Why Have Aggregate Skilled Hours Become So Cyclical Since the Mid-1980’s?*

Rui Castro† Daniele Coen-Pirani‡

First Version June 2003
This Version March 2005

Preliminary and Incomplete - Comments Welcome

Abstract

This paper documents and discusses a dramatic change in the cyclical behavior of aggregate hours worked by individuals with a college degree (skilled workers) since the mid-1980’s. Using the CPS outgoing rotation data set for the period 1979:1-2003:4, we find that the volatility aggregate skilled hours relative to the volatility of GDP has nearly tripled since 1984. In contrast, the cyclical properties of unskilled hours have remained essentially unchanged. We evaluate the extent to which a simple supply/demand model for skilled and unskilled labor based on the hypothesis of capital-skill complementarity in production can help explain this stylized fact. Within this framework, we identify three effects which would lead to an increase in the relative volatility of skilled hours: (i) a reduction in the absolute volatility of GDP (and unskilled hours), (ii) an increase in the level of capital equipment relative to skilled labor, and (iii) a reduction in the degree of capital-skill complementarity. We provide empirical evidence in support of each of these effects. Our conclusion is that these three mechanisms can jointly explain about sixty percent of the observed increase in the relative volatility of skilled labor. The reduction in the degree of capital-skill complementarity contributes the most to this result.

*We thank Paul Beaudry, Per Krusell, José-Victor Ríos-Rull, Scott Schuh, and Gianluca Violante for helpful conversations and comments, as well as seminar attendants at Carnegie Mellon, NYU, Université Laval, 2004 CEA Meeting in Toronto, 2003 Rochester Wegmans conference, and 2003 SED Meeting in Paris, for helpful suggestions on earlier drafts of this paper. Thanks to Gianluca Violante for providing us with updated data for capital equipment. The usual disclaimer applies.

†Department of Economics and CIREQ, Université de Montréal. Email: rui.castro@umontreal.ca. Web: http://www.fas.montreal.ca/sceco/castroru

‡Tepper School of Business, Carnegie Mellon University. E-mail: coenp@andrew.cmu.edu. Web: http://www.andrew.cmu.edu/user/coenp/web.
1 Introduction

Since the mid-1980's aggregate hours worked by individuals with a college degree have become much more procyclical and volatile relative to aggregate output. In contrast, the cyclical properties of aggregate hours for individuals without a college degree have remained roughly constant over the sample period. The increased cyclical instability of skilled labor has received attention in the popular press, but has not been extensively documented, quantified or formally discussed by academics so far.\(^1\) In this paper we first document and then try to formally explain these facts.

Empirical Analysis. We use the Current Population Survey (CPS)’s Merged Outgoing Rotation Groups to construct quarterly measures of the quantity and price of hours worked by college educated (“skilled”) and non-college educated (“unskilled”) workers for the sample period 1979:1-2003:4. To compute the quantity and price of labor of each skill group, hours worked by different individuals are aggregated controlling for compositional effects. Fluctuations in total hours are further attributed to variation in employment and hours per employed worker. Inspection of these data reveal a striking change in their cyclical behavior, starting around 1984. Whereas the series for unskilled workers follow closely the behavior of real Gross Domestic Product (GDP) and become substantially less volatile after 1984, the series for skilled workers become slightly more volatile. This motivates us to split the sample in 1984 and to consider the two subperiods separately.

In the 1979:1-1983:4 subperiod, aggregate total hours worked by skilled individuals are not very volatile relative to output, with a standard deviation relative to GDP of 0.37. Instead, the unskilled labor input is roughly as volatile as GDP, with a relative standard deviation of 0.97.

This pattern changes dramatically sometime in the 1984:1-2003:4 subperiod. Whereas the behavior of unskilled hours relative to GDP remains basically the same as in the first subperiod, the relative volatility of skilled hours, in sharp contrast, increases to 1.04, a figure that actually exceeds the corresponding one for unskilled hours (0.90). This pattern is dominated by a change in the behavior of skilled employment rather than average hours per employed worker. In contrast

\(^1\)See, for example, the 1996 article by Paul Krugman and the 2002 article by Alan Krueger in the New York Times. The former writes that: “As economists quickly pointed out, the rate at which Americans were losing jobs in the 90s was not especially high by historical standards. Why, then, did downsizing suddenly become news? Because for the first time white-collar, college-educated workers were being fired in large numbers, even while skilled machinists and other blue-collar workers were in high demand. This should have been a clear signal that the days of ever-rising wage premia for people with higher education were over, but somehow nobody noticed.” Below we review the related empirical literature.
to the change in the behavior of quantities, the skill premium has remained essentially acyclical throughout this period, and not very volatile relative to GDP.

**Theory.** Our second goal is to try to qualitatively and quantitatively explain the increase in the cyclical volatility of skilled hours. For this purpose, we adopt a simple relative demand/supply framework. On the demand side, we consider the problem of a competitive representative firm optimally choosing its labor inputs and capital stocks for given input prices, technology, and business cycle shocks. Consistently with recent empirical literature on the low-frequency behavior of the skill premium (see e.g. Krusell, Ohanian, Ríos-Rull, and Violante (2000)), we postulate that the production function exhibits capital-skill complementarity. On the supply side, and in line with the empirical evidence we discussed previously, we assume preferences that yield an infinitely elastic relative supply of skilled labor, and hence a constant skill premium at the cyclical frequency.

In equilibrium, capital-skill complementarity implies that skilled hours are cyclically less volatile than unskilled hours. To see this, consider for example, a recession. In a recession, demand for skilled and unskilled hours drops. However, given that the stock of capital equipment changes slowly at high frequencies, capital-skill complementarity in production increases the relative demand for skilled hours, leading to a smaller reduction in the quantity of this type of labor input. Oi (1962) and Rosen (1968) call this mechanism the “substitution hypothesis”.

Our hypothesis is that there has been a weakening of this mechanism since 1984, leading to the observed increase in the relative volatility of skilled hours. This might have happened for three independent reasons: 1) a decrease in the volatility of unskilled labor relative to the volatility of capital equipment, 2) an increase in the level of capital equipment relative to skilled labor, and 3) a structural decrease in the degree of capital-skill complementarity itself.

**Empirical Implementation and Results.** In order to evaluate this hypothesis quantitatively, we first provide empirical evidence in support of the three effects just mentioned. We find direct evidence for the first two, as well as indirect evidence pointing to a significant decrease in the degree of capital-skill complementarity: the skill premium has been growing much more slowly since the late 1980’s, while at the same time investment in equipment has boomed.

