that the increase in R is entirely supplied by computer capital and that labor supply to the manual task, L_M, increases. In addition, they conclude that as P decreases, the wage level of the abstract task measured in efficiency units, W_A, increases, and so does the relative wage between manual and routine tasks, W_M/W_R. Note that the model allows the possibility of both, an average reduction in earning of the unskilled workers, and an increase in earnings of the unskilled at the lower end of the distribution relative to those of unskilled workers in the middle of the distribution, what could help to explain the reduction in earnings at the lower end referred to as a puzzle by Acemoglu (2002), and previously addressed by Galor and Moav (2000), Acemoglu (1999), and Caselli (1999), as it simultaneously could explain polarization in the labor market.

Very importantly, note that, unlike the SBTC models, this model can be consistent with an increase in both the amount of labor supplied to the manual tasks, and an increase in the wage received by workers performing manual tasks, that is, with a positive covariation between earnings and quantities at the lower end of the income distribution. It would as well be consistent with a reduction in inequality among workers at the bottom 50 percent of the distribution as inequality among worker at the upper 50 percent increases. These implications go beyond the scope of most SBTC models. Furthermore, a slight variation of AKK's model, using the same intuition, would be consistent with a simultaneous increase in both earnings and workers at the upper end of the earnings distribution, as standard SBTC predict.

Goos, Manning and Salomons (2009b) claim that the SBTC model fails to predict correctly the changes on employment between qualified and non-Qualified workers, and points to the evidence provided by the studies by AKK for the United States, and Goos and Manning (2007) for the United Kingdom, which have shown that employment has been growing for both, skilled and unskilled occupations, while medium qualification jobs have lost participation in the labor market, a result labeled “Job Polarization” by Goos and Manning (2007) and "Task-Biased Technological Change" by Goos, Manning and Salomons (2009a).

Goos, Manning and Salomons (2009a) propose at least three reasons that could explain the job polarization hypothesis. First, routinary jobs substitution through the technical change process suggested by ALM. Second, the phenomenon of general globalization and offshoring, that have caused important changes on labor structure of richest countries and even on some of medium income countries like Colombia. Third, they argue that the proportion of rich persons has grown both in the United States and the United Kingdom, which has caused a significant increase in the demand for unskilled work that carries out service activities with high component on manual tasks.

Their empirical assessment of the case of the United Kingdom lead them to conclude that the UK has experienced a job polarization process since the early nineties, and that its main explanation is the hypothesis based on the adoption of new technologies that complemented the jobs that required greater qualification and substituted jobs intensive in intermediate skills.

In the next section we will describe the main empirical regularities of the Colombian labor market, and suggest to what extent the SBTC or polarization models could be able to explain them.

3 Dynamics of Colombian Labor Market Over the Past 25 Years

To describe the key features of Colombian labor market over the last two decades we use Colombian household surveys provided by the Administrative Department of National Statistics, DANE, from 1984 to 2009. Even though DANE's household surveys currently cover more than 20 of the main Colombian cities, it used to cover only seven cities during the 1980s and part of the 1990s, and that is why we focus our analysis on these cities throughout the paper.[9] In addition, we only study labor market dynamics of males to avoid getting involved into considerations different to the focus of our analysis, like the effects of technical change on gender wage inequality. Unless specifically stated, the analysis considers males 19 and older.[10] Finally, we will additionally present descriptive statistics and results of the described population restricted to wage earners or skilled (regardless of whether they are wage earners) workers, a subset of workers which we will refer to as modern employment, and that each year represents between 70 and 75 percent of our sample in the analyzed period.[11]

3.1 Changes in Key Employment Indicators

Figure 6 allows us to analyze the evolution of key labor market indicators, namely the unemployment, participation and occupation rates, between 1984 and 2009, for the seven main Colombian cities. The graphs at the top of the figure illustrate the evolution of the unemployment rate for all males 12 and older (left), and for those males by skill (right), defining skilled males as those with 12 or more years of education, that is, with at least one completed year of college. The vertical lines indicate the dates at which the unemployment rate reached its minimum (third quarter of 1994) and maximum (third quarter of 1999) levels, which were characterized by periods of high and negative growth rates respectively (5.2% and -4.2% annual real GDP growth rates respectively). The high unemployment levels reached during the economic crisis of late 1990s were unprecedented in the analyzed period. It affected both skilled and unskilled males. As graphs at the bottom of the figure show, skilled males kept high their participation rates during the period, and even during the economic crisis, so that changes in their unemployment rates were fully explained by reductions in their occupation rate rather than by new males coming into the active labor force. Unskilled males on their part, reduced their participation rate somewhat constantly since the mid 1990s, which contributed to attenuate their unemployment rates to the extent that they became comparable to those of the skilled workers in the second half of the 2000s.

3.2 Changes in Wage Inequality

To analyze the evolution of wage inequality we focus on males 19 and older working 20 hours or more a week. As it is shown in the graphs on the left in Figure 7, for both the whole sample of workers and that of workers in the modern sector (wage earners or skilled), wage inequality, measured by the standard deviation of log hourly earnings, registered a slight increase between 1984 and the third quarter of 1996, when it began to continuously increase much more markedly until 2001-2002, when it stayed at its highest level before beginning a permanent decrease to levels still above those of the early 1980s. The picture depicted by that graph conceals the different patterns followed by males according to their education levels. As it is shown in the graphs on the right in the figure, although the overall evolution of wage inequality among the unskilled males is similar to that followed by all males, that of skilled males registers a permanent increase since the early 1990s rather than since 1996. The increase in wage inequality of skilled males took place mostly between 1992 and 1994, matching a period in which the economy was becoming more opened to international trade, and then between 1997 and 2002, when computer technologies were being massively implemented. In addition, inequality among the unskilled returned to its early 1980s level, when we consider the whole sample of workers, and even to lower levels when we only consider worker in the modern sector; while inequality among the skilled remained above its late 1990s levels for both samples of workers.

The role of international trade has been empirically addressed for Colombia by Attanasio, Goldberg, and Pavcnik (2003), Cárdenas and Bernal (1999), Núñez and Sánchez (1998a), Robbins (2001), and Santamaria (2004). Although all studies but the one by Santamaria (2004) find that trade increased inequality in Colombia, all suggest that the magnitude of its impact was moderate, as most of the literature reviewed by

[9] The cities included are Bogotá, Medellín, Cali, Barranquilla, Bucaramanga, Manizales and Pasto. Dane's household surveys were subject to changes that do not allow us to obtain comparable figures for the second semester of 2006, so we do not consider them.

[10] We do not include unpaid family workers. Earnings are corrected for top-coding (wages were top-coded in $1'000,000 until June 1993) using cite: Nuñez and Jimenez methodology.

[11] A detailed analysis of the evolution of modern employment in Colombia is made by López (2010)

Acemoglu (2003) find it as well for the United States. Both of those findings seem consistent with international evidence for developed and developing countries quoted by Acemoglu (2003) and Robbins (2003).[12]

To better understand the dynamics of wage inequality by skill, Figure 8 shows kernel densities of log hourly wages for groups of years and by skill for the sample of workers in modern employment. As it becomes clear from the figure, during the analyzed period the unskilled males's income distribution shifted slightly to the right and became more equal. In addition, the wage distribution of skilled males became flatter and with a larger share of people under eight, implying that a share of skilled males from the middle of the distribution moved to the left. This regularity is very important since it shows that as the total set of workers with low earnings, both skilled and unskilled, became more numerous, those among the unskilled increased their earning, thus evidencing a the positive covariation between quantities and prices usually linked to demand forces.

Figure 9 shows the evolution of male's hourly wages for five income percentile groups: 90, 75, 50, 25 and 10, and for all males (left), unskilled males (center) and skilled males (right). On the whole, males' wages slightly decreased between 1984 and 1992, when they began to increase, until 1994 for the unskilled, and until 1998 for the skilled. Between 1998 and 2005, and further until 2009, wages of the unskilled males became more equally distributed since earnings of worker at the 90 and 75 percentiles increased relatively less than earnings of workers at the bottom percentiles. Since 1997-1998 unskilled males began a permanent process of deterioration of their wages until reaching values about 30% below their 1984 levels due to the late 1990s economic crisis that particularly affected that group's earnings. Among the skilled workers the period or largest increase in inequality was right after the economic crisis, but still after earnings bottomed, they remained more unequally distributed that they were in 1984 or the early 1990s, when computer technology was just beginning to be introduced in the country. That history is clear when we analyze Figure 10, which shows that between the early 1990s and the second half of the 2000s, the reduction in earnings inequality among the unskilled was mostly explained by a reduction in the 90-50 ratio, while the increase in earnings inequality among the skilled was mostly explained by the increase in the 90-50 ratio.

In short, among the unskilled males, earnings decreased substantially during most of the analyzed period, and when inequality decreased it was because wages of the better off in the group decreased, while the increases in inequality was due to reductions in wages of the worse off. On the other hand, among the skilled males, when inequality decreased it was because wages at the median of the group decreased, while the increases in inequality was mostly due to increases in wages of the better off, those at percentile 90 relative to percentile 50, consistent with the process of flattening of their income distribution depicted in Figure 8. As it is shown in Figure 11, the result of these dynamics led to a pattern of relative wages between skilled and unskilled males similar to the one of the standard deviation of log hourly earnings presented in Figure 7. That is, when inequality increased, it did both within and between skills, a so it did when it decreased. In addition, its is important to highlight that while the premium between workers with complete higher education or more and those unskilled remains in the second half of the 2000s much higher that it was in the early 1990s, the premium between workers with incomplete higher education and the unskilled decreased, again consistent with what was observed in the income distributions of Figure 8 and with the findings by Posso (2008) that show that earnings of workers with higher education in the 10 and 50 percentiles, those more likely to have incomplete higher education, fell constantly since 1999.

In the analysis that follows we will focus on three different periods: from 1984 to 1990, from 1990 to 2005 and from 1990 to 2009. The first period is characterized by important increases in the education level of the labor force, the second one includes the economic crisis of late 1990s, and it is the one expected to have accounted for the main increases in technology adoption, as it will be shown below, along of course with the third period. The period ending in 2009 though is less likely to be contaminated by the economic crisis of the late 1990s, since by 2005 the economy was just bottoming up, and it was not until 2006 and 2007 that it was fully recovered.

[12] Acemoglu (2003) quotes references that provide evidence that the skilled-unskilled wage gap increased in Mexico, Brazil, Venezuela, Argentina and Bolivia, and remained approximately constant in Chile and Costa Rica, despite substantial global trade opening during the analyzed period. Robbins (2003) reviews evidence of increases in the relative demand for skills in Argentina, Chile, Colombia, Costa Rica, Mexico, Peru, the Philippines, Taiwan and Uruguay, as these economies were opening to trade.

Figure 12 shows the changes in average wages by wage percentile within education levels for three different periods: 1985-1995, 1995-2005, and 1985-2005, and for the whole sample of workers for different periods of time. The figure shows that during the first period the wages of the less educated population equalized, since those of males with primary or incomplete secondary increased relative to those of males with complete secondary. On the other hand, during the same period the increases in the wage gap between skilled and unskilled workers was mostly due to the high increase in earnings of males in the highest percentile of the distribution.

During the second period, the wage gap between males with complete secondary with respect to those with primary or incomplete secondary decreased for the lowest 40 percent of the wage distribution, but increased for the rest. On the other hand, only males with higher education at or above the 70 percentile increased their wage gap with respect to the unskilled males. This empirical regularity suggest a movement of males with complete secondary education, who are the most likely to perform routinary tasks (those of intermediate level of complexity and that often can be automated/computerized), from these tasks to other more manual. A similar history can emerge from the figures of the skilled males: the sharper decrease in the income of those below their median wage suggest they might as well have moved from more to less complex tasks (from analytic to routinary tasks).

Finally, the graph in the lower right of Figure 12 shows the results for the whole set of workers. The graph shows a pattern similar to the one reported for the United States by ALM and AKK, with two exceptions: first, in the Colombian case, after the economic crisis of the late 1990s there was a pronounced reduction in the average wages of all groups of workers, as it became clear from Figure 9, that particularly impoverished the unskilled, and an important share of the skilled workers, explaining the dramatic fall in wages of the very poorest, as it is shown in the lowest percentiles of the wage distribution in Figure 12. Secondly, between 1995 and 2005 or 2009, the period in which computers began to be adopted by firms, the curve has a much more pronounced U-shaped that in the case of the United States, but only for the upper 75% of the income distribution, since the lowest 25% was the one most severely hit by the crisis, and even by then had not recovered.

It is still important to highlight that the SBTC models would not predict the U-shaped pattern of the figure but rather a continuous pattern of increase in earnings inequality along the income distribution. Nonetheless, previous work by Núñez and Sánchez (1998a, b), Arango, Posada and Uribe (2004), Cárdenas and Bernal (1999), Attanasio, Goldberg and Pavcnik (2003), and Santamaría (2004), has attributed the increase in the wages of skilled relative to unskilled workers that took place in the 1990s, or the increase in the cost of skilled relative to that of unskilled labor reported by Cárdenas and Bernal (2003), to the huge increase in the demand for skilled relative to unskilled labor, and suggest a roll for Skill Biased Technological Change, SBTC, and the liberalization of trade in the early 1990s.

3.3 Changes in Labor Supply by Skill

Figure 13 shows the permanent trend of increase in the number of college educated workers in our sample, and for the subset of wage earners or skilled workers. By 2005, college educated workers were three times as many as they were in 1984, while high school workers fluctuated between 1.75 and 2.0, and workers with primary education were nearly as many as those in 1984.

4 Assessing the Role of SBTC in Colombia

As we mentioned before, the relation between the skill premium and the relative supply of skills in Colombia has been widely analyzed. In this section we reassess the previous evidence using household surveys from 1984 to 2009. Although we expect that our results in this section are not going to show major differences to those of previous studies, we do want to simultaneously show the results of this exercise and the one we will perform below to assess the polarization model using the same dataset, as a way to validate our data both when compared to the one used in previous studies, and here between the two models.

Note first that in the early 2000s, the skill premium of Colombia, Mexico and Brazil were among the highest when compared with the broad set of countries included in Figure 14. We estimate (1) for the Colombian case.[13] Panel A of Table 1 shows our estimates, which reveals that when we use the equivalent skill premium, and the relative equivalent employment and unemployment rates, the implied elasticity of substitution for Colombia is 1.47. When we use the equivalent work hours instead, the elasticity of substitution becomes 1.16. Panel B of Table 1 shows the results obtained when we additionally control for the minimum wage. In that case, the elasticity is equal to 1.31, with equivalent jobs, and to 1.27 with equivalent work hours. In all cases $\sigma > 1$, implying that skilled and unskilled workers in Colombia are gross substitutes.

Our estimated elasticity of substitution for equivalent employment when not controlling for the minimum wage, is similar to the ones previously found by Núñez and Sánchez (1998a) and Santamaría (2004) which were equal to 1.37 and 1.48 respectively.[14] Estimates of this elasticity for Chile, obtained by Gallego (2006), range between 1.39 and 1.67, while Katz and Murphy (1992) and Acemoglu (2002) estimate it in 1.41 for The United States. In short, our dataset allow us to get estimates that are consistent with those of previous work.[15]

To try to understand whether computer adoption in Colombia can contribute to explain the magnitude of the changes in the skill composition of the Colombian labor force and the skill premium and earnings inequality in general previously documented, we proceed in the next section to assess whether the polarization model can provide a consistent story to explain those changes. To do it, in the following section we will begin explaining the way we empirically introduce the task dimension, a dimension that incorporates a direct relationship between workers' activities and computer use, and a dimension on which utility maximizer workers, endogenously sort.