We then calibrate the parameters of the model, by matching some key long-run features of the data: the average growth rate of the skill-premium, the average labor share, and the average wage-
bill ratio. These estimates are then used, together with the actual data, to compute the cyclical properties of skilled hours predicted by the model. We find that the mechanisms we propose jointly account for about sixty percent of the increase in the relative volatility of skilled hours. The main effect, from a quantitative point of view, comes from the reduction in the degree of capital-skill complementarity, followed by the lower volatility of unskilled labor.

**Related Literature.** This paper is related to several literatures. The first one concerns the pre-1984 stylized facts reported above: the lower cyclicality of skilled hours relative to unskilled hours, and the cyclical behavior of the skill premium. Oi (1962) and Reder (1964) were among the first to document and discuss the fact that employment of unskilled workers tends to be more cyclical than the one of unskilled workers. Kydland (1984) writes that “it is a well-known fact that unskilled workers in the United States labor force exhibit greater employment fluctuation over the business cycle than do skilled workers.” He finds further evidence in favor of this proposition by considering Panel Study on Income Dynamics (PSID) data for the period 1970-80 and documenting that annual hours worked by individuals with less education tend to be more sensitive to business cycle conditions than hours worked by more educated individuals. Ríos-Rull (1993) uses the PSID for the period 1969-1982 and reports (Table 2) that workers in higher wage groups are characterized by a lower standard deviation of annual hours worked. Keane and Prasad (1993) use yearly data from the National Longitudinal Study of Youth for the period 1966-1981 and report (page 725) that “workers with a college degree have essentially acyclical employment patterns.” Reder (1955), instead, focuses on the skill premium and provides evidence that the latter tends to move countercyclically over the cycle. This evidence is challenged by Keane and Prasad (1993) who, instead, find the skill premium to be acyclical. In general these papers tend to confirm our findings for the pre-1984 subperiod.

A few formal models have attempted to rationalize these pre-1984 facts. Kydland (1984) and Prasad (1996) extend the representative agent real business cycle model to allow for skilled and unskilled workers. In Kydland’s model, the relative efficiency of unskilled workers moves procyclically, leading to more volatile hours for these workers and to a countercyclical skill premium. In Prasad’s extension of Hansen’s (1985) model, instead, variations in skilled employment are subject to an adjustment cost that makes the employment of skilled workers less volatile over the business
cycle. The problem with both models is that they don’t explain, but rather assume from the start, why skilled hours tend to be less cyclical than unskilled hours. One contribution of our analysis is to try to explain this fact within a neoclassical framework. Young (2003) and Lindquist (2004) use calibrated general equilibrium models with capital-skill complementarity in production to explain the cyclical behavior of the skill premium. They analyze the same CPS data we use in our empirical analysis, but do not split the sample and therefore fail to detect the dramatic increase in the volatility of skilled hours since 1984.²

A growing literature, reviewed by Stock and Watson (2002), has documented and discussed the reduction in the volatility of GDP and aggregate hours that occurred around 1984. As far as we are aware, we are the first to provide a comprehensive documentation of the change in the cyclical behavior of skilled and unskilled hours that occurred in the mid-1980’s. This decomposition is interesting because, while unskilled hours follow closely the behavior of GDP, skilled hours display a very different pattern. Farber (1997) provides some independent evidence consistent with the data we analyze. Using the Displaced Workers Survey supplements of the CPS he examines rates of job loss between 1981 and 1995 for different demographic groups. He finds that over the sample period job loss rates increased for workers in all educational categories, but proportionally more for more educated ones. In particular, the 1990-91 recession has been characterized by larger rates of job loss for white collar workers than the 1981-82 one.

Finally, this paper is related to the recent literature that has tried to explain the low frequency dynamics of the skill premium (see Acemoglu (2002) for a review of this literature). Some influential papers in this literature (e.g. Katz and Murphy (1992) and Krusell, Ohanian, Ríos-Rull, and Violante (2000)) have argued that the decline of the skill premium in the 1970’s and its increase in the early 1980’s are consistent with a simple supply/demand view of the labor market.³ In

²Both papers focus more on the behavior of prices (the skill premium) than on allocations (relative hours worked). When focusing on the entire sample 1979:1-2003:4 we find that our empirical results concerning the correlation of the skill premium with output are similar to the ones reported in Young (2003) and Lindquist (2004). However, contrary to Lindquist (2004) and similarly to Young (2003), we find that the skill premium is significantly less volatile than output. This discrepancy might be explained by the fact that Lindquist (2004) defines skilled (unskilled) wages as the average of hourly wages across skilled (unskilled) workers. Instead, we define skilled wages as the ratio of total weekly earnings by skilled workers and their total hours. The difference between these two approaches is that the former weights all individual wages equally while the latter uses individuals’ relative hours as weights.

³These two papers differ in one important dimension. Katz and Murphy (1992) argue that the dynamics of the skill premium in the period 1963-1987 can be explained by variations in the relative supply of skilled workers combined with a constant rate of growth of skill-biased technological change. Krusell, Ohanian, Ríos-Rull, and Violante (2000), instead, argue that the acceleration in the growth rate of capital equipment since the late 1970s, plays a major role in accounting for the increase in the skill premium in the 1980s.
particular, in Krusell, Ohanian, Ríos-Rull, and Violante (2000) skilled workers are relatively more complementary to capital equipment than unskilled workers, so an increase in the stock of capital equipment leads to an outward shift in the relative demand for skilled workers. The assumption of capital skill complementarity is relevant for our analysis at the cyclical frequency, where the capital stock can be taken as given. Capital skill complementarity, in fact, leads to an increase in the relative demand for skilled hours in recessions, explaining, at least qualitatively, why the volatility of skilled hours might be lower than the volatility of unskilled hours.