5 Assessing the Role of the TBTC Model in Colombia

As we mentioned previously, we want to quantify changes in relative wages and supply of skills in the labor market, to computer use. To do it, we adopt the task dimensions proposed by ALM and previously described. According to the theoretical model outlined above, there are key implications of that framework that can be used to test for the effects of computer use on wages and supply of workers with different skills. In this section we begin defining the tasks in our empirical data that we expect could perform the roles implicit in the polarization model previously sketched. Then we show how has been the adoption of computers and internet in Colombia, and how computer use is related to the different occupations when we order them by skill or earnings. Finally, we show how workers have moved across occupations of different skill intensities, and assess to what extent the results consistent to the polarization model.

5.1 Linking Computer Use and Workers Skills

Since the work by ALM, other authors like Goos and Manning (2007), Goos, Manning and Salamons (2009), Spitz-Oener (2006), AKK, Dustmann, Ludsteck and Schönberg (2007), and Autor, Katz and Kearney (2008), have adopted models in which workers with different skills choose to supply their work to different tasks in which their input might be complementary, substitute, or unrelated to computers, in order to explain changes in the relative demand and wages of skilled workers.[16] Here we follow this approach and use Colombian household survey data to classify Colombian workers' occupations in the task dimension, according to the conceptual grounds used by ALM.

In particular, we use the National Classification of Occupations of the Department of National Statistics of Colombia (DANE by its acronym in Spanish), which adopted the CNO70 international classification of occupations, to classify occupations according to the same five tasks categories ALM did: (i) Non-Routine

[13] We use a Vector Error Correction Model (VEC), because the series presented a cointegration process. We estimated a system where skill premium and relative supply were endogenous variables.

[14] Núñez and Sánchez (1998a) and Santamaría (2004) do not control for the unemployment rate though.

[15] Our results also reveals, by means of estimating the relative demands (not show here), that contrary to the tendencies registered by relative labor demand that suggested that it would keep constantly growing, it actually decreases in the late 2000s.

[16] Some controversy about the polarization and other approaches can be found in Hilton (2008)

Cognitive/Analytic (MATH), (ii) Non-Routine Cognitive/Interactive (DCP), (iii) Routine Cognitive (STS), (iv) Routine Manual (Finger), and (v) Non-Routine Manual (EHF).[17]

First notice that the five tasks are split into two groups: routine and non-routine tasks. Routine tasks are meant to be those that can be computerized and non-routine tasks those that cannot. We follow the conventions used by ALM, according to which among the routine tasks there are some manual, that require "finger dexterity" (Finger), in which they include tasks like "monitoring the temperature of a steel finishing line or moving a windshield into place on an assembly line", and others that are cognitive, that require "setting limits, tolerances or standards" (STS), like call centers or automatic teller machines. On the other hand, among the non-routine tasks we can find some that are analytic, that require "from arithmetic to advanced mathematics" (MATH), like those performed by researchers, engineers, etc., others that are interactive, which require "direction, control and planning" (DCP), like those performed by managers, lawyers, etc.; and finally, others that are manual, which require "eye-hand-foot" (EHF) coordination, like the one performed by truck drivers.

The previous classification of occupations according to their intensities in the five different tasks described above, allows us to assess the changes that intensities of each task across occupations experience with time, since workers' movements across occupations weight differently tasks intensities, leading to changes in task intensities in the aggregate. This dimension of variation in tasks intensities is what ALM call the 'extensive' margin, that is, the one that is obtained maintaining the task content within occupations at its 1984 level.[18] Since the international classification of occupations adopted in Colombia was not updated during the analyzed period, we cannot measure variations in tasks intensities along the 'intensive' margin, meaning, the one determined by changes within occupations.[19]

5.2 Computer Related Technology Adoption in Colombia

As Figure 15 shows, personal computers began to be introduced in Colombia in the early 1990s, while the internet began to be introduced in the mid 1990s. On the other hand, Figure 16 shows that computer and internet adoption in Colombia has taken place at a lower pace than most South American countries. Although Colombia registered similar use of computers and internet to Brazil until 1999,from 2000 on Brazil began to move ahead, and to increase the gap with respect to Colombia.

It is worth noticing that the 90/50 percentiles wage gap among the skilled workers shown in Figure 10 picked up in 1992, and the 50/10 percentiles wage gap increased beginning in 1995. In addition, the 50/10 wage gap among the unskilled began to increase as well by 1992, while the 90/50 wage gap stagnated between 1993 and 1998, slightly increased until 2000, and then dramatically and continuously fell. This pattern could be consistent with AKK theoretical model previously outlined if the decrease in the price of computer capital shown in Figure 15 increased computerization, reducing relative wages of routine (middle income) versus abstract (higher income) skilled workers. It would also explain the fluctuations in percentiles wage gaps of the unskilled workers, since there actually was a decrease in the 90-50 percentile differential, if there was a decrease in the relative wages of routine (higher income) versus manual (middle income) unskilled workers.

In order to assess more accurately the relationship between computerization and relative wages and supply of skilled versus unskilled workers, we proceed now to assess the empirical link observed in our data between computer use and workers skill through the introduction of the task dimension.

5.3 Tasks Intensities and Computer Use

We begin by showing how computer use is characterized in our data, and whether our tasks dimensions actually relate consistently with computer use at the industry level.

[17] Other applications of the tasks dimension can be found in Peri and Sparber (2008, 2009) who have shown that the small effect on wages of native Americans has been the result of a process of specialization of them in different tasks than those in which the immigrants specialize. Medina and Posso (2009) use the tasks South American Immigrants perform in the United States to determine their quality of jobs by country of origin, and related them to their individual skills.

[18] See also Levy and Murnane (1996)

[19] See more details about the occupations classification in Appendix A.

Figures 17 and 18 show that the higher the average initial wage by occupation, the higher the share of workers using personal computers and internet respectively, in their occupations. Here by initial conditions we mean their values in 1984-5. Actually, the share of workers in occupations in which wages are at or below the 40 average wage percentile is negligible. The figure also shows that high frequencies of computer use is basically exclusive of occupations with a high share of skilled workers, or in general, for occupations at or above the 50 wage or skill percentiles. This empirical pattern seems consistent with only occupations intensive in skilled labor, and the most intensive in the most skilled among the unskilled workers, having access to personal computers at work.

Now we proceed to implement a test used by ALM, that seeks to assess whether the reported declines in the price of computer capital increased computers use relatively more in industries intensive in routine tasks, in order to substitute the more expensive routine labor input. Computer capital would have as well increased in industries intensive in non-routine cognitive tasks, in which computers complement skills. Finally, in industries not intensive in non-routine manual tasks, there should have been a much smaller increase in computer use, since these tasks cannot be substituted by computer use. The test consists of estimating the following model

$$\Delta C_{k,1984-2001} = \alpha + \beta T_{k,1984} \tag{6}$$

where $\Delta C_{k,1984-2001}$ is the change between 1984 and 2001 in the share of workers in industry k using a computer at work, and $T_{k,1984}$ is a measure of industry task intensity in 1984.[20] As it is shown in figure 15, by 1984 computer use in Colombian industries was basically nil, thus the share of workers using computers at work by industry in 2001, is actually its change.

The results of estimating equation (6) are presented in Table 2. Our table has two panels: at the top we present estimates using a measure of task intensity weighted by the number of employees in the occupation, while at the bottom we weight task intensities with total hours of all workers in the occupation. As it was expected, all coefficients but one (routine manual) have the correct sign, and once we control for the share of workers with college in the industry, three coefficients have the correct significant sign (despite the small number of industries), the one of routine manual becomes statistically insignificant, and that of non-routine manual has the correct nearly significant sign. These results imply that our task classification is, as a whole, consistent with the concepts they were meant to capture from ALM's model.

5.4 Assessing TBTC in the Colombian Labor Market

As pointed at by Goos and Manning (2007), ALM, and AKK, the decreasing price of computer technology reduces demand for routine labor on the one hand, and on the other hand, increases the demand for the other tasks which are complementary to the routine task, that is, for both cognitive non-routine tasks, and for the non-routine manual tasks. Thus, provided that relative average wages of manual versus routine tasks increases, and the relative wages of abstract versus routinary tasks increases as well, we should observe an increase in the share of workers at the extremes of the wage distribution, and a reduction at the middle of it. As noted by Acemoglu (2002) and Goos and Manning (2007), this implication is at odds with the SBTC hypothesis, since according to that hypothesis, we should observe a monotonic positive relationship between initial wages and increases in employment.

To provide evidence of the relationship between changes in task demands and changes in skill demands, we begin by using Figure 19, which illustrates how workers of different skills sort into the three broad tasks categories defined above: abstract, routine and manual tasks.[21] In the figure each dot represents a combination of the average skill of a specific occupation, measured as the average number of years of education of its workers, and its task intensity, defined as the percentile of that occupation's specific intensity in the 1984 distribution. As it is clear from the figure, regardless of whether occupation are organized by average skill or wage, low skilled workers work on average in non-routine manual intensive occupations, middle

[20] We use the special 2001 formularie of the household survey that inquires about the use and posesion of technologies of information and communications in people's houses or at work.

[21] The Abstract task is built from both non-routine cognite tasks, analytic and interactive, and the routine task from the cognitive and manual routine tasks defined above.

skilled workers in routine intensive occupations, and high skilled workers in abstract intensive occupations. The polarization hypothesis predicts that under decreasing costs of computer technology, routine activities are more demanded basically by an important increase in computers demand, but simultaneously, it is implied a reduction in demand for routine labor. Thus, we should expect demand for workers in occupations of intermediate levels of skills to fall.

Figure 20 illustrates the change in occupation's employment shares between 1984 and 1990, between 1990 and 2004, and between 1990 and 2008, using occupation wage and skill percentiles in 1984. The two graphs at the top of the figure show the results for the sample of all workers while those at the bottom show them for the sample of wage earners or skilled workers. Graphs on the left order occupations according to their wages while those on the right order them according to their skills. Figure 21 shows the same set of graphs, but now each one assesses the whole periods between 1984 and 1990,1984 and 2004 and 1984 and 2008. Finally, Figures 22 and 23 show the same information as the previous two figures, but now changes are estimated on the number of total hours of work rather than on employment.

Evidence represented in most of these figures are at odds with the SBTC, since rather than presenting a monotonic relationship between skills or wages, and changes in employment, they show a clear relative reduction of employment around the median of the respective distributions, at least for a subset of the whole analyzed period, precisely where we would expect to be most of the workers employed in routinary tasks. For Colombia, in both periods 1990-2004 and 1990-2008 we find a U-shaped curve, implying that jobs polarized at the extremes of the wage distribution. Actually, the difference in the relative changes of the shares between workers in occupations at the lower end of the distribution, and those that show the largest drop in the analyzed period, fluctuates around 10 percent, magnitudes similar to the ones represented in the figures obtained by AKK, and by Autor, Katz and Kearney (2008) for the United States.

Note that graphs that order occupations in their x axis according to their wages show a monotone increase in the shares among the better paid occupations, while those that order occupations according to their skills produce an inverted U-shaped curve among the most skillful occupations. This relationship implies that the workers in occupations at the lower end of the distribution would have had a dynamic consistent with AKK polarization model previously outlined, but suggests that some occupations that, given their location in the wage distribution, might be composed by both routinary and non-routinary cognitive tasks, would have gained workers in the analyzed period well beyond what the most skillful occupations did.

We can complement the empirical evidence provided in figures 19 and 20, 21, 22 and 23, by estimating Goos and Manning (2007) models of the form

$$\Delta E = \beta_0 + \beta_1 w_0 + \beta_2 w_0^2 + \varepsilon \tag{7}$$

where ΔE is the change in the participation of employment per occupation, and w_0 is the median wage in the occupation in 1984. The results of estimating equation (7) are presented in Table 3. The table contains four panels, those at the top consider changes in employment and those at the bottom in hours of work. Panels at the left use occupation's wages in the estimation and those at the right use occupation's skills. In order to provide evidence not only that the pattern in the previous figures is U-shaped, but also that such U-shaped pattern became more pronounced in the period beginning in 1990 than it could have been in the period 1984-1990, we include in the estimation data for both the whole period 1984-2008, and for the period 1984-1990 to estimate the following modified regression

$$\Delta E = \beta_0 + \beta_1 w_0 + \beta_2 w_0^2 + \beta_3 \left(t \cdot w_0^2\right) + \varepsilon \tag{8}$$

where t is a dummy variable equal to 1 if the data was of the period 1984-1990, and zero otherwise. We expect to have a positive coefficient in the quadratic term, β_2, and a negative coefficient in the interaction between the quadratic wage or skill and the dummy variable that indicates the data was of the period 1984-1990, β_3, so that we can provide evidence that the U-shaped pattern became more pronounced after computer technology began to become available in the Colombian economy. Notice that a key implication of polarization is the U-shaped form of the relationship between wages and changes in employment, which implies that our estimates would support the polarization hypothesis.

As it can be seen in the table, in the estimation on wages all β_2 coefficients are positive and significant, and all β_3 coefficients are negative and significant, while estimates on skills have the same sign but not always are statistically different from zero. That is, evidence for Colombia is consistent with a polarization in employment in the period between 1984 and 2008, and with a deepening of that polarization in the period between 1990 and 2008, since after 1990 was when computer technologies began to become popularly used by workers.

5.5 On the Role of Offshoring

As Goos, Manning and Salomons (2009a) argue, another channel that could lead to this sort of polarization in the labor market is offshoring. If routine occupations are more offshorable, then the change in the share of workers employed in the manual and abstract tasks relative to the share of those employed in the routine task would be similar to the one predicted by the polarization model based on technical change. The empirical assessment of this hypothesis requires determining how offshorable are the different occupations. As Blinder (2007a, b) and Goos, Manning and Salomons (2009a) found, routine occupations are actually more offshorable than manual and abstract occupations in the United States and Europe respectively, although some occupations among the abstract are also at risk of offshoring.

We do not have data to directly assess how much of the measured effect in our exercise is due to offshoring, but previous work suggests it might have had a role. First, Núñez and Sánchez (1998) assessed the changes in relative demand of workers of different levels of education due to changes in net international trade, and found that relative demand of workers with incomplete high school fell 4.7 percent between 1991 and 1995, while that of workers with lower education fell 1 percent, those with complete secondary fell 0.5 percent, and that of workers with incomplete higher or more increased. This evidence is consistent with workers more likely to perform routine occupations experiencing a reduction in their participation in the labor market. Secondly, Attanasio et al. (2003) found that in the 1990s wage premiums decreased more in sectors that experienced larger tariff cuts. Although that result is not directly linked to the average skills of the affected sectors nor to the type of their most intensive tasks, it would be consistent with the finding provided by Núñez and Sánchez (1998) if sectors more offshorable were as well the most intensive in routine tasks.

Despite the results provided by those articles, there are reasons to expect that the magnitude of offshoring on the polarization in the labor market was much smaller than that of technical change in the case of Colombia. First, the magnitude of trade in the case of Colombia has historically been much smaller than that of the United States of the European countries. While Imports in Europe increased from 26 percent to 40 percent between 1993 (when the European Union was established) and 2008, in Colombia they increased from 15 percent to 22 percent between 1990 and 2008, a much smaller level and increase.[22] In addition, the magnitude of the effects of changes in international trade found by Núñez and Sánchez (1998) of less than 5 percent is small when compared to the relative decreases in the share or workers performing routine task found in the previous section of around 10 percent. Also, the results obtained by Attanasio et al. (2003) led them to conclude that the overall effect of trade reforms on wage distribution would have been small. Lastly, Bernal and Cárdenas (1999) provided evidence that the larger increases in the relative earnings of the more educated workers took place in the non-traded sectors, which is consistent with the results provided by both Núñez and Sánchez (1999) and Attanasio et al. (2003), but most importantly, it is consistent with technical change, beyond offshoring, playing a role in determining relative wages in the first half of the 1990s.[23]

5.6 On the Role of Labor Market Institutions

As stated by Goos, Manning and Salomons (2009a), the effect of polarization in the labor market should be augmented in the presence of higher wage rigidities, since in that case, technical change would be less likely to lead to lower wages and thus to a lower decrease in the demand of workers performing routine tasks,

[22] World Development Indicators, World Bank. In the case of Colombia, the average tariff was reduced from 44 percent at the beginning of 1990 to 11.8 percent in March 1992 (See Ocampo et al. (1998)).

[23] Ocampo et al. (1998) also attributes the increase in the premium of the most skilled in that period to the increase in government consumption.

but rather, under a fall in the price of computer capital wage rigidities would imply larger changes in the demand of routine labor. A similar rationale applies in the cases of the manual and abstract tasks. In the case of workers at the lower end of the occupation distribution, consider the effect of a binding minimum wage on labor demand. A binding minimum wage actually diminishes labor demand of the unskilled, but once technical change leads to a labor demand increase, and the minimum wage is not binding anymore, demand for the unskilled can overshoot, and higher wage rigidity could lead to a higher increase in their demand compared to what could have happened had not there been a binding minimum wage. Figures 20 to 23 suggest that institutions might be playing a role in our results. When we compare the results of the sample of all workers with those of the sample of wage earners or educated, it is clear that the later have a more pronounced reduction in the share of workers performing routine tasks, and their share of workers performing manual tasks falls much less than it does for the sample of all workers. Since wage earners are expected to have their wages more affected by the minimum wage regulation, the comparison suggests that technical change, although having had an effect in both cases, would have had a more pronounced effect in the formal sector due to labor market rigidities.

5.7 Assessing TBTC in the Brazilian and Mexican Labor Markets

Figures 24 and 25 present similar graphs for Brazil and Mexico to the ones presented above for Colombia. Although we do not have tasks intensities by occupation for these countries, provided that workers of different skills sorted across tasks according to the way Colombian workers do (that is, the low skilled mostly in manual intensive tasks, the middle skilled mostly in routine intensive tasks, and the highly skilled mostly in abstract tasks), which is shown in Figure 19, then, based on the pattern illustrated in those figures, we could conclude that Mexico might have as well experienced a period of polarization in the 1990s, but could not conclude the same for the case of Brazil.

We now proceed to test our preliminary conclusion for Mexico by estimating equation (7). The equation can only be estimated for the period 1990-2000, since for 1980 we only have available a few set of occupation categories. Results of the estimation are presented in Table 4. Estimates in the table are consistent with the pattern shown in Figure 25: whenever we consider employment or hours of work the estimates support the U-shaped relationship between initial wages and changes in employment in Mexico.

Previous evidence regarding the way technology complements skills in Brazil is mixed. Acemoglu (2003) quotes the studies by Desjounqueres, Machin and Van Reenen (1999), who found that wage differentials between nonproduction and production workers increased in countries like Chile and Pakistan, but remained stable in Brazil, while the demand for skills in several countries including Brazil, increased; and quotes also Duryea and Szekely (2000), Behrman, Birdsall and Szekely (2001), and Davis (1992), who reported an increase in wage inequality in Brazil during the 1980s and mid 1990s. Nonetheless, Sanchez-Paramo and Schady (2003) find that while relative wages of the skilled increased in Argentina, Chile, Colombia, and Mexico, as relative supply increased as well, they did not increase in Brazil, and claim that out of those five countries, Brazil would be the only one where the evolution of relative wages would not have been determined by relative demand, but by relative supply of skills. Also Fajnzylber and Fernandes (2004) find evidence for Brazil of a negative effect of exports on skilled labor demand in plants that export most of their output, and a positive effect on skilled labor demand for the remaining exporting plants. In short, the evidence suggests that Brazil has responded somewhat differently to the way other countries of the region have responded to SBTC, and likewise, to the mechanics behind the polarization model. A possibility to assess in future work is whether the much larger size of its unskilled labor force in relation to that of the other countries in the region, has played a role in the type of technologies (skill-replacing vs. unskilled replacing) that have been adopted in the country.

Although we followed in the cases of Brazil and Mexico the same steps we followed for the Colombian case, we consider our results for these countries as preliminary since we did not analyze as deeply the empirical regularities in those countries, neither we had available the necessary data to test whether our assigned task intensities by occupation matched the use of computer technologies in their data.

5.8 Discussion

Despite the power of ALM polarization model to describe some key empirical regularities of the US labor market, there are still some stylized facts that cannot be accounted for by that model at least for the Colombian case. First, consider the importance of skilled labor in the US. Since one of the goals of the polarization model is, by linking tasks to skills, to explain the dynamics of relative wages and supply of skills, limiting the model to have an exogenous group of high skilled workers does not allow the model to actually relate highly skilled workers to tasks other than the abstract ones, even though empirical evidence provided by ALM, AKK, and others, clearly suggests that the occupations with some degree of intensity of routine tasks cover a very wide spectrum of the skill distribution. In other words, since empirical evidence suggest that a subset of the highly skilled workers must be working in routine tasks, the polarization model fails to account for the effects that decreasing the cost of computer capital would have on the wages of those skilled workers in routine task, in which case a first question to answer would be to define whether skilled labor and computer capital enter in routine tasks as substitutes, as it is the case with unskilled labor, or as complements. Depending on the way unskilled capital enters in the routine tasks production function, aggregate wages of skilled workers would increase more or less than in the baseline polarization model of ALM, or actually, wages might decrease.

Take as an example the analysis of the dynamics of workers across occupations in Colombia. According to the bottom right graph in Figure 20, between 1990 and 2004, and between 1990 and 2008, there was an increase in the supply of workers around the 80 percentile of the wage distribution, even larger than the one experienced at the very top of it. In addition, as we saw in Figure 8, many skilled workers experienced a drop in their earnings in the analyzed period, as it becomes also clear from the premium of skilled workers with incomplete higher education shown in Figure 11. A model that would allow skilled workers to perform in both abstract and routine tasks, could allow either some skilled workers to cluster around the 80 percentile, or experience a drop in their earnings, while the baseline polarization model, which assumes skilled labor being supplied perfectly inelastically, would require the unskilled labor to explain such increase in labor supply in occupations at that level of the skilled, an unlikely scenario for unskilled workers.

In order to account for the interaction between fluctuations in the cost of computer capital, and the endogenous choices of skilled workers, in the next section we introduce the participation of the skilled workers in routine tasks, so that they can now supply labor to both routine and abstract tasks.

6 Model

In this section we present a model that allows skilled workers to participate in both routine and abstract tasks, in order to account for the interactions that changes in the price of capital and choices of unskilled labor, have on the decisions of the skilled workers, and vice-versa. We keep assuming substitutability between computer capital and unskilled labor, but now we allow for the possibility that some skilled workers perform in the routinary tasks, entering as a complement of computer capital an as substitute of unskilled labor.

6.1 The Firm

The production function maintains the same form it had in the baseline model expressed in (2), but now we introduce the new production function of the routine task as

$$R = L_R + \mu X^{\theta} H_R^{1-\theta} \tag{9}$$

which maintains the substitutability between L_R and X, but now introduces the possibility that some of the skilled labor, H_R, performs in the routine tasks, but complementing rather substituting X.[24]

[24] Note the similarities between this model and the one of organizational models by Kremer and Maskin (1999), and Acemoglu (1999a), presented and reviewed by Acemoglu (2003), in which output is equal to $B_p\left[(A_l L)^{\rho} + (A_h h_O)^{\rho}\right]^{1/\rho} + B_s A_h^{\beta}(H - h_O)$, where skilled workers can perform in the old or new organizational sectors. Although the concepts behind the models are different, their formulations would be even much closer if in the organizational model we would allow L to perform in both sectors.

6.2 The Consumer

There are N worker in the economy, a share Θ of them are Low Skilled workers, L, and the remaining $1-\Theta$ are High Skilled, H.

$$N : \text{Number of workers}$$

$$H = (1-\Theta) N$$

$$L = \Theta N$$

H workers are endowed with no Manual tasks, one efficiency unit of Routine tasks and h units of Abstract tasks, where

$$Ln(h) \sim N\left(\mu_h, \sigma_h^2\right)$$

L workers are endowed with no Abstract tasks, one efficiency unit of Manual tasks and l units of Routine tasks, where

$$Ln(l) \sim N\left(\mu_l, \sigma_l^2\right)$$

Workers self-select into specific tasks according to

$$h = \begin{cases} h_A & if \quad W_A h_A > W_R^H h_r \longrightarrow h_A > \frac{W_R^H}{W_A} h_r = \frac{W_R^H}{W_A} = \eta_h^* \\ h_R & if \quad W_A h_A < W_R^H h_r \longrightarrow h_A < \frac{W_R^H}{W_A} h_r = \frac{W_R^H}{W_A} = \eta_h^* \end{cases}$$

$$l = \begin{cases} l_r & if \quad W_R^L l_r > W_M l_M \longrightarrow l_r > \frac{W_M}{W_R^L} l_M = \frac{W_M}{W_R^L} = \eta_l^* \\ l_m & if \quad W_R^L l_r < W_M l_M \longrightarrow l_r < \frac{W_M}{W_R^L} l_M = \frac{W_M}{W_R^L} = \eta_l^* \end{cases}$$

The labor supply functions of L workers can be written as

$$L_R^s\left(\eta_l^*\right) = \Theta N \cdot P\left(l_r > \eta_l^*\right) \cdot E\left[l_r | l_r > \eta_l^*\right] = \Theta N \left[1 - \Lambda\left(\eta_l^* | \mu, \sigma^2\right)\right] \int_{\eta_l^*}^{\infty} \frac{l \cdot d\Lambda\left(l|\mu,\sigma^2\right)}{\left[1-\Lambda\left(\eta_l^*|\mu,\sigma^2\right)\right]} \tag{10}$$

where $\Lambda\left(x|\mu,\sigma^2\right) = \int_0^x \frac{e^{-\frac{1}{2}\left[\frac{Ln(z)-\mu}{\sigma}\right]^2}}{\sqrt{2\pi}\sigma z} dz$, that is, it is the lognormal distribution. Now let $y = \frac{Ln(l)-\left(\mu+\sigma^2\right)}{\sigma}$, then $\sigma l \cdot dy = dl$, and[25]

$$\begin{aligned} L_R^s\left(\eta_l^*\right) &= \Theta N \left\{1 - \Phi\left[\frac{Ln\left(\eta_l^*\right) - \mu_l}{\sigma_l}\right]\right\} \int_{\frac{Ln\left(\eta_l^*\right)-\left(\mu_l+\sigma_l^2\right)}{\sigma_l}}^{\infty} \frac{e^{\mu_l + \sigma_l^2/2} \cdot \phi\left(y\right) dy}{\left\{1 - \Phi\left[\frac{Ln\left(\eta_l^*\right)-\mu_l}{\sigma_l}\right]\right\}} \\ &= \Theta N \cdot E\left(l\right) \cdot \left\{1 - \Phi\left[\frac{Ln\left(\eta_l^*\right) - \left(\mu_l + \sigma_l^2\right)}{\sigma_l}\right]\right\} \end{aligned} \tag{11}$$

where $\Phi\left(x\right) = \int_{-\infty}^{x} \frac{e^{-\frac{z^2}{2}} dz}{\sqrt{2\pi}}$, that is, it is the normal distribution and $\phi\left(z\right)$ is the standard normal density function. Similarly for $L_M^s\left(\eta_l^*\right)$ we find that

[25] Note that from (10) we have $ze^{-\frac{1}{2}\left[\frac{Ln(z)-\mu}{\sigma}\right]^2} = e^{\mu+\sigma^2/2} e^{-\frac{1}{2}\left[\frac{Ln(z)-\left(\mu+\sigma^2\right)}{\sigma}\right]^2}$

$$L_M^s(\eta_l^*) = \Theta N \cdot [1 - P(l_r > \eta_l^*)] \cdot E[l_m | l_r < \eta_l^*] = \Theta N \cdot \Phi\left[\frac{Ln(\eta_l^*) - \mu_l}{\sigma_l}\right] \tag{12}$$

where the second equality follows from the fact that $E[l_m|l_r < \eta_l^*] = E(l_m) = 1$.Labor supply of H workers is

$$H_A^s(\eta_h^*) = (1-\Theta) N \cdot P(A) \cdot E[h_A | h_A > \eta_h^*] = (1-\Theta) N \cdot E(h) \left\{1 - \Phi\left[\frac{Ln(\eta_h^*) - (\mu_h + \sigma_h^2)}{\sigma_h}\right]\right\} \tag{13}$$

and

$$H_R^s(\eta_h^*) = (1-\Theta) N \cdot [1 - P(A)] \cdot E[h_R | h_A < \eta_h^*] = (1-\Theta) N \cdot \Phi\left[\frac{Ln(\eta_h^*) - \mu_h}{\sigma_h}\right] \tag{14}$$

where the second equality follows from the fact that $E[h_R|h_A < \eta_h^*] = E(h_R) = 1$.

6.3 Equilibrium

This economy gets to an equilibrium when firms maximize profits, workers maximize their utility functions, and labor markets clear.

Given these condition we now present some key results of the model.

Claim 1 *The following results are observed in the equilibrium of this economy:*

(i)

$$\frac{\partial \eta_h^*}{\partial P} < 0 \tag{15}$$

and

(ii)

$$\frac{\partial \eta_l^*}{\partial P} < 0 \tag{16}$$

Thus

$$\frac{\partial \eta_h^*}{\partial P} < 0 \Rightarrow \downarrow P \longrightarrow \uparrow \eta_h^* = \frac{W_R^H}{W_A} \longrightarrow \begin{cases} \downarrow H_A \\ \uparrow H_R \end{cases} \tag{17}$$

$$\frac{\partial \eta_l^*}{\partial P} < 0 \Rightarrow \downarrow P \longrightarrow \uparrow \eta_l^* = \frac{W_M}{W_R^L} \longrightarrow \begin{cases} \uparrow L_M \\ \downarrow L_R \end{cases} \tag{18}$$

See the details of this result in Appendix B. These results allow the possibility to have as the cause of a reduction in the cost of computer capital, a decrease in the wage of the unskilled working in routine task, followed by an increase in the supply of unskilled workers to the non-routine manual tasks as the AKK model does. Simultaneously, it would allow skilled workers performing abstract tasks to move to routine tasks, since the lower price of computer capital would rise the demand of skilled labor in routine tasks. If that was the case, a pattern of changes in employment similar to the one depicted in the bottom left graph of figure 20 could be reasonable explained by this model, since those skilled workers moving from abstract to routine task might cluster around the 80 percentile of the distribution as it is the case in the figure.

A caveat of this scenario is that this result would require the relative wage of skilled workers performing routine tasks, W_R^H, to increase in relation to the one earned by skilled workers performing abstract tasks, W_A^H. leading to a reduction in earnings inequality among the skilled workers, which goes against the evidence provided by Figures 7 and 9, which as we had already noted, show an increase in earnings inequality among the skilled workers.

Such increase in earnings inequality among the skilled workers could be captured by a model that would replace (9) by

$$R = L_R^{\theta} H_R^{1-\theta} + \mu X \tag{19}$$

Under (19), and after some straightforward calculations following those made in the previous case, now we would get that $\frac{\partial \eta_h^*}{\partial P} > 0$, thus $\frac{\partial \eta_h^*}{\partial P} > 0 \Rightarrow \downarrow P \longrightarrow \downarrow \eta_h^* = \frac{W_R^H}{W_A} \longrightarrow \left\{ \begin{array}{l} \uparrow H_A \\ \downarrow H_R \end{array} \right.$, leading to the desired result that would allow us to explain the drop in the premium of the skilled workers with incomplete higher education, as well as the increase in earnings inequality among skilled workers. The actual model that could explain the regularities of the Colombian labor market might be something with a R function that captured features of the two proposed functions.

7 Conclusions

In this paper, we show that the traditional Skill Biased Technological Change, SBTC, model that includes two skill groups performing two distinct and imperfectly substitutable occupations, is unable to explain some features of the dynamics of the Colombian labor market. Specifically, two factors models like that by Katz and Murphy (1992), are unable to capture U-shaped dynamics in the distribution of labor across occupations in the Colombian labor market, previously found for the American and some European economies, as Task Biased Technical Change, TBTC (polarization) models, do.