Part of our explanation for the dramatic increase in the volatility of skilled hours after 1984 tries to link a change in the low frequency dynamics of the skill premium in the late 1980’s and in the 1990’s to a structural change in the degree of capital-skill complementarity. Card and DiNardo (2002) and Beaudry and Green (2002) have also pointed out that the skill premium has grown at a lower rate during the 1990’s than in the early 1980’s, despite the slowdown in the growth rate of the relative supply of college-educated workers, and the absence of evidence indicating a slowdown in the rate of technological change. It follows that, using the relative demand equation for skilled workers estimated with pre-1984 data to predict the subsequent behavior of the skill premium, would lead to a substantial overprediction of its growth rate. This observation (among others) leads Card and DiNardo (2002) to question the usefulness of the skill-biased technical change hypothesis, in favor of an explanation of the rising skill premium based on the fall of the real value of the minimum wage. Beaudry and Green (2002), instead, assume an alternative production structure to the one employed by Krusell, Ohanian, Ríos-Rull, and Violante (2000). In their model, at each point in time a traditional and a modern production technology coexist. The modern technology is assumed to use more capital relative to any kind of labor, more skilled labor relative to unskilled labor, and less capital per unit of output than the traditional one. They attribute the rise in the skill premium in the early 1980’s to the increase in the supply of skilled labor relative to capital, and its subsequent slowdown to the reversal of this trend starting from the late 1980’s.\(^4\) Differently from these two papers, we interpret these facts from the point of view of Krusell, Ohanian, Ríos-Rull, and Violante (2000)’s capital skill complementarity hypothesis. In particular, we take the deceleration in the growth rate of the skill premium and the contemporaneous acceleration in the growth rate of capital

\(^4\)Notice that, differently from Krusell, Ohanian, Ríos-Rull, and Violante (2000), their restrictions on technology guarantee that an increase in the ratio of skilled labor to capital gives rise to an increase in the skill premium.
equipment that occurred starting from the late 1980’s, as evidence of a structural decline in the degree of complementarity between skilled labor and capital equipment. Our hypothesis is that while skilled labor and capital equipment do tend to always be complementary in production, the degree of complementarity is likely to depend on the specific nature of technology. In particular, according to our hypothesis, a unique feature of the most recent technological vintage (computers and information technologies) is that, once they have diffused and matured, they require less supervision and maintenance by highly skilled workers.

The remainder of the paper is organized as follows. In Section 2 we present and discuss the stylized facts about the behavior of the skilled and unskilled labor inputs and their relative price that are the object of our empirical analysis. In Section 3 we discuss our hypothesis from a qualitative point of view. Section 4 presents the quantitative results. Section 5 concludes. Appendix A contains a more detailed description of how we constructed our statistics than is found in the main text.

2 Empirical Analysis

Our goal in this section is to document the business cycle dynamics of total hours, employment, weekly working hours per employed worker, and relative wages of skilled and unskilled individuals. An individual is “skilled” if he/she has obtained at least a four-year college degree. In order to construct “skilled” and “unskilled” aggregates for these variables we take an efficiency units approach, analogous to Katz and Murphy (1992) and Krusell, Ohanian, Rios-Rull, and Violante (2000).

2.1 Data

We now describe in some detail the data set and the way our variables of interest are constructed.\footnote{More details on the data and the variables are provided in Appendix A.}

The main data set we use is the Merged Outgoing Rotation Groups (MORG) extracts from 288 Monthly Current Population Surveys (CPS), prepared by the NBER and covering the period from 1979 through 2003. Monthly observations are obtained by using information on each individual’s interview month. Each monthly sample contains about 30,000 individuals which are associated with a sample weight and are therefore representative of the U.S. population with 16 years of age
and over. In what follows we always use these weights to aggregate individual observations.


For each quarter, we restrict attention to individuals in the labor force that are not self-employed to concentrate on paid earnings. After applying some standard sample selection criteria to deal with missing observations and coding errors we end up, for each quarter, with a cross-section of about 45,000 representative individuals, of which, on average, about 10,000 hold at least a college degree.

The variables we use to construct measures of employment and hours of work for skilled and unskilled workers are: employment status, usual weekly earnings (inclusive of overtime, tips and commissions), usual weekly hours worked, and a series of demographic variables such as age, sex, race and years of education.

Weekly earnings are top-coded in the CPS. The top-code was revised twice during the sample, at the end of 1988 and at the end of 1997. We imputed top-coded earnings by multiplying every top-coded value in the sample by 1.3. This adjustment factor ensures that average earnings in the top decile remain constant from December 1988 to January 1989 (when only a very small number of observations is top-coded). It turns out that the same adjustment factor works for 1997. For each quarter, real weekly earnings are computed by deflating nominal weekly earnings by the Consumer Price Index (CPI). We use the monthly CPI, not seasonally adjusted. Real hourly wages are computed as real weekly earnings divided by usual weekly hours.

The variables of interest are defined in some more detail as follows.

**Employment.** Aggregate employment for skilled (unskilled) individuals in a given quarter is just given by the sum of skilled (unskilled) individuals, weighted by their sampling weight, who report to be employed in that period. Aggregate skilled employment grew over the sample period at the average rate of 3.3 percent per year, against an yearly growth rate of 0.8 percent of unskilled employment. Thus, the skilled share of aggregate employment went from 18 percent in 1979:1 to 29 percent in 2003:4.

**Total Hours.** To construct a measure of total hours worked by skilled (unskilled) individuals in
a given quarter we adopt an efficiency units approach.\(^6\) This amounts to using some time-invariant measure of individuals’ hourly wages as weights when aggregating the hours worked by different individuals. The purpose of this procedure is to control for composition effects. For example, if labor force quality is countercyclical, then a simple aggregation of hours across workers is likely to introduce a countercyclical bias in the measure of the real wage and exaggerate the volatility of hours over the cycle.\(^7\) We first partition the sample into 176 demographic groups. Demographic groups are constructed using information on individuals’ sex, age, race and education. First, for each quarter and for each demographic group in our partition we compute total weekly hours worked by individuals in that group and their associated total earnings by summing the individual data. This amounts to assuming that individuals in each group are perfect substitutes. We then divide total weekly earnings by total hours to obtain a measure of the hourly wage rate for that demographic group. A group’s average hourly wage rate across all quarters is then used, together with its sampling weight, to aggregate hours of work across demographic groups. Total hours for skilled (unskilled) workers in a quarter are then defined as the weighted sum of total hours worked by demographic groups composed by skilled (unskilled) individuals. These series two series are reported in Figure 1. This figure documents an increase in total hours throughout the sample period, at a significantly higher pace for skilled workers. The main driving force was an increase in the relative employment of skilled workers.

**Average Weekly Working Hours.** This variable is defined as Total Hours divided by Employment.

**Hourly Wage.** To define the hourly wage for skilled (unskilled) individuals we divide the sum of weekly earnings across the appropriate demographic groups by our measure of total hours.

**Skill Premium.** The skill premium is defined as the ratio of hourly wages of skilled and unskilled

---

\(^6\)This is a point of departure of our empirical analysis from Young (2003) and Lindquist (2004), who do not control for cyclical changes in the demographic composition of skilled and unskilled employment. Also, Young’s (2003) reported statistics computed using the MORG data (Table 1, page 24) suggest that he is focusing on average hours worked by employed individuals, rather than total hours (which are significantly more volatile).