Even though the traditional SBTC model has been widely used to explain the main facts of the earnings inequality dynamics in Colombian, we argue that various empirical regularities observed over the longer period of time, that includes most of the 2000s, reveals several characteristics that are hard to be predicted by the standard model, and that might be better explained by that introducing the task dimension into the production function, like the TBTC models developed by Autor, Katz and Kearney (2006), Goos and Manning (2007), and others.

We use household survey data of Colombia to assess whether the polarization model could contribute to explain key stylized facts of its labor market. We present evidence of aggressive implementation of computer technology in Latin American countries, and of important reductions in the cost of computer capital in Colombia during the last decade, and link its rate of adoption to specific tasks and occupations, as previous literature do.

The evidence found is consistent with TBTC having taken place in Colombia. TBTC would have led to an increase in the supply of both unskilled labor performing manual tasks, at the bottom of the wage or skills occupation distribution, and skilled labor performing abstract tasks, at the top of the occupation distribution, relative to workers performing routine tasks. Reductions in the cost of computer capital would have led to an increase in the wages of unskilled workers in manual tasks relative to those in routine tasks, and similarly, to an increase in the relative wages of the skilled workers performing abstract tasks relative to those performing routine tasks. Altogether, the evidence implies a positive covariance between changes in wages and employment at the extremes of the wages or skills occupation distribution.

The mentioned effects of the more aggressive adoption of computer technology in Colombia would also help to explain both the observed increase in earnings inequality among skilled workers, and the decrease, or at the best stability, in earnings inequality among unskilled workers. Finally, we replicate Colombia's empirical work to the cases of Mexico and Brazil, and found evidence consistent with polarization having taken place in Mexico, but not in Brazil.

The evidence provided calls for caution at the moment of implementing policies in Colombia or Mexico, and potentially, in other countries of the region, seeking to raise public funds, promote private investment, etc., by distorting the relative price between capital and labor, and in particular, the relative price of computer capital, given its potential implications on the assignment of labor in the economy, and on earnings inequality. It also calls into question the institutional policies seeking to guarantee minimum levels of earnings to workers, or to impose restrictions to labor turnover, rather than promoting the provision of the necessary qualifications to workers for them to adapt to the technical changes experienced by the economy.

8 Appendix A: Data on Occupations and Tasks Definitions

8.1 Colombia

In the case of Colombia, we use 77 occupations and all of them are comparable for the period 1984-2006 (see table 5). We exclude individuals who are engaged in tasks such as (i) priests, missionaries, or (ii) athletes, sportsmen and related workers.

The definitions of the different tasks are available in the National Classification of Occupations of the Department of National Statistics of Colombia, DANE, which adopted the CNO70 which is based in The International Standard Classification of Occupations (ISCO). The manual of CNO70 has a name and definition that describes the main task, obligations and functions for every occupation.

According to CNO70, what is relevant for classifying an individual in a special occupation is the nature of the functions or task that he performs, rather than the academic achievements, like degrees or academic certificates he had earned. Thus, an economist who works as a taxi driver will not be classified in the occupation "Economists", but in "drivers of vehicles other than dump trucks".

For each occupation we calculate the median income and the average education in the initial period, in this case, 1984, Using this information, we build the test and figures of polarization in the labor market.

The occupations were classified into five groups according to whether their main task was abstract, routine or manual. The five groups are the same as defined by ALM: (i) non-routine cognitive/interactive (DCP); (ii) non-routine cognitive/analytical (MATH); (iii) routine cognitive (STS); (iv) routine manual (FINGER), and (v) non-routine manual (EHF). To develop the classification we used the manual of the CNO70 and the definitions developed by ALM .

In the first group - DCP – were classified occupations that perform task with high managerial analytical component as those occupations which are responsible for the direction of enterprises or institutions. In the second group - MATH – were classified those task with high requirements of quantitative reasoning, for example, the occupations associates with engineering, medicine or economics. The third group - STS - comprises task with high component where the main requirement is the ability to adapt to jobs that require set limits, tolerances or standards. The fourth group - Finger – includes those tasks with high routine component and manual skill requirement. The last group - EHF – contains those tasks with a high component on non-routine manual skills, playing an important role the eye-hand-foot coordination. Some examples are domestic workers and drivers.

8.2 Brazil

In the case of Brazil, we have information from household surveys for the period 1981-2005. The occupation variable changed its definition in 2002, and it is not possible to compare both versions. The new definition is based on CBO-household, which in turn is based on ISCO-88. We only used the information for the period 1981-2001 given the no-comparability between surveys. Finally, we have 199 kinds of occupations. As in Colombia, for each occupation we calculate the median income and the average education in the initial period, in this case, 1981. The available occupation can be consulted in *Instituto Brasileiro de Geografia e Estatística* (IBGE, http://www.ibge.gov.br/concla/cl_corresp.php?sl=3).

8.3 Mexico

For Mexico we have information from census data of 1990 and 2000, available from IPUMS international (https://international.ipums.org/international). For our exercise we used 280 occupations. As in Colombia and Brazil, for each occupation we calculate the median income and the average education in the initial period, in this case, 1990.

9 Appendix B

The claim follows from some straightforward calculations. The profits of the firm are

$$\pi = Y - W_A \cdot H_A - W_R^H \cdot H_R - W_R^L \cdot L_R - W_M \cdot L_M - P \cdot X \tag{20}$$

with first order conditions,

$$\frac{\partial \pi}{\partial H_A} = \alpha H_A^{\alpha-1} R^{\beta} M^{1-\alpha-\beta} - W_A = 0 \tag{21}$$

$$\frac{\partial \pi}{\partial H_R} = \beta H_A^{\alpha} R^{\beta-1} M^{1-\alpha-\beta} \mu \left(1-\theta\right) X^{\theta} H_R^{-\theta} - W_R^H = 0 \tag{22}$$

$$\frac{\partial \pi}{\partial L_R} = \beta H_A^{\alpha} R^{\beta-1} M^{1-\alpha-\beta} - W_R^L = 0 \tag{23}$$

$$\frac{\partial \pi}{\partial L_M} = \left(1-\alpha-\beta\right) H_A^{\alpha} R^{\beta} M^{-\alpha-\beta} - W_M = 0 \tag{24}$$

$$\frac{\partial \pi}{\partial X} = \beta H_A^{\alpha} R^{\beta-1} M^{1-\alpha-\beta} \mu \theta X^{\theta-1} H_R^{1-\theta} - P = 0 \tag{25}$$

$(21) / (24) :$

$$\frac{\alpha}{\left(1-\alpha-\beta\right)} \frac{L_M}{H_A} = \frac{W_A}{W_M} \tag{26}$$

$(22) / (25) :$

$$\frac{\left(1-\theta\right)}{\theta} \frac{X}{H_R} = \frac{W_R^H}{P} \tag{27}$$

$(24) / (23) :$

$$\frac{\left(1-\alpha-\beta\right)}{\beta} \frac{\left(L_R + \mu X^{\theta} H_R^{1-\theta}\right)}{L_M} = \frac{W_M}{W_R^L} = \eta_L^* \tag{28}$$

$(22) / (21) :$

$$\frac{\beta}{\alpha} \frac{H_A}{\left(L_R + \mu X^{\theta} H_R^{1-\theta}\right)} \mu \left(1-\theta\right) \left(\frac{X}{H_R}\right)^{\theta} = \frac{W_R^H}{W_A} = \eta_H^* \tag{29}$$

(29) implies that

$$Ln\left(\eta_h^*\right) = Ln\left(\frac{\beta}{\alpha}\right) + Ln\left(H_A\right) + Ln\left(L_R + \mu X^{\theta} H_R^{1-\theta}\right) + Ln\left(1-\theta\right) + \theta\left[Ln\left(X\right) - Ln\left(H_R\right)\right] \tag{30}$$

$$\frac{\partial \eta_h^*}{\partial P} = \frac{\frac{L_R^{'}(\cdot) \cdot \partial \eta_l^* / \partial P \, + \, \mu \theta X^{\theta-1} H_R^{1-\theta} \cdot \partial X / \partial P}{L_R + \mu X^{\theta} H_R^{1-\theta}} - \frac{\theta \cdot \partial X / \partial P}{X}}{\frac{1}{\eta_h^*}\left[-1 + \frac{\eta_h^* \cdot H_A'(\cdot)}{H_A} - \frac{\mu(1-\theta)\eta_h^* \cdot X^{\theta} H_R^{-\theta} H_R'(\cdot)}{L_R + \mu X^{\theta} H_R^{1-\theta}} - \frac{\theta \eta_h^* \cdot H_R'(\cdot)}{H_R}\right]} \tag{31}$$

Using (**??**) , (**??**) , we get

$$\Omega = \frac{1}{\eta_h^*}\left[-1 + \frac{\eta_h^* \cdot H_A'\left(\cdot\right)}{H_A} - \left(\frac{\theta L_R + \mu X^{\theta} H_R^{1-\theta}}{L_R + \mu X^{\theta} H_R^{1-\theta}}\right) \frac{\eta_h^* \cdot H_R'\left(\cdot\right)}{H_R}\right] < -1 \tag{32}$$

Notice that $\eta_h^* \Omega < -1$. On the other hand, (28) implies that

$$Ln\left(\eta_l^*\right) = Ln\left(\frac{1-\alpha-\beta}{\beta}\right) + Ln\left(L_R + \mu X^{\theta} H_R^{1-\theta}\right) + Ln\left(L_M\right) \tag{33}$$

$$\frac{\partial\eta_l^*}{\partial P}=\frac{\frac{\mu\theta X^{\theta-1}H_R^{1-\theta}\cdot\partial X/\partial P+\mu(1-\theta)X^{\theta}H_R^{-\theta}H_R'(\cdot)\cdot\partial\eta_h^*/\partial P}{L_R+\mu X^{\theta}H_R^{1-\theta}}}{\frac{1}{\eta_l^*}\left[1-\frac{\eta_l^*\cdot L_R'(\cdot)}{L_R+\mu X^{\theta}H_R^{1-\theta}}+\frac{\eta_l^*\cdot L_M'(\cdot)}{L_M}\right]} \tag{34}$$

Using (**??**) , (**??**) , we get

$$\tilde{\Omega}=\frac{1}{\eta_l^*}\left[1-\frac{\eta_l^*\cdot L_R'(\cdot)}{L_R+\mu X^{\theta}H_R^{1-\theta}}+\frac{\eta_l^*\cdot L_M'(\cdot)}{L_M}\right]>1 \tag{35}$$

(34) in (31) :

$$\frac{\partial\eta_h^*}{\partial P}\frac{P}{\eta_h^*}=-\frac{\partial X}{\partial P}\frac{P}{X}\frac{\theta}{\eta_h^*\Omega\bar{\Omega}}\left\{1-\tilde{X}\left[\frac{L_R'(\cdot)}{\tilde{\Omega}\left(L_R+\mu X^{\theta}H_R^{1-\theta}\right)}+1\right]\right\} \tag{36}$$

where $\tilde{X}=\frac{\mu X^{\theta}H_R^{1-\theta}}{\left(L_R+\mu X^{\theta}H_R^{1-\theta}\right)}$, and

$$\bar{\Omega}=1-(1-\theta)\frac{L_R'}{\tilde{\Omega}\left(L_R+\mu X^{\theta}H_R^{1-\theta}\right)}\left(\frac{\tilde{X}H_R'}{\Omega H_R}\right) \tag{37}$$

Notice that the term in brackets is smaller than one whenever

$$\left(\frac{\theta L_R+\mu X^{\theta}H_R^{1-\theta}}{L_R+\mu X^{\theta}H_R^{1-\theta}}\right)>\frac{\mu X^{\theta}H_R^{1-\theta}}{\left(L_R+\mu X^{\theta}H_R^{1-\theta}\right)}=\tilde{X}$$

which is always the case. Using (**??**) , (**??**) , (32), (35), we find that the absolute value of each term after the minus sign in (37) is lower than one, and that term is negative, then

$$0<\bar{\Omega}<1 \tag{38}$$

since the term in brackets in the numerator of the second line of (36) is positive and lower than one, then the term in braces is negative, and thus

$$\frac{\partial\eta_h^*}{\partial P}<0 \tag{39}$$

(39) in (34) :

$$\frac{\partial\eta_l^*}{\partial P}<0 \tag{40}$$

To establish whether $\frac{\partial\eta_h^*}{\partial P}\frac{P}{\eta_h^*}$ is lower than $\frac{\partial X}{\partial P}\frac{P}{X}$, notice that $\left(\frac{\partial\eta_h^*}{\partial P}\frac{P}{\eta_h^*}\right)/\left(\frac{\partial X}{\partial P}\frac{P}{X}\right)<1$, from (36)implies

$$\begin{aligned}
&-\frac{\theta}{\eta_h^*\Omega}\left\{1-\frac{\mu X^{\theta}H_R^{1-\theta}}{\left(L_R+\mu X^{\theta}H_R^{1-\theta}\right)}\left[\frac{L_R'(\cdot)}{\tilde{\Omega}\left(L_R+\mu X^{\theta}H_R^{1-\theta}\right)}+1\right]\right\}\\
&< \quad 1-\frac{\mu(1-\theta)L_R'(\cdot)X^{\theta}H_R^{-\theta}H_R'(\cdot)}{\left(L_R+\mu X^{\theta}H_R^{1-\theta}\right)^2\Omega\tilde{\Omega}}=\bar{\Omega}\\
&\to\theta\left\{\frac{-1}{\eta_h^*\Omega}\left\{1-\tilde{X}\left[\frac{L_R'}{\tilde{\Omega}\left(L_R+\mu X^{\theta}H_R^{1-\theta}\right)}+1\right]\right\}\right\}
\end{aligned}$$

$$+(1-\theta)\left\{\frac{L_R^{'}(\cdot)}{\tilde{\Omega}\left(L_R+X^\theta H_R^{1-\theta}\right)}\frac{\tilde{X}H_R'}{\Omega H_R}\right\}<1$$

Since each of the terms in braces is smaller than one, we have a linear combination of them which is as well smaller than one, thus

$$\left(\frac{\partial\eta_h^*}{\partial P}\frac{P}{\eta_h^*}\right)/\left(\frac{\partial X}{\partial P}\frac{P}{X}\right)<1\rightarrow\frac{\partial\eta_h^*}{\partial P}\frac{P}{\eta_h^*}>\frac{\partial X}{\partial P}\frac{P}{X} \tag{41}$$

where the change in the inequality follows from the fact that $\frac{\partial X}{\partial P}\frac{P}{X}<0$. The final expression for $\partial\eta_h^*/\partial P$ is obtained replacing (36) in (34) :

$$\frac{\partial\eta_l^*}{\partial P}\frac{P}{\eta_l^*}=\frac{\partial X}{\partial P}\frac{P}{X}\frac{\theta\tilde{X}}{\Omega\tilde{\Omega}}\left\{\Omega-(1-\theta)\frac{H_R'}{H_R}\frac{1}{\bar{\Omega}}\left\{1-\tilde{X}\left[\frac{L_R^{'}}{\tilde{\Omega}\left(L_R+\mu X^\theta H_R^{1-\theta}\right)}+1\right]\right\}\right\} \tag{42}$$

Thus

$$\frac{\partial\eta_h^*}{\partial P}<0\Rightarrow\downarrow P\longrightarrow\uparrow\eta_h^*=\frac{W_R^H}{W_A}\longrightarrow\left\{\begin{array}{l}\downarrow H_A\\ \uparrow H_R\end{array}\right. \tag{43}$$

$$\frac{\partial\eta_l^*}{\partial P}<0\Rightarrow\downarrow P\longrightarrow\uparrow\eta_l^*=\frac{W_M}{W_R^L}\longrightarrow\left\{\begin{array}{l}\uparrow L_M\\ \downarrow L_R\end{array}\right. \tag{44}$$

Other results:

$\mathbf{W}_A - \mathbf{W}_M$: To establish how wages of H workers evolve relative to those of L workers, we use (26)

$$\partial\left[\ln\left(W_A\right)-\ln\left(W_M\right)\right]/\partial P=\frac{L_M^{'}}{L_M}\frac{\partial\eta_l^*}{\partial P}-\frac{H_A^{'}}{H_A}\frac{\partial\eta_l^*}{\partial P}<0 \tag{45}$$

That is, the wage gap between the most and the least skilled workers (H_A and L_M respectively) increases as P decreases.

$\mathbf{W}_R^L - \mathbf{W}_R^H$: Now (23) / (22) implies

$$\frac{W_R^L}{W_R^H}=\frac{1}{\mu(1-\theta)}\left(\frac{H_R}{X}\right)^\theta \tag{46}$$

log differentiating we get

$$\frac{P}{W_R^L}\frac{\partial W_R^L}{\partial P}-\frac{P}{W_R^H}\frac{\partial W_R^H}{\partial P}=-\theta\left(\frac{P}{X}\frac{\partial X}{\partial P}-\frac{\eta_h^* H_R^{'}}{H_R}\frac{P}{\eta_h^*}\frac{\partial\eta_h^*}{\partial P}\right) \tag{47}$$

using (36) :

$$\frac{P\partial\left[Ln\left(W_R^L\right)-Ln\left(W_R^H\right)\right]}{\partial P}=-\frac{\theta P}{X}\frac{\partial X}{\partial P}\left\{1+\frac{\frac{\theta}{\Omega}\frac{H_R^{'}}{H_R}}{\bar{\Omega}}\left\{1-\tilde{X}\left[\frac{L_R^{'}(\cdot)}{\tilde{\Omega}\left(L_R+\mu X^\theta H_R^{1-\theta}\right)}+1\right]\right\}\right\} \tag{48}$$

The expression is positive if the term in braces is positive, which is the case as long as $\frac{-\frac{\theta}{\Omega}\frac{H_R^{'}}{H_R}}{\bar{\Omega}}<1$, that is,

$$-\frac{\theta}{\Omega}\frac{H_R^{'}}{H_R}<1-(1-\theta)\frac{L_R^{'}}{\tilde{\Omega}\left(L_R+\mu X^\theta H_R^{1-\theta}\right)}\frac{\tilde{X}H_R'}{\Omega H_R}=\bar{\Omega}<1+(1-\theta)\frac{\tilde{X}H_R'}{\Omega H_R}$$

$$\rightarrow 0 < 1 + \left[(1-\theta) \tilde{X} + \theta \right] \frac{H_R'}{\Omega H_R} = 1 + \left[\frac{\theta L_R + \mu X^{\theta} H_R^{1-\theta}}{L_R + \mu X^{\theta} H_R^{1-\theta}} \right] \frac{H_R'}{\Omega H_R}$$

which always holds because the second term is smaller than one in absolute value by the definition of Ω. It follows that $\frac{P\partial\left[Ln\left(W_R^L\right) - Ln\left(W_R^H\right)\right]}{\partial P} > 0$, that is, when P falls the wage gap between H_R and L_R workers increases.

Prices: Now let us establish the implications of changes in P on wages.

$\mathbf{W_R^H/P}$: From (27) :

$$\frac{P}{\left(W_R^H/P\right)} \frac{\partial\left(W_R^H/P\right)}{\partial P} = \frac{P}{X}\frac{\partial X}{\partial P} - \frac{\eta_h^*}{H_R}\frac{\partial H_R}{\partial \eta_h^*}\frac{P}{\eta_h^*}\frac{\partial \eta_h^*}{\partial P} \tag{49}$$

using (36) :

$$\frac{P}{\left(W_R^H/P\right)} \frac{\partial\left(W_R^H/P\right)}{\partial P} = \frac{P}{X}\frac{\partial X}{\partial P} \left\{ 1 + \frac{\frac{\theta \eta_h^*}{H_R}\frac{\partial H_R}{\partial \eta_h^*}}{\bar{\Omega}\eta_h^* \Omega} \left\{ 1 - \tilde{X} \left[\frac{L_R'(\cdot)}{\tilde{\Omega}\left(L_R + \mu X^{\theta} H_R^{1-\theta}\right)} + 1 \right] \right\} \right\} \tag{50}$$

where $\tilde{X} = \frac{\mu X^{\theta} H_R^{1-\theta}}{\left(L_R + \mu X^{\theta} H_R^{1-\theta}\right)}$. Since all components of the second term in braces are smaller than one and that term is negative, we find that

$$\frac{P}{\left(W_R^H/P\right)} \frac{\partial\left(W_R^H/P\right)}{\partial P} < 0 \tag{51}$$

That is, W_R^H increases relative to P as P decreases.

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Men (sample 1984q1 - 2006q2)	Long run					
	Equation 1					
Depend variable: Ln(Skill Premium)		Empleos			Horas	
	coef	z	Sigma	coef	z	Sigma
Ln(Relative supply)	-0.682	3.180	**1.47**	-0.860	3.670	**1.16**
TD	2.133	4.860		2.218	4.770	
	Equation 2					
Depend variable: Ln(Skill Premium)		Empleos			Horas	
	coef	z	Sigma	coef	z	Sigma
Ln(Relative supply)	-0.764	3.470	**1.31**	-0.790	3.580	**1.27**
TD	2.830	6.090		2.842	6.250	
SM	0.001	2.960		0.001	3.310	

Figure 1: Vector Error-Correction Model for the Skill PremiumSource: Colombian Household Survey

The Impact of Industry Task Content in 1984 on Industry Computer Adoption between 1984 and 2001.

PANEL A.

Dependent Variable: % of Industry Employees Using a Computer on the Job in 2001

	Nonroutine Analytic	Nonroutine Interactive	Routine Cognitive	Routine Manual	Non-Routine Manual
(1) Share Industry	0.46	0.34	0.16	-0.13	-0.14
task requiments 1984	(0.418)	(0.093)	(0.104)	(0.058)	(0.049)
R2	0.10	0.45	0.12	0.12	0.22
(2) Share Industry	0.11	0.36	0.16	-0.07	-0.09
task requiments 1984	(0.421)	(0.153)	(0.070)	(0.047)	(0.049)
Proportion with college	0.34	-0.03	0.39	0.37	0.30
educational level	(0.099)	(0.226)	(0.102)	(0.129)	(0.100)
R2	0.33	0.45	0.50	0.43	0.41

Note: Robust standard errors are in parentheses. It's assumed that the use of computer is zero in the initial year (1984). The task is measured in employment. There are 26 industries.

PANEL B.

Dependent Variable: % of Industry Employees (in Hours) Using a Computer on the Job in 2001

	Nonroutine Analytic	Nonroutine Interactive	Routine Cognitive	Routine Manual	Non-Routine Manual
(1) Share Industry	0.41	0.36	0.16	-0.13	-0.13
task requiments 1984	(0.399)	(0.099)	(0.101)	(0.057)	(0.049)
R2	0.09	0.45	0.12	0.12	0.19
(2) Share Industry	0.08	0.38	0.16	-0.07	-0.08
task requiments 1984	(0.398)	(0.156)	(0.068)	(0.045)	(0.049)
Proportion with college	0.35	-0.02	0.39	0.37	0.30
educational level	(0.104)	(0.217)	(0.102)	(0.129)	(0.101)
R2	0.33	0.45	0.50	0.43	0.40

Note: Robust standard errors are in parentheses. It's assumed that the use of computer is zero in the initial year (1984). The task is measured in hours. There are 26 industries.

Figure 2: The Impact in Colombia of Industry Task Content in 1984 on Industry Computer Adoption between 1984 and 2001.

Employment Growth and Initial Median Wage or Skill:					
	$\Delta OCC_j = \beta_0 + \beta_1 W_{j0} + \beta_2 W_{j0}^2 + \gamma(t * W_{j0}^2)$			$\Delta OCC_j = \beta_0 + \beta_1 S_{j0} + \beta_2 S_{j0}^2 + \gamma(t * S_{j0}^2)$	
	All	Wage Earners or Skilled		All	Wage Earners or Skilled
Wage	-7.04***	-6.65**	Skill	-0.08	-0.05
	(2.30)	(2.97)		(0.07)	(0.06)
Wage2	0.43***	0.41**	Skill2	0.0060*	0.0046
	(0.14)	(0.18)		0.0033*	(0.0031)
t * Wage2	-0.005***	-0.004***	t * Skill2	-0.0033***	-0.0025***
	(0.001)	(0.001)		(0.0007)	(0.0006)

Employment (in hours) Growth and Initial Median Wage or Skill:					
	All	Wage Earners or Skilled		All	Wage Earners or Skilled
Wage	-6.85***	-6.83**	Skill	-0.07	-0.04
	(2.39)	(3.05)		(0.07)	(0.07)
Wage2	0.42***	0.42**	Skill2	0.0058*	0.0045
	(0.14)	(0.18)		0.0034*	0.0032
t * Wage2	-0.0060***	-0.0048***	t * Skill2	-0.0037***	-0.0029***
	0.0009***	(0.0009)		0.0008***	0.0007***

Note: Occupation uses two digit CNO70 codes. Regressions are weighted by the number of individuals within an occupation in the initial period. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Data contain information of periods 1984-1990 and 1984-2008. t is a dummy variable equal to 1 if data belongs to period 1984-1990 and zero otherwise.

Figure 3: The Relation Between Employment Growth and Initial Median Wage or Skill in Colombia. 1984-1990 and 1984-2008

Employment Growth and Initial Median Wage: $\Delta OCC_j = \beta_0 + \beta_1 W_{j0} + \beta_2 W_{j0}^2 + \beta_3 W_{j0}^3$

Sample Period	Employment Measure	β1	β2	β3
1990-2000	Employment	-65.16**	6.66**	-0.23**
		(30.3)	(3.11)	(0.11)
	Hour	-65.24**	6.67**	-0.23**
		(31.87)	(3.27)	(0.11)

Note: Mexican clasification of ocupations. Regressions are weighted by the number of individuals within an occupation in the initial period. Robust standard errors are in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Figure 4: The Relation Between Employment Growth and Initial Median Wage or Skill in Mexico. 1990-2000.

1	Chemists and physicists in all specialties	39	Chief of staff easement hotel. Cooks, bartenders, waiters. Staff servitude not previously classified
2	Arquitectos and Engineers	40	Guardians of buildings, cleaning staff and workers assimilated
3	Technicians in engineering and statistics	41	Washer, dry cleaners and / or machine
4	Surveyors and land surveyors	42	Hairdressers, beauty treatment specialists and workers assimilated
5	Technicians and designers	43	Personal Protection and Safety
6	Pilots' deck officers and officers drivers	44	Service workers not classified
7	Biologists, zoologists and related scientists	45	Managers and heads of farms
8	Technicians in the field of health and biology	46	Farmers and ranchers or owners are not specialized
9	Medical doctors, Dentists, Veterinarians and Professional nurses	47	Agricultural workers in general: forestry workers, fishermen, hunters and assimilated
10	Statisticians, Mathematicians, Systems Analysts and Related Technicians	48	Mining jobs: foremen, supervisors and foremen factories
11	Economists	49	Miners, quarry workers, and workers treated sondistas
12	Accountants	50	Metal workers, the smelter's of blast furnace and heat treatment of metal workers
13	Jurists, Lawyers and Judges	51	Workers in wood treatment and the manufacture of paper and paperboard
14	Teachers (Without teachers in physical education)	52	Operators of thermal plants for chemical treatments
15	Authors, Journalists and Related Writers	53	Spinners, weavers, dyers and similar workers
16	Sculptors, Painters, Photographers and Related Creative Artists	54	Workers in the preparation, tanning and leather processing
17	Composers and Performing Artists	55	Workers preparing food and drinks
18	Professional, Technical and Related Workers Not Elsewhere Classified	56	Workers in the processing of snuff
19	Legislative Officials and Government Administrators	57	Tailors, dressmakers, upholsterers and workers assimilated
20	Managers	58	Cobblers
21	Chiefs of office employees	59	Cabinet makers, machine operators to carve wood and Carpenters
22	Administrative staff of public administration	60	Ornaments of stones such as granite, marble and limestone
23	Secretaries and typists	61	Workers in the to cut metal
24	Bookkeepers, Cashiers and Related Workers	62	Fitters, assemblers and installers of machinery and precision instruments
25	Bookkeeping and calculating machine operators	63	Electricians, radio and television repairmen, assemblers of electronic devices
26	Transport and Communications Supervisors	64	Operators of radio and television stations and film showings
27	Postmen and messengers	65	Welders, plumbers and pipe fitters
28	Telephones, telegraphs, radio operators and maritime navigation and radio operator	66	Jewelers and silversmiths, carver and polisher of precious stones
29	Administrative staff and workers treated unclassified	67	Glassmakers, potters and workers assimilated
30	Directors and Managers of wholesale trade and retail	68	Manufacture of rubber and plastic
31	Dealers owners of wholesale and retail	69	Made of paper products and cardboard
32	Heads of sales promoters, sales supervisors	70	Workers in the graphic arts
33	Technical sales agents and representatives of factory	71	Painters of buildings and structures
34	Insurance agents, brokers and real estate	72	Manufacturing workers and workers not previously classified assimilated
35	Sellers employees and trade workers assimilated	73	Construction workers
36	Merchants and vendors not previously classified	74	Machine operators of fixed and similar facilities
37	Directors of hotels, bars and the like	75	Freight handlers, stevedores, shippers and packers
38	Managers of hotel owners, bars and the like	76	Drivers of vehicles other than dump trucks
39	Chief of staff easement hotel. Cooks, bartenders, waiters. Staff servitude not previously classified	77	Laborers in general, shoeshine boys, garbage collector or other materials on hand

Figure 5: Occupations in Colombian Data. Source: Households surveys and National Classification of Occupations, Department of National Statistics of Colombia, DANE.

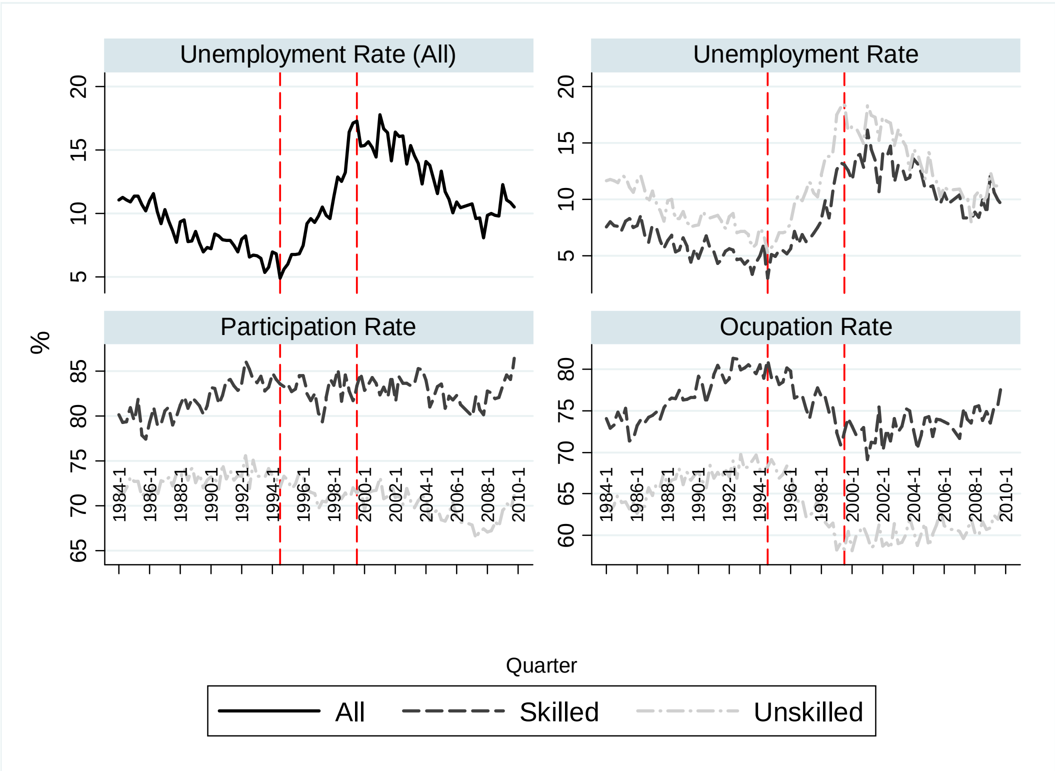

Figure 6: Evolution of Male's Unemployment, Participation and Occupation Rates. 7 Main Colombian Cities, 1984-2009.