\(^7\)Rather than focussing on hours in efficiency units as a way to overcome the aggregation bias, several papers in the literature have alternatively exploited the panel dimension of the data, in order to control for worker characteristics - see Bils (1985), Solon, Barski, and Parker (1994) and Keane and Prasad (1993). For papers that have also used an efficiency units approach see Hansen (1993), Kydland and Prescott (1993) and Bowlus, Liu, and Robinson (2002).
workers. It is represented in Figure 1. The figure documents a steady increase in the skill premium in the last two decades, 22 percent between 1979:1 and 2003:4, with a slower growth rate in the 1990’s.

2.2 Stylized Facts

In what follows we are interested in the behavior of the quantity and price variables described above at the business cycle frequency. The raw series of these variables, like the ones displayed in 1, typically display a trend, seasonal cycles and fluctuations with higher frequencies than standard business cycles. The logarithm of each series is detrended using the Hodrick-Prescott filter with parameter 1600, as is standard with quarterly data. In order to deseasonalize the series we use the Census Bureau’s seasonal adjustment program, X12. Finally, in order to smooth the high frequency variations in the data, we applied a centered five quarters moving average to the seasonally adjusted series.  

---

\[\text{This high frequency noise is likely due to measurement error. In fact, it becomes more significant for more disaggregated time-series, such as the ones underlying Tables 3 and 5, which are based upon a smaller number of observations.} \]

\[\text{Filtering away the high frequency fluctuations in the data does not significantly affect the stylized facts emphasized in this section. Appendix B contains the main data tables reported in this section using deseasonalized but unfiltered data.}\]
We start by documenting the business cycle behavior of broad aggregates. We then verify the robustness of our findings by repeating the analysis by sector and occupation, by restricting the sample to white males, aged 31 to 55, and finally by using a more stringent definition of skilled workers. For the reader’s convenience we organize our main findings into a number of “stylized facts”.

2.2.1 Breaking the Sample

Figure 2 shows the cyclical behavior of total hours per skill group, together with real GDP.\textsuperscript{10} A quick glance at this figure reveals a clear difference between the first and the second halves of our sample. In the first two NBER recessions (1980 and 1981-82), the unskilled labor input is strongly procyclical and essentially as volatile as output.\textsuperscript{11} The skilled labor input, instead, is not very volatile. The last two recessions (1990-91 and 2001) display a remarkably different pattern: the skilled input becomes strongly procyclical and essentially as volatile as both GDP and the unskilled input.

This dramatic increase in the \textit{absolute} volatility of skilled labor is remarkable because, as doc-

\textsuperscript{10}Real GDP is expressed in billions of chained 2000 dollars and is seasonally adjusted. The series can be downloaded from the BEA website.

\textsuperscript{11}NBER recessions are represented by the shaded areas in the figure.
umented by McConnell and Perez-Quiros (2000), Stock and Watson (2002) and many others, the volatility of most macroeconomic aggregates has declined since the mid-1980’s. The time-series for the skill premium reveals a similar pattern, becoming more volatile since the mid-1980’s. However, it has remained essentially acyclical throughout the whole sample period.

In Figure 3 we present the rolling standard deviations of GDP, unskilled and skilled hours. In each quarter $t$ the figure represents the standard deviations of the cyclical component of these variables computed using observations from $t$ to $t + 40$. As the figure shows, around the mid-1980’s the standard deviations of all variables settle down to a new level, which is lower than in 1979 for GDP and unskilled hours, and is actually slightly higher for skilled hours. In our view this is the main puzzle that has to be addressed: why didn’t skilled hours become less volatile when business cycle volatility declined?

Using formal tests McConnell and Perez-Quiros (2000) date the break in the volatility of the growth rate of GDP to 1984:1. Based upon this evidence, we split the sample in two subperiod around 1984:1. For each of the two subsamples 1979:1-1983:4 and 1984:1-2003:4, we characterize the cyclical behavior of skilled and unskilled labor.\footnote{The statistics we present in this section are robust to variations in the break date. We obtained very similar results with alternative break dates, at 1986:4-1987:1 (mid-point of the expansion that started at the trough (1982:4) of the 1981-82 recession and ended at the onset of the 1990-91 recession (1990:3)) and at 1989:4-1990:1 (just before}
Table 1: Volatility and co-movement of total hours, employment and average weekly hours per skill group (Household Survey). Legend: $a, b, c$ denote correlations significant at 1, 5, and 10 percent level, respectively.

### 2.2.2 Broad Aggregates

Table 1 summarizes the cyclical properties of total hours of work by skill group and in the aggregate, before and after 1984:1. In this table we also decompose the fluctuations in total hours into variations in employment (extensive margin) and in working hours per employed workers (intensive margin). In the “Relative Volatility” columns we report the standard deviation of the cyclical component of a variable relative to that of real GDP. The “Comovement” columns, instead, report the contemporaneous correlation between the cyclical component of a variable and the cyclical component of real output.

From this table we observe that, even though the statistical properties of aggregate hours tend to be similar across the two subsamples, there is a significant amount of heterogeneity across skill groups. We draw two main conclusions:

**Stylized Fact #1.** Before 1984 total hours worked by skilled individuals are procyclical but not very volatile relative to GDP. After 1984 their relative volatility nearly triples. These results are driven by an increase in the relative volatility of skilled employment after 1984.

**Stylized Fact #2.** The cyclical properties of total hours worked by unskilled individuals remain roughly constant relative to GDP after 1984. Specifically, their relative volatility remains virtually unchanged and close to one.\(^{14}\)

---

\(^{13}\) Aggregate hours are obtained by aggregating the hours worked by all individuals in the sample, following the efficiency units approach described in Section 2.1.

\(^{14}\) Unskilled total hours display a one quarter lag with respect to GDP in both subperiods. Notice that the contemporaneous correlation of GDP with unskilled hours, employment, and especially average weekly hours drops after 1984.
Table 2: Volatility and co-movement of the skill premium and wages per skill group and in the aggregate (Household Survey). Legend: $a, b, c$ denote correlations significant at 1, 5, and 10 percent level, respectively.

Despite the changes in the cyclical behavior of quantities, we do not observe a significant change in the behavior of prices. Table 2 summarizes the cyclical behavior of wages and the skill premium by skill group and in the aggregate, before and after 1984.