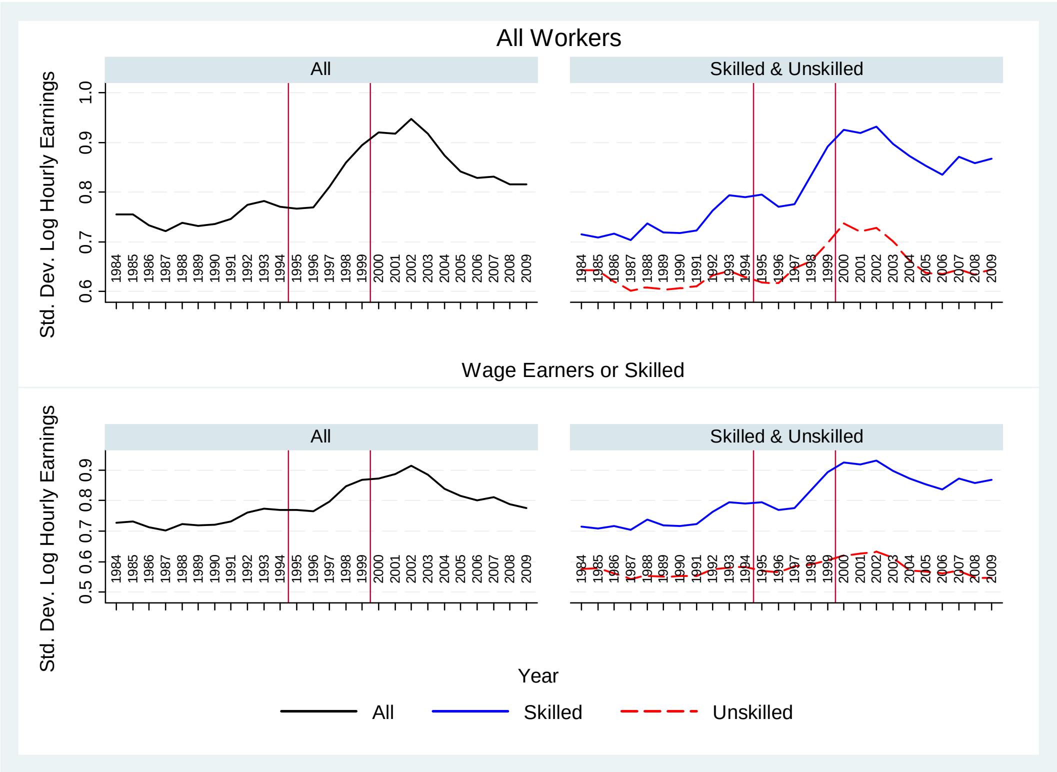

Figure 7: Evolution of Male's Wage Inequality. & Main Colombian Cities, 1984-2009.

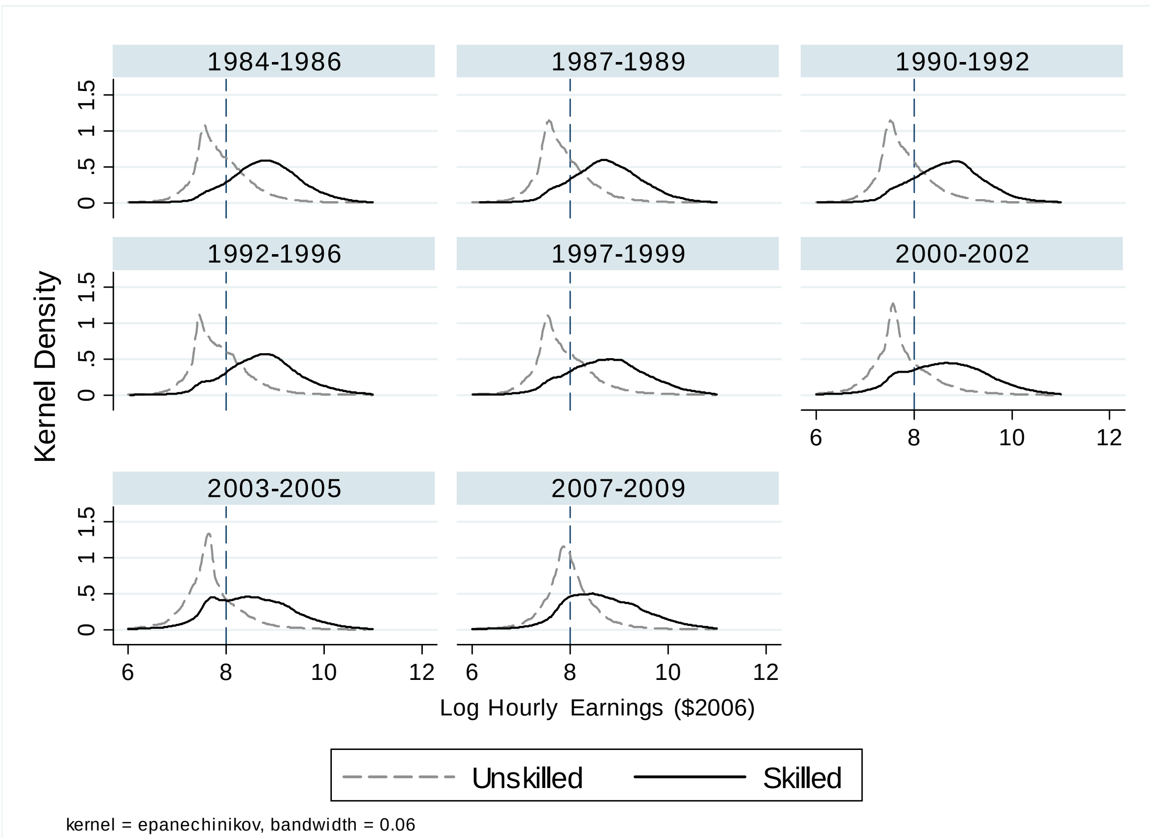

Figure 8: Evolution of the Distribution of Wage Earners or Skilled Male's Log Hourly Wages. & Main Colombian Cities, 1984-2009.

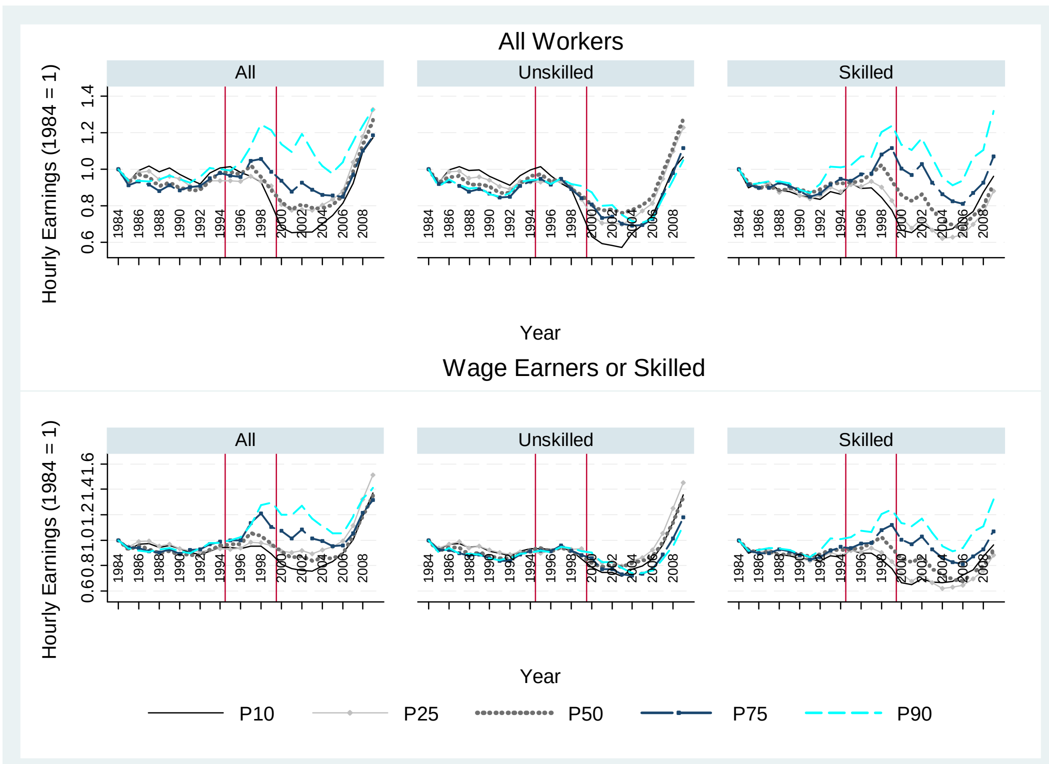

Figure 9: Evolution of Male's Hourly Wages By Percentile. 7 Main Colombian Cities, 1984-2009.

Figure 10: Evolution of Male's Earnings Inequality. 7 Main Colombian Cities, 1984-2009

Figure 11: Log Wage Difference Between Skilled and Unskilled Males. 7 Main Colombian Cities, 1984-2009

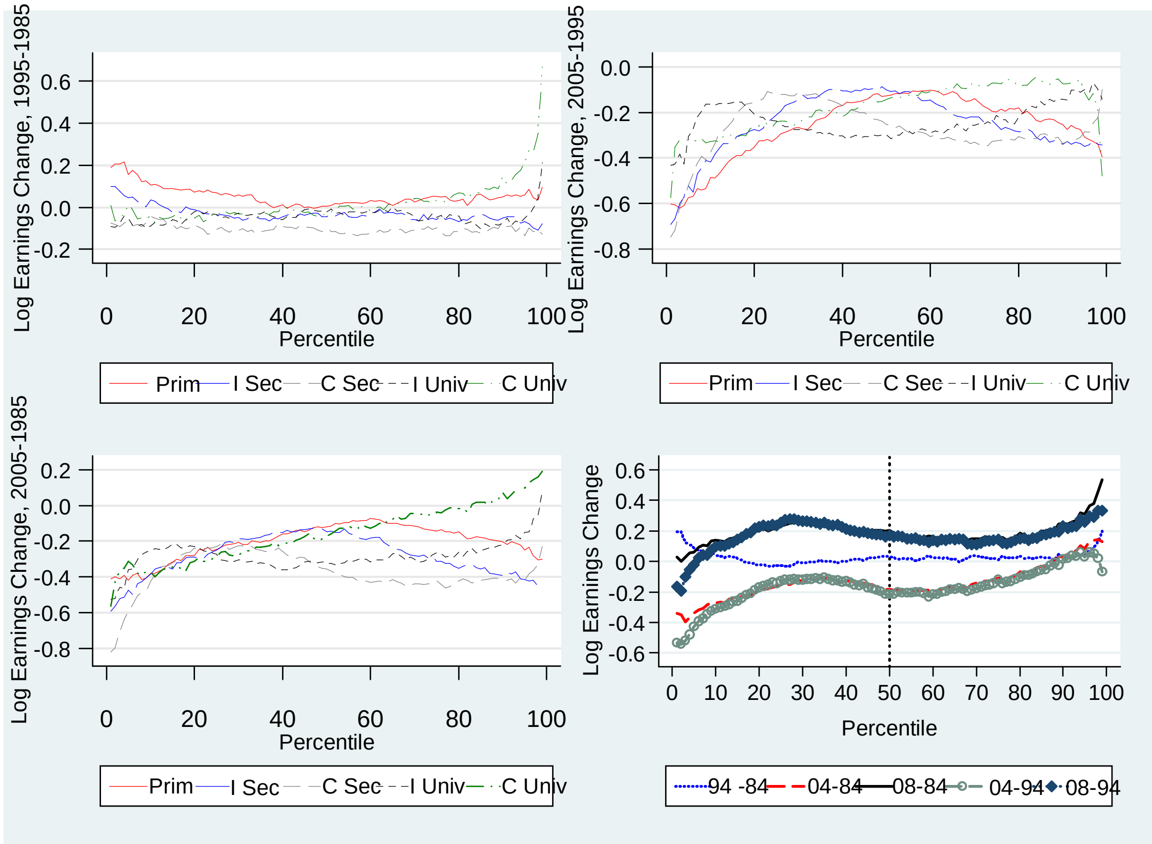

Figure 12: Change in log Real Hourly Wages by Education Level and Aggregated, and by Percentile. 7 Main Colombian Cities, 1985-2009.

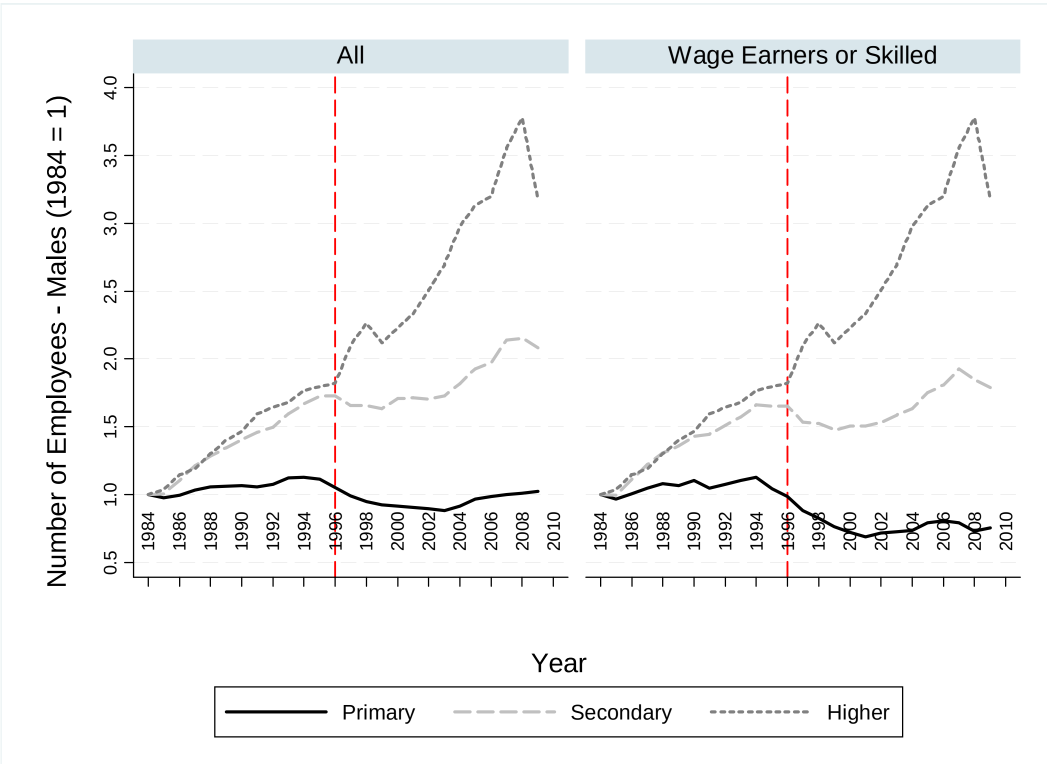

Figure 13: Evolution of the Number of Occupaid and Wage Earners Males. 7 Main Colombian Cities, 1984-2009

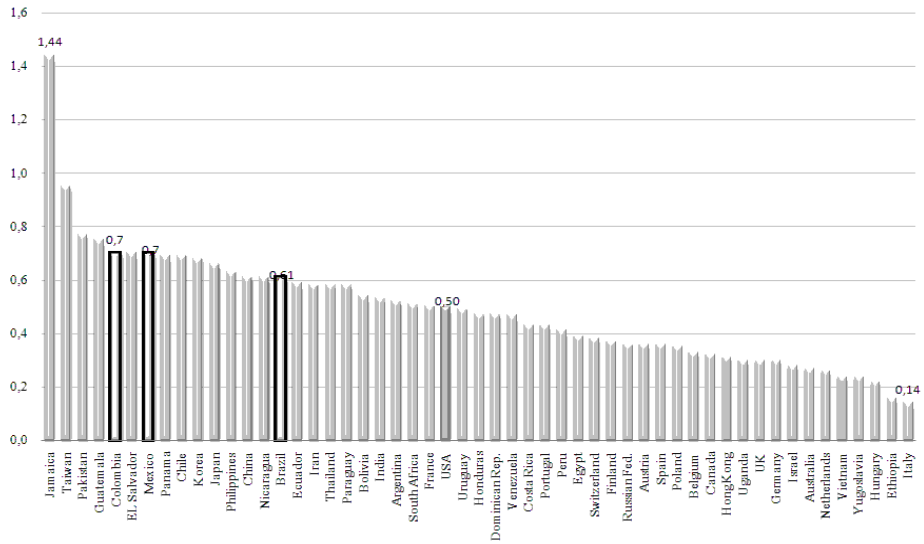

Figure 14: College/High School Skill Premium
Source: Author's calculation using data from Contreras (2002) for Chile; Autor et al. (2005) for the US; iAnd Acemoglu (2003b); Benerjee and Duflo (2005), and Caselli and Coleman (2006) for other countries.