This table shows that, even though prices tend to become more volatile after 1984, they do not exhibit a strong systematic cyclical pattern throughout the samples. Our main conclusion is thus that:

**Stylized Fact #3.** The skill premium is acyclical both before and after 1984.

Unfortunately the CPS data we are using are available only from 1979 onwards. This leaves us with a relative short sample for the period 1979:1-1983:4 (20 observations). To verify the robustness of these stylized facts we have analyzed employment data for production and non-production workers from the establishment survey (CES) for the period 1964:1-2002:4. The CES data tend to confirm our first two stylized facts. In particular, the relative volatility of non-production workers’ employment goes from 0.70 before 1984 to 1.04 afterwards, while for production workers it goes from 0.98 to 1.18. Quantitatively, though, the increase in the relative volatility of non-production workers’ employment is smaller than the one experienced by skilled workers in the household survey.\[^{15}\]

\[^{15}\]This discrepancy might be due in part to the fact that the categories of “skilled” and “non-production” workers do not necessarily include the same type of individuals. In particular, the category of “non-production” workers will also include a certain number of non-college educated individuals.
2.2.3 Sectors

In this section we report the business cycle statistics of total hours for skilled and unskilled workers by sector, at the one-digit level of disaggregation.\(^{16}\) We do so in order to verify the extent to which the statistics reported in the previous section tend to reflect the different distribution of skilled and unskilled employment across sectors. For example, it could be argued that the 1980 and 1981-82 recessions affected mostly the manufacturing sector, where most of unskilled employment tends to be concentrated, while the subsequent recessions affected more the service sector, where most of skilled employment tends to be concentrated.

Before proceeding, we would like to provide a cautionary note regarding the interpretation of the results in this and in the next subsection. The reason is that our labor aggregates per sector (or per occupation, as in the next subsection) have to be computed with a relatively small number of observations. This means the series become very noisy. Moreover, since the number of observations differs across sectors/occupations, comparing the cyclical behavior of labor aggregates across sectors/occupations becomes difficult. We still think these data are informative, since there is no reason to suppose that this problem changes across subperiods. Hence, we believe it is meaningful to compare the cyclical behavior of the different labor market aggregates per sector/occupation across periods, and to then compare the resulting changes across sectors/occupations. This is what we emphasize in our analysis.

Table 3 displays the sectoral distribution of total hours worked by skill group and the behavior of total hours by one digit sector and skill group.\(^{17}\)

As the table suggests, in many service industries (see for example the row “Various Service Industries,” which includes Business and Repair Services, Personal Services, Entertainment and Recreational Services, and Professional and Related Services) the volatility of aggregate hours has increased for both skilled and unskilled workers, even if proportionally more for skilled workers. Moreover, within the manufacturing sector the relative volatility of skilled hours has increased.

\(^{16}\)The statistics on employment and working hours per employed workers are available from the authors upon request. As already observed in the previous section, most of the change across the two subperiods is accounted for by changes in the behavior of employment.

\(^{17}\)For the analysis by sectors and occupation, one major difficulty is that our data does not provide a consistent occupational classification over time. Until 1982, it is based on the 1970 Census, but from 1983 onwards it is based on the 1980 Census. To overcome this problem, we have developed an assignment between 2-digit occupational codes (and when necessary 3-digit codes) and 1-digit codes. Using this assignment we do not observe any break in the number of people in each 1-digit occupational category from 1982 to 1983.
<table>
<thead>
<tr>
<th>Total hours in</th>
<th>Hours' share (%)</th>
<th>Relative Volatility</th>
<th>Comovement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>skilled</td>
<td>unskilled</td>
<td>skilled</td>
</tr>
<tr>
<td>1979:1-1983:4</td>
<td>Aggregate</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Agriculture, Forestry and Fisheries</td>
<td>0.67</td>
<td>1.77</td>
<td>2.54</td>
</tr>
<tr>
<td>Mining</td>
<td>1.06</td>
<td>1.28</td>
<td>2.88</td>
</tr>
<tr>
<td>Construction</td>
<td>2.13</td>
<td>6.83</td>
<td>3.10</td>
</tr>
<tr>
<td>Manufacturing - durables</td>
<td>11.21</td>
<td>17.36</td>
<td>1.12</td>
</tr>
<tr>
<td>Manufacturing - nondurables</td>
<td>6.66</td>
<td>10.57</td>
<td>1.22</td>
</tr>
<tr>
<td>Transportation, Communications</td>
<td>4.94</td>
<td>9.26</td>
<td>1.29</td>
</tr>
<tr>
<td>Wholesale and Retail Trade</td>
<td>10.13</td>
<td>19.74</td>
<td>1.11</td>
</tr>
<tr>
<td>Finance, Insurance and Real Estate</td>
<td>7.64</td>
<td>5.61</td>
<td>1.13</td>
</tr>
<tr>
<td>Various Service Industries</td>
<td>47.30</td>
<td>21.27</td>
<td>0.27</td>
</tr>
<tr>
<td>Public Administration</td>
<td>8.30</td>
<td>6.41</td>
<td>1.22</td>
</tr>
<tr>
<td>1984:1-2002:4</td>
<td>Aggregate</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Agriculture, Forestry and Fisheries</td>
<td>0.59</td>
<td>1.75</td>
<td>9.20 (3.62)</td>
</tr>
<tr>
<td>Mining</td>
<td>0.66</td>
<td>0.80</td>
<td>12.30 (4.26)</td>
</tr>
<tr>
<td>Construction</td>
<td>2.12</td>
<td>7.63</td>
<td>5.52 (1.78)</td>
</tr>
<tr>
<td>Manufacturing - durables</td>
<td>9.73</td>
<td>13.65</td>
<td>3.42 (3.06)</td>
</tr>
<tr>
<td>Manufacturing - nondurables</td>
<td>5.77</td>
<td>8.56</td>
<td>2.84 (2.32)</td>
</tr>
<tr>
<td>Transportation, Communications</td>
<td>6.14</td>
<td>9.68</td>
<td>2.87 (2.23)</td>
</tr>
<tr>
<td>Wholesale and Retail Trade</td>
<td>10.51</td>
<td>21.19</td>
<td>1.73 (1.56)</td>
</tr>
<tr>
<td>Finance, Insurance and Real Estate</td>
<td>8.76</td>
<td>5.65</td>
<td>2.84 (2.51)</td>
</tr>
<tr>
<td>Various Service Industries</td>
<td>47.88</td>
<td>25.79</td>
<td>1.15 (4.22)</td>
</tr>
<tr>
<td>Public Administration</td>
<td>7.89</td>
<td>5.31</td>
<td>3.37 (2.73)</td>
</tr>
</tbody>
</table>

Notes: Hours’ share is the average ratio of of total hours in a particular occupation relative to the aggregate. The numbers in parenthesis are the ratio of post to pre 1984 relative standard deviations. <sup>a</sup>, <sup>b</sup>, <sup>c</sup> denote correlations significant at 1, 5, and 10 percent level respectively.