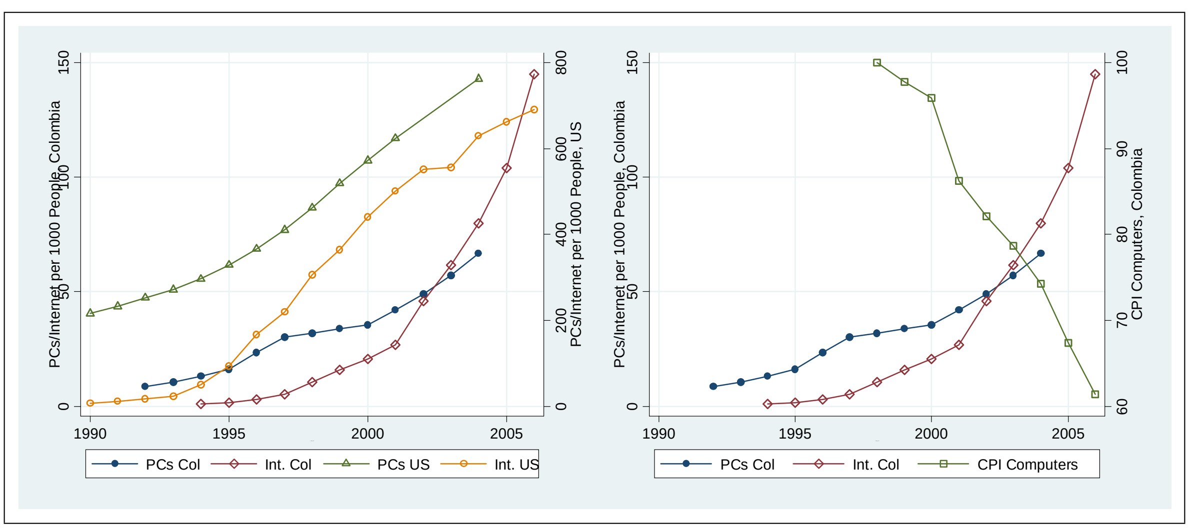

Figure 15: Computer and Internet Use in Colombia and the United States versus Evolution of PCs CPI for Colombia.

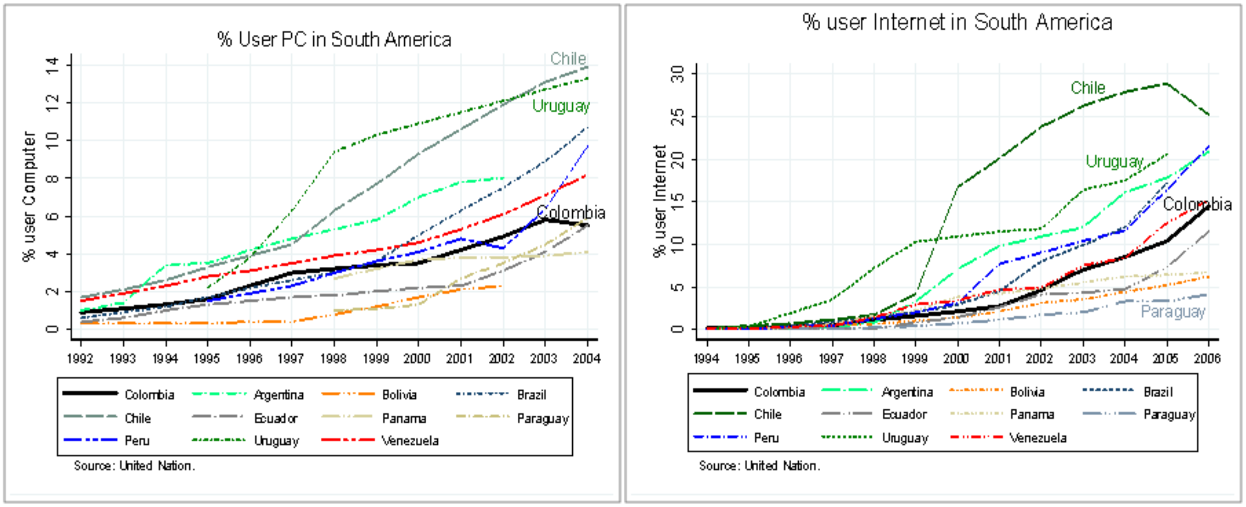

Figure 16: Computer and Internet Use in Colombia and South American Countries.

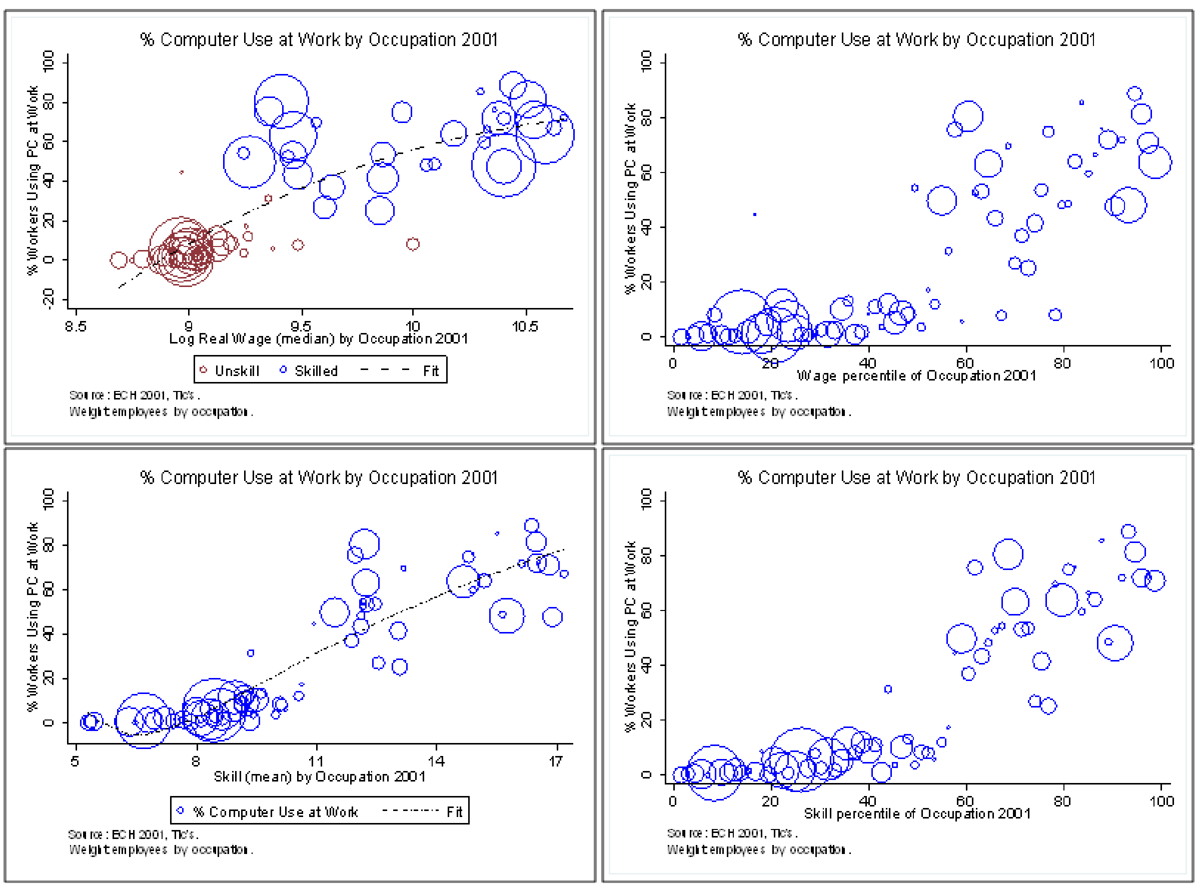

Figure 17: Percent of Workers Using PC at Work by Occupation, Wage and Education Levels. 13 Main Colombian Cities, 2001.

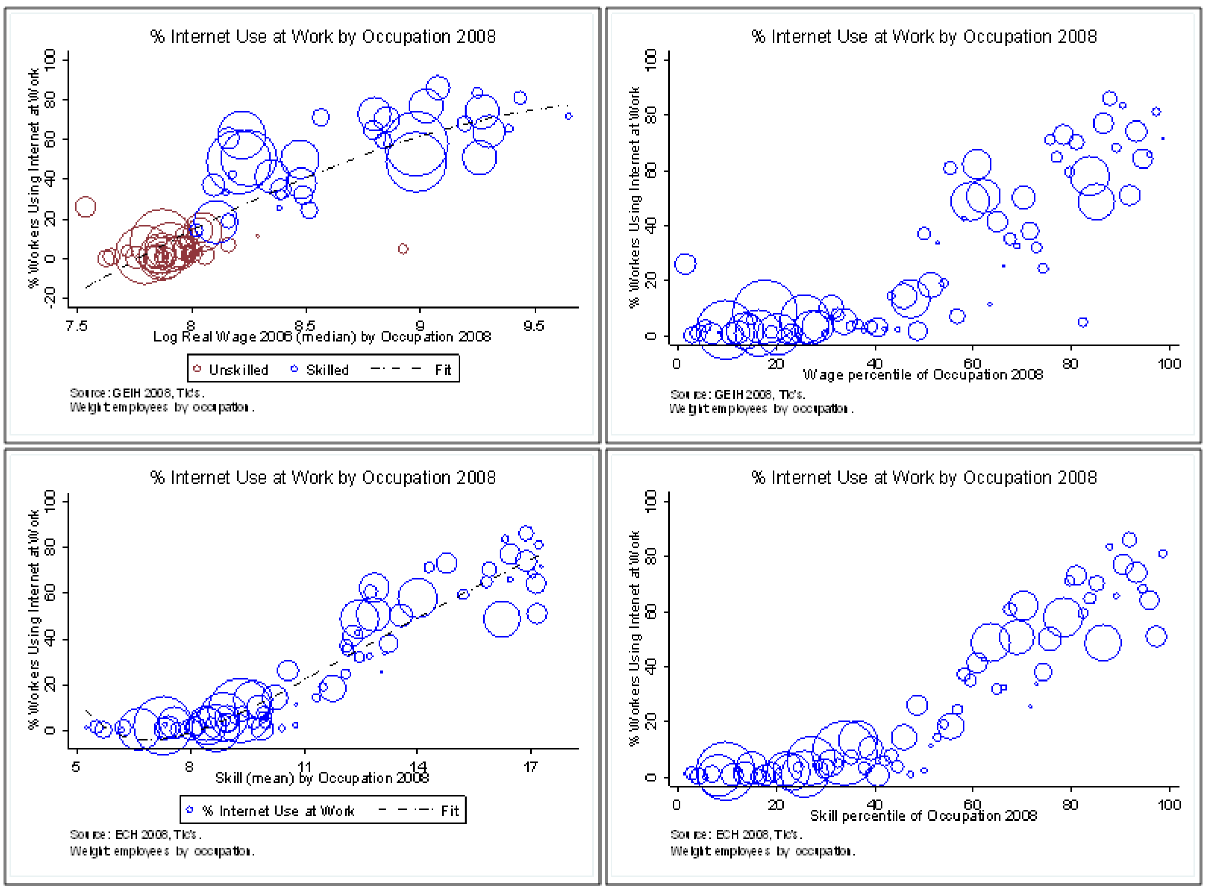

Figure 18: Percent of Workers Using Internet at Work by Occupation, Wage and Education Levels. 13 Main Colombian Cities, 2008.

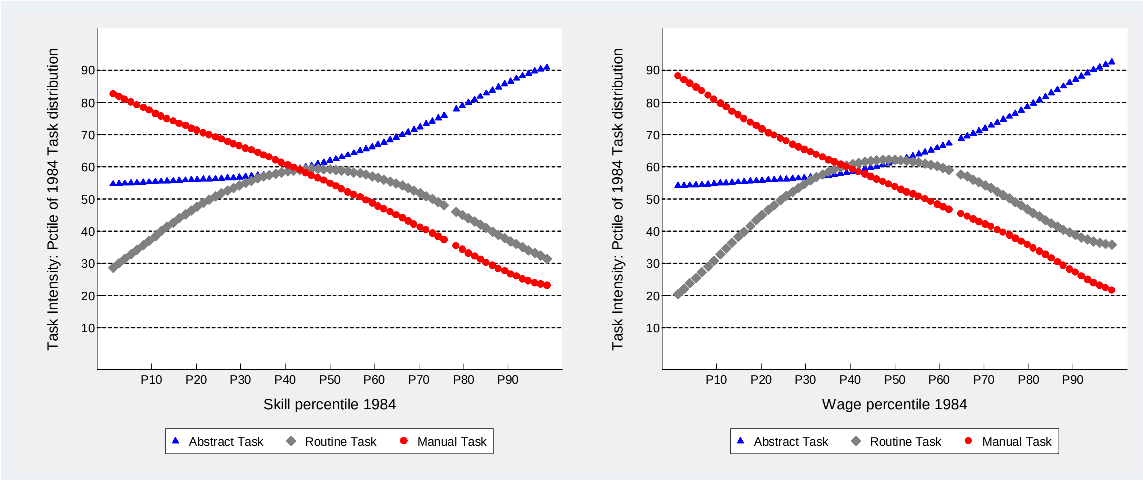

Figure 19: Task Intensity by Occupational Skill and Wage Percentile, Defined as Occupational Rank in Percentiles in Mean Years of Schooling and Wages, Colombia

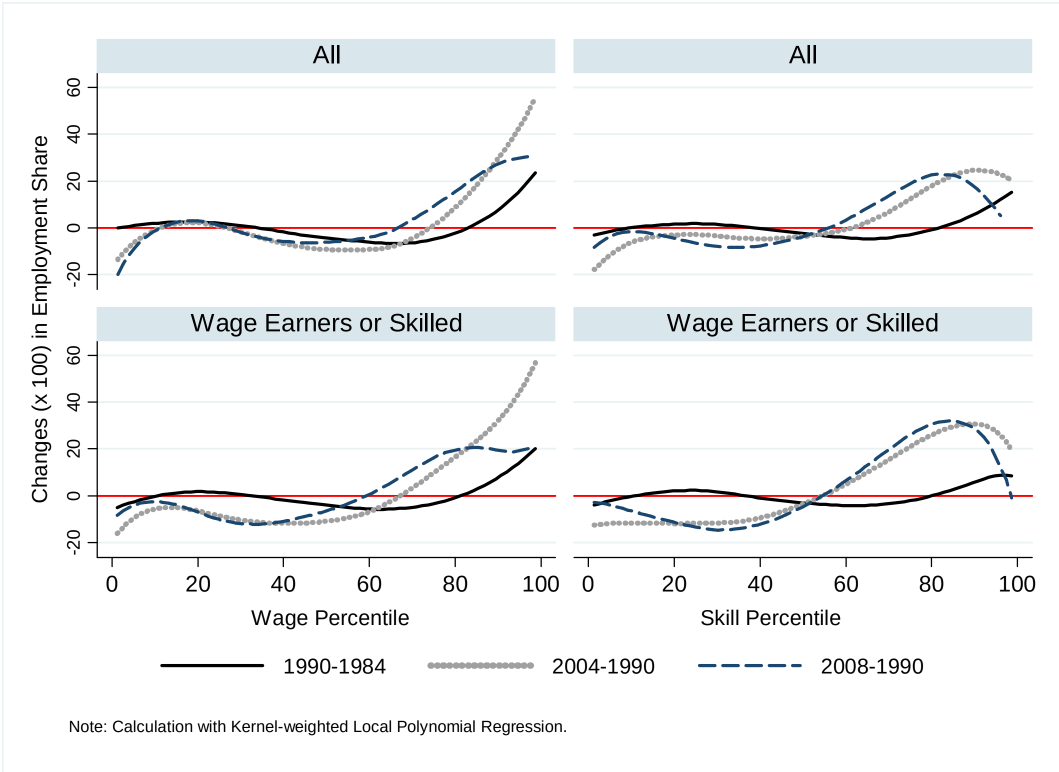

Figure 20: Change in Occupation Employment Shares 1984-1990, 1990-2004 and 1990-2008, by Occupation Wage and Skill Percentiles in 1984, Colombia.

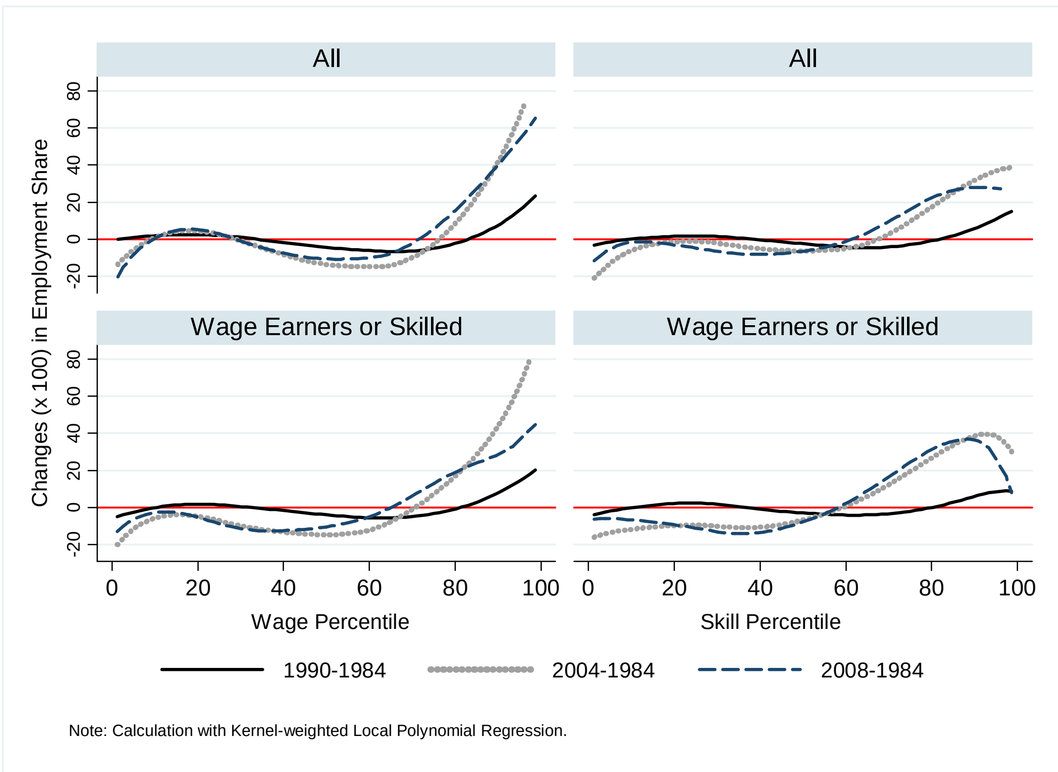

Figure 21: Change in Occupation Employment Shares 1984-1990, 1984-2004 and 1984-2008, by Occupation Wage and Skill Percentiles in 1984, Colombia.

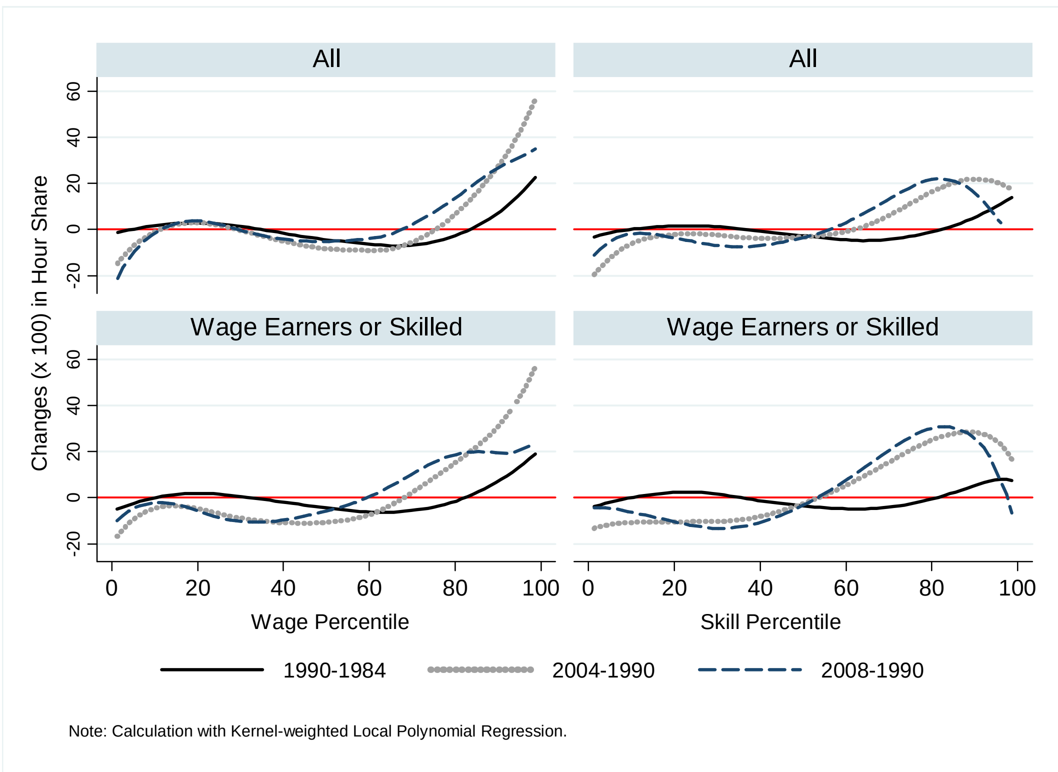

Figure 22: Change in Occupation Hour Shares 1984-1990, 1990-2004 and 1990-2008, by Occupation Wage and Skill Percentiles in 1984, Colombia.

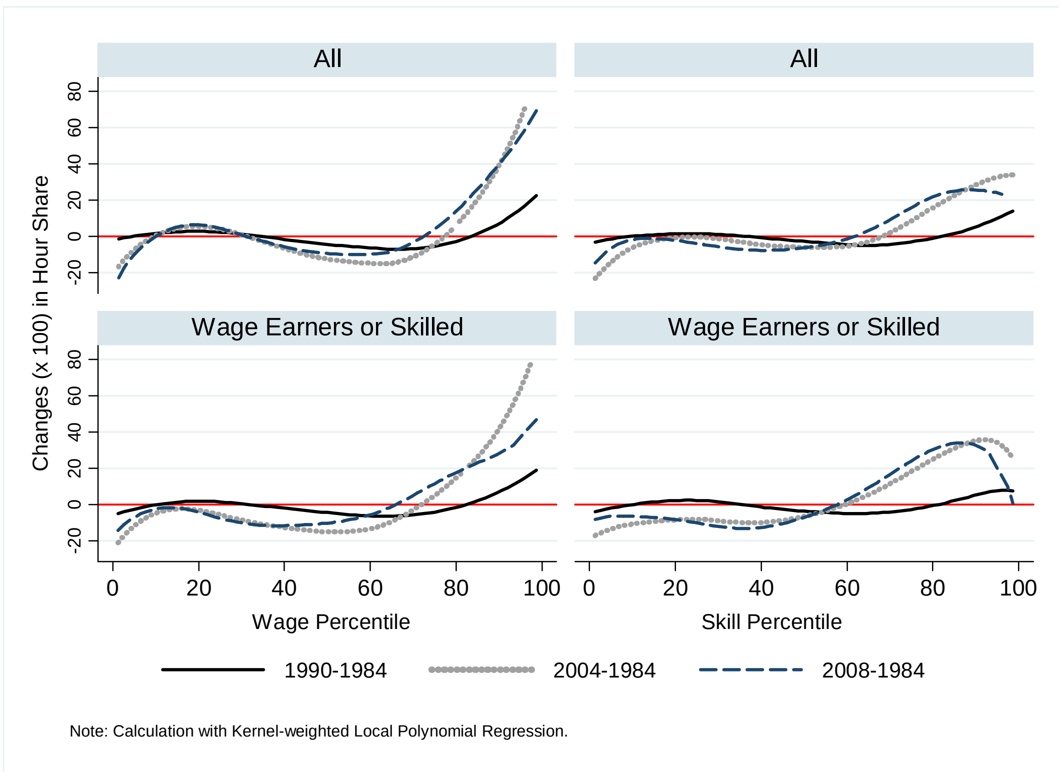

Figure 23: Change in Occupation Hour Shares 1984-1990, 1984-2004 and 1984-2008, by Occupation Wage and Skill Percentiles in 1984, Colombia.

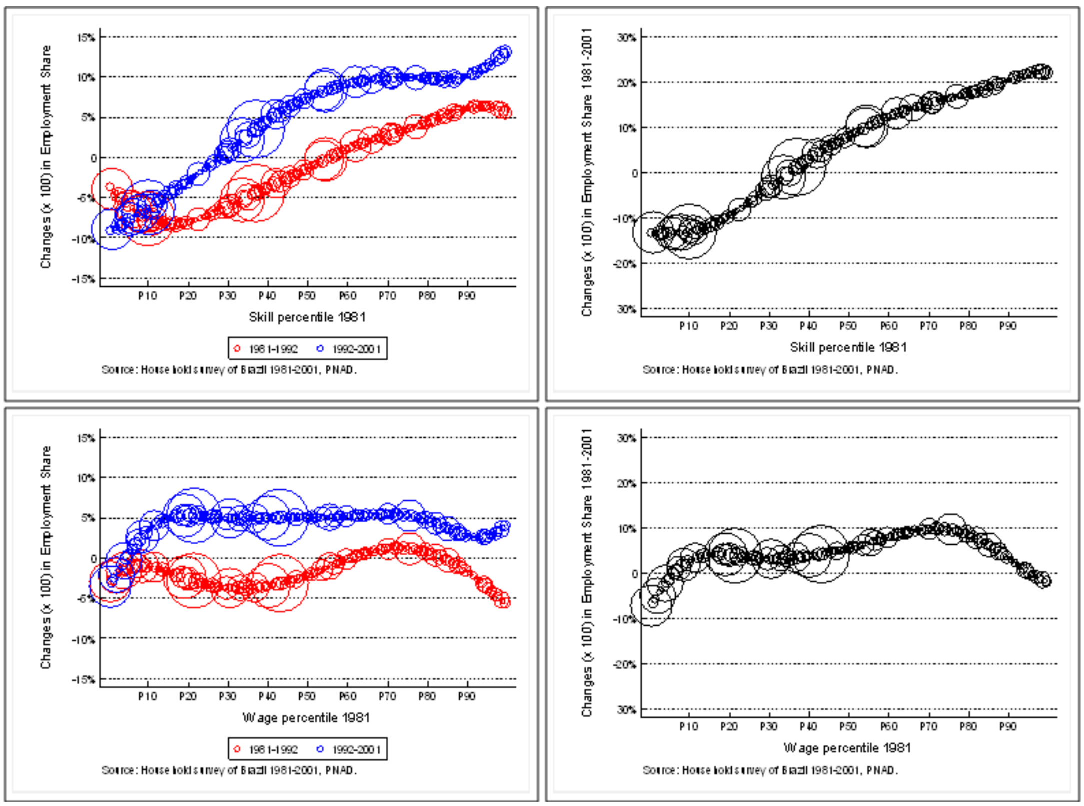

Figure 24: Change in Occupation Employment Shares 1981-1992 and 1992-2001 by Occupation Wage and Skill Percentiles in 1981, Brazil.

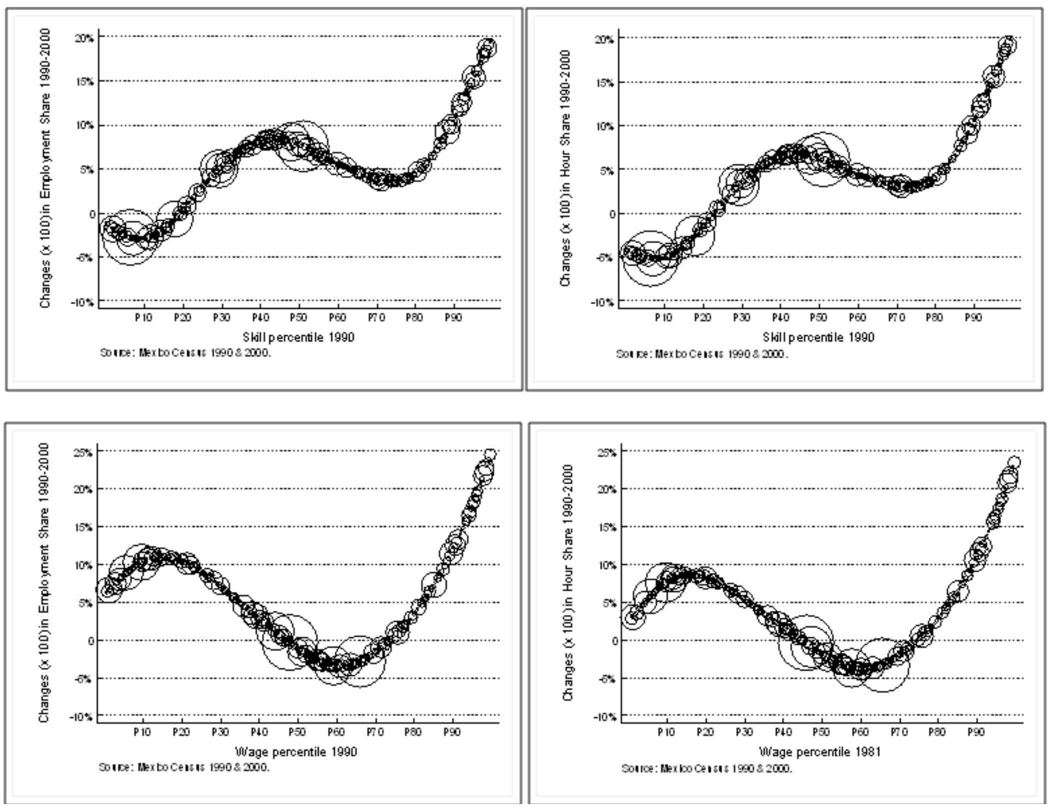

Figure 25: Change in Occupation Employment and hours Shares 1990-2000 by Occupation Wage and Skill Percentiles in 1990, Mexico.