Table 3: Volatility and co-movement of total hours per skill group, 1-digit industry (Household Survey).
significantly while the relative volatility of unskilled hours has remained approximately constant (as in durables) or increased proportionally less (as in nondurables).

More formally, in order to control for differences in the sectoral composition of skilled and unskilled hours we recompute the aggregate statistics of Table 1 by imposing that the share of aggregate skilled hours worked in each industry is equal to the analogous share for unskilled hours. To do so, we exploit the fact that the cyclical component of aggregate skilled and unskilled hours, denoted by $\tilde{s}_t$ and $\tilde{u}_t$, can be expressed (approximately) as the weighted average of the cyclical components $\tilde{s}_j^t$ and $\tilde{u}_j^t$ of industries’ hours, where the weights $\kappa_{st}^j$ and $\kappa_{ut}^j$ are equal to the share of total hours worked in industry $j$ in period $t$:

$$
\tilde{s}_t \approx \sum_{j=1}^{10} \kappa_{st}^j \tilde{s}_j^t,
$$

(1)

$$
\tilde{u}_t \approx \sum_{j=1}^{10} \kappa_{ut}^j \tilde{u}_j^t.
$$

(2)

Our experiment consists of constructing a new measure of skilled hours, denoted by $\tilde{s}_u^t$, which is characterized by the same sectoral distribution as unskilled hours:

$$
\tilde{s}_u^t \equiv \sum_{j=1}^{10} \kappa_{ut}^j \tilde{s}_j^t.
$$

(3)

### Table 4: Volatility and co-movement of total skilled hours adjusting for sectoral composition effects (Household Survey).

<table>
<thead>
<tr>
<th></th>
<th>Relative volatility</th>
<th>Comovement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>skilled ($\tilde{s}_t$)</td>
<td>skilled ($\tilde{s}_u^t$)</td>
</tr>
<tr>
<td>1979:1-1983:4</td>
<td>0.37</td>
<td>0.49</td>
</tr>
<tr>
<td>1984:1-2002:4</td>
<td>1.04</td>
<td>1.18</td>
</tr>
</tbody>
</table>

Legend: $a$, $b$, $c$ denote correlations significant at 1, 5, and 10 percent level, respectively.

Table 4 reports the cyclical properties of $\tilde{s}_u^t$. This table reveals that imposing the same

---

18 As a way of checking the validity of this approximation, we have recomputed the moments of Table 1 using the right-hand side of equations (1) and (2) as our measure of the cyclical component of skilled and unskilled hours, obtaining basically the same results as in that table.

19 Notice that for this exercise we are using the sample period 1979:1-2002:4 because of changes in the definition of sectors in the 2003 MORG.
distribution of skilled and unskilled hours across sectors tends to make the former more volatile in both subperiods. The relative volatilities of $\hat{s}_t^{u}$ and $\hat{s}_t^{s}$ in the second subperiod exceed the ones in the first subperiod by a factor of, respectively, 2.41 and 2.81. We conclude that, even controlling for differences in the composition of hours across sectors, there has been a significant increase in the relative volatility of skilled hours since 1984.

### 2.2.4 Occupations

The next question we address is whether skilled workers are particularly concentrated in occupations that have become more cyclical after 1984. Table 5 displays the volatility and comovement with aggregate GDP of total hours by skill group and one-digit occupation.

After 1984 skilled total hours tend to be significantly more volatile and procyclical in the three major occupations for skilled workers. Instead, the cyclical properties of unskilled total hours in these same occupations do not change in an important way after 1984. This observation therefore does not lend support to the idea that the change in the dynamics of the skilled labor input after 1984 can be attributed to the increased cyclicalness of certain occupations where skilled workers tend to be more concentrated. Table 5 also does not support the idea that skilled total hours have become more cyclical and volatile because skilled workers have been more and more employed in traditionally unskilled occupations. The share of skilled employment in each of the four major occupations for unskilled workers (lines 3 to 6 in Table 5) has been remarkably stable during the sample period.

### 2.2.5 Restricted Sample: White Males Aged 31 to 55

In this subsection, in order to further control for potential compositional effects, we restrict attention to the subsample of white males workers aged 31 to 55. For this restricted sample, we repeat the analysis of Table 1 and report the results in Table 6. The results of this exercise not only confirm our stylized facts #1 and #2, but also contribute to show that the phenomenon we are documenting affects a category of workers (skilled white males with some work experience) that

---

20 A related question is whether the increased volatility of skilled hours is due to an increase in their variances at the sectoral level, or in their covariances. Decomposing the increase in the variance of total skilled hours relative to GDP into these two components reveals that approximately 70 percent of this increase is due to higher sectoral variances and the remaining 30 percent to higher sectoral covariances.

21 The associated results for wages and the skill premium are available from the authors upon request.
<table>
<thead>
<tr>
<th>Year</th>
<th>Total hours in</th>
<th>Hours' share (%)</th>
<th>Relative volatility</th>
<th>Comovement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>skilled</td>
<td>unskilled</td>
<td>skilled</td>
</tr>
<tr>
<td>1979:1-1983:4</td>
<td>Aggregate</td>
<td>100</td>
<td>100</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td>Professional, Technical workers</td>
<td>55.84</td>
<td>8.83</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>Managers, Officials, Proprietors</td>
<td>20.39</td>
<td>8.67</td>
<td>1.06</td>
</tr>
<tr>
<td></td>
<td>Clerical, Sales workers</td>
<td>15.37</td>
<td>25.55</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>Craftsmen, Foremen</td>
<td>4.52</td>
<td>20.74</td>
<td>1.83</td>
</tr>
<tr>
<td></td>
<td>Operatives</td>
<td>1.73</td>
<td>18.27</td>
<td>2.78</td>
</tr>
<tr>
<td></td>
<td>Laborers, Service workers</td>
<td>2.93</td>
<td>17.96</td>
<td>3.09</td>
</tr>
<tr>
<td></td>
<td>Farmers, Farm managers</td>
<td>0.07</td>
<td>0.95</td>
<td>9.04</td>
</tr>
<tr>
<td>1984:1-2002:4</td>
<td>Aggregate</td>
<td>100</td>
<td>100</td>
<td>1.04</td>
</tr>
<tr>
<td></td>
<td>Professional, Technical workers</td>
<td>53.77</td>
<td>11.23</td>
<td>1.44</td>
</tr>
<tr>
<td></td>
<td>Managers, Officials, Proprietors</td>
<td>21.40</td>
<td>9.89</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>Clerical, Sales workers</td>
<td>15.48</td>
<td>24.49</td>
<td>1.75</td>
</tr>
<tr>
<td></td>
<td>Craftsmen, Foremen</td>
<td>4.40</td>
<td>19.48</td>
<td>4.32</td>
</tr>
<tr>
<td></td>
<td>Operatives</td>
<td>1.84</td>
<td>15.58</td>
<td>5.97</td>
</tr>
<tr>
<td></td>
<td>Laborers, Service workers</td>
<td>3.08</td>
<td>19.25</td>
<td>4.36</td>
</tr>
<tr>
<td></td>
<td>Farmers, Farm managers</td>
<td>0.06</td>
<td>0.09</td>
<td>42.78</td>
</tr>
</tbody>
</table>

Notes: Hours' share is the average ratio of total hours in a particular occupation relative to the aggregate. The numbers in parenthesis are the ratio of post to pre 1984 relative standard deviations. a, b, c denote correlations significant at 1, 5, and 10 percent level respectively.

Table 5: Volatility and co-movement of total hours per skill group, 1-digit occupation
Table 6: Volatility and co-movement of total hours, employment and average weekly hours per skill group - Restricted sample: white, males, aged 31-55. Legend: \(a, b, c\) denote correlations significant at 1, 5, and 10 percent level, respectively.

The share of the labor force accounted for by workers with a college degree has increased steadily over the sample period, from 18 percent in 1979 to 29 percent in 2003. In this section we investigate the possibility that this trend has been accompanied by a change in the distribution of unobserved skills. This might have happened for at least two reasons. The first is a reduction in the quality of college relative to high school education. The second reason is a possible change in the distribution of unobserved abilities of those obtaining a college degree. In order to address this concern, we change our definition of unskilled and skilled labor. Skilled workers are now those with at least a master’s degree (or with at least 18 years of school attendance), and unskilled workers are all the remaining. For this alternative definition of skill, we repeat the analysis of Table 1 in Table 7.

The results clearly indicate that the standard deviation of aggregate skilled hours has risen dramatically after 1984, even adopting this more restrictive definition of skills. As further evidence that there has not been a reduction in the “skill content” of a college degree relative to a high school one, Card and DiNardo (2002) document that the rise in the skill premium since the early 1980’s has been concentrated among younger workers aged 26-35.

---

22 Focusing on female, rather than male, workers yields qualitatively similar results. The relative standard deviation of total hours increases for both groups, but proportionally more so for skilled females. The relative standard deviation of total hours for them goes from 0.61 to 0.99, while for unskilled females it goes from 0.76 to 0.92. The correlation between total hours worked by skilled females and GDP goes from 0.23 before 1984 to 0.52 afterwards, while the analogous correlation for unskilled females declines from 0.72 to 0.59.

23 Acemoglu (2002) reviews both of these potential composition effects in regard to the increase in the college premium and overall inequality in the 1980s and concludes that neither of the two can explain these phenomena.

24 The associated results for wages and the skill premium are available from the authors upon request.
### Table 7: Volatility and co-movement of total hours, employment and average weekly hours per skill group: alternative skill definition (skilled workers must have a master degree). Legend: $a, b, c$ denote correlations significant at 1, 5, and 10 percent level, respectively.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Relative volatility</th>
<th>Comovement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>skilled</td>
<td>unskilled</td>
</tr>
<tr>
<td><strong>1979:1-1983:4</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total hours</td>
<td>0.51</td>
<td>0.80</td>
</tr>
<tr>
<td>Employment</td>
<td>0.45</td>
<td>0.71</td>
</tr>
<tr>
<td>Average weekly hours of work</td>
<td>0.19</td>
<td>0.13</td>
</tr>
<tr>
<td><strong>1984:1-2003:4</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total hours</td>
<td>1.99</td>
<td>0.80</td>
</tr>
<tr>
<td>Employment</td>
<td>1.85</td>
<td>0.74</td>
</tr>
<tr>
<td>Average weekly hours of work</td>
<td>0.33</td>
<td>0.21</td>
</tr>
</tbody>
</table>

2.2.7 Canada

[TO BE COMPLETED]

### 3 Capital-Skill Complementarity and the Business Cycle

In addition to documenting the stylized facts reported in the previous section, the goal of this paper is to try to advance a candidate explanation for them. Ideally, one would want to do this using a full-fledged general equilibrium model. In what follows, we take a different route. Specifically, we try to explain the cyclical behavior of skilled hours in the two subperiods, using a simple relative demand/supply framework that takes as given the series for unskilled hours and the stock of capital equipment. In doing so, we focus on the equation for the relative demand of skilled labor, which would have to hold in a general equilibrium version of the model. One advantage of this approach is that it allows us to easily connect our exercise with the literature that has tried to account for the long-run behavior of the skill premium, particularly Krusell, Ohanian, Ríos-Rull, and Violante (2000). Moreover, it is not obvious how to make a general equilibrium business cycle model consistent with the “non-balanced growth” kind of dynamics exhibited by the series for capital and the two labor inputs.

Since the cyclical properties of unskilled hours, relative to GDP, have not changed significantly

---

25 This literature has employed simple demand/supply frameworks to model the low frequency dynamics of the skill premium. Models based on insurance contracts between firms and workers, search and matching, etc. are less amenable to addressing these questions from a quantitative point of view.

26 Lindquist (2004) considers a general equilibrium real business cycle model with capital skill complementarity in production. His model is calibrated with reference to the average ratio of unskilled to skilled labor and the average skill premium in the sample period 1979-2002. However, these ratios display significant trends over that period.
during the sample period (stylized fact #2), our goal, in what follows is to try to explain stylized fact #1:

- In the pre-1984 period, skilled hours are significantly less volatile than unskilled hours and GDP.

- In the post-1984 period, skilled hours become roughly as volatile as unskilled hours and GDP.

In this section we illustrate our mechanisms from a qualitative point of view, while in the next section we develop their quantitative implications.

Relative demand for skilled and unskilled workers can be derived from the two-level CES production function recently used by Krusell, Ohanian, Ríos-Rull, and Violante (2000):

\[
y_t = z_t \left[ \mu u_t^\sigma + (1 - \mu) (\lambda k_t^\rho + (1 - \lambda)s_t^\rho)^{\sigma/\rho} \right]^{1/\sigma}, \quad \sigma, \rho < 1 \text{ and } \mu, \lambda \in (0, 1),
\]

where \( y_t \) denotes output, \( z_t \) total factor productivity, \( u_t \) and \( s_t \) total unskilled and skilled hours, respectively, and \( k_t \) the capital stock.\(^{27}\) In this production function, the direct elasticity of substitution between unskilled labor and either skilled labor or capital equals \( 1/(1 - \sigma) \), and the direct elasticity of substitution between skilled labor and capital equals \( 1/(1 - \rho) \).

Assuming perfectly competitive factor markets, profit maximization yields the inverse relative demand for skilled workers:

\[
\omega_t = \frac{(1 - \mu) (1 - \lambda)}{\mu} \left( \frac{s_t}{u_t} \right)^{\sigma-1} \left[ \lambda \left( \frac{k_t}{s_t} \right)^\rho \left( \frac{k_t}{s_t} \right)^{1-\rho} + 1 - \lambda \right]^{\frac{\sigma-\rho}{\rho}},
\]

where \( \omega_t \) denotes the skill premium:

\[
\omega_t = \frac{w_t^s}{w_t^u},
\]

and \( w_t^j \) is the real hourly wage of a worker of type \( j = s, u \).\(^{28}\)

\(^{27}\)In the empirical section, we distinguish between the stock of capital equipment and the stock of capital structures. Here, to simplify the notation, we only consider capital equipment, denoted by \( k_t \).

\(^{28}\)The relative demand for skilled workers can be easily derived from the firm’s profit maximization problem with respect to \( s \) and \( u \). The first order condition for profit maximization is

\[
w_t^j = (1 + m_t^{-1}) MP_{jt}, \quad j = s, u,
\]

where \( m_t \) denotes the price elasticity of the demand functions faced by the firm’s output and \( MP_{jt} \) is the (physical) marginal product of factor \( j \). If the output market is competitive, \( m_t = \infty \). In what follows we take this to be our benchmark specification.
Equation (5) has been used by Krusell, Ohanian, Rios-Rull, and Violante (2000) to study the long-run behavior of the skill premium. Their exercise consists of using data on the input ratios $s_t/u_t$ and $k_t/s_t$, together with estimates of the production function’s parameters, to predict the low frequency variations in the skill premium over the period 1963-1992.

Our main focus is, instead, on the cyclical dynamics of the skill premium and the input ratios. In order to introduce a relative supply for skilled labor at the cyclical frequency, we decompose each variable $x_t$ in equation (5) into a trend component, $x^T_t$, and cyclical component $x^c_t$. The latter is defined as

$$x^c_t = \frac{x_t}{x^T_t}.$$  

Using this notation, equation (5) can be rewritten as:

$$\omega^c_t = \frac{(1 - \mu) (1 - \lambda)}{\mu \omega^T_t} \left( \frac{s^c_t s^T_t}{u^c_t u^T_t} \right)^{\sigma - 1} \left[ \lambda \left( \frac{k^c_t k^T_t}{s^c_t s^T_t} \right) \right]^{\rho} + 1 - \lambda \frac{\sigma - \rho}{\rho}.$$  

The relationship between the cyclical component of the skill premium, $\omega^c_t$, and the ratios of the cyclical components of skilled and unskilled total hours $s^c_t/u^c_t$ is represented in Figure 4. In drawing this curve we take as given the trends $\omega^T_t$, $s^T_t/u^T_t$, $k^T_t/s^T_t$, as well as the ratio of the cyclical components of capital and skilled labor $k^c_t/s^c_t$. This relative demand curve is downward sloping in the space $(s^c_t/u^c_t, \omega^c_t)$ because a firm is willing to hire more skilled hours only at a lower relative wage (relative quantity effect). Moreover, if $\sigma > \rho$, the production function (4) displays capital-skill complementarity and an increase in $k^c_t/s^c_t$ gives rise to an outward shift of this curve (capital-skill complementarity effect).\footnote{Fallon and Layard (1975) show that capital-skill complementarity is in fact characterized by the same condition on the parameters of the production function (4) even if alternative definitions of the elasticity of substitution are used, namely either the elasticity of complementarity or the Hicks-Allen elasticity of substitution. Differently from the notion of direct elasticity of substitution used in the text, these alternatives yield elasticities which depend upon input shares, as well as on production function parameters.}

To close our simple model, we add to Figure 4 an horizontal relative supply of skilled workers:

$$\omega^c_t = v.$$  

The assumption that the skill premium does not display any cyclical variations can be motivated\footnote{Krusell, Ohanian, Rios-Rull, and Violante (2000) estimate equation (5), given the observed behavior of the labor inputs and capital stock in the U.S. for the period 1963-92. Their estimates indicate that $\sigma > \rho$.}
in two complementary ways. First, from an empirical point of view, the data in Section 2.1 show that the cyclical component of the skill premium is not very volatile relative to GDP and is virtually uncorrelated with it. Second, from a theoretical point of view, a constant skill premium at the cyclical frequency would emerge in an indivisible labor model with skilled and unskilled workers, along the lines of Rogerson (1988) and Hansen (1985). In such model, the skill premium would be proportional to the ratio of the constant disutilities from work experienced by the two types of agents.\footnote{Prasad (1996) considers such model. A difficulty in constructing a full-fledged general equilibrium model here is represented by the fact that the skill premium and the production inputs display trends over time. Empirically, these trends play an important role because they allow us to calibrate the parameters of the model. For this reason we choose to retain the low-frequency variations in the series in our relative supply/demand model. Our model is mute about the low frequency supplies of skilled and unskilled labor, which are taken as given, as in much of the literature on the long-run behavior of the skill premium (see e.g. Krusell, Ohanian, Rios-Rull, and Violante (2000)). Instead, we assume that skilled and unskilled labor are elastically supplied at the business cycle frequency.}

![Diagram](image)

**Figure 4: Capital-Skill Complementarity and the Business Cycle**

The effect of capital-skill complementarity on the relative volatility of skilled labor is represented in Figure 4. In a recession, firms wish to employ less unskilled labor. Therefore, \( u_t^c \) declines. If the relative demand curve did not shift, the fact that the skill premium is constant would imply that \( s_t^c \) would decrease proportionally to \( u_t^c \), in order to keep the ratio \( s_t^c/u_t^c \) constant. In this case, which corresponds to a Cobb-Douglas production function, the volatilities of skilled and unskilled hours would be the same. However, the relative demand curve does shift. In particular, if the capital stock...
does not vary much at the business cycle frequency, variations in $k^c_t/s^c_t$ are dominated by variations in $s^c_t$. The relative demand curve, therefore, shifts outward in a recession. This is because fewer skilled workers work with a given stock of capital, and hence their productivity increases relative to that of unskilled workers. For given skill premium, the outward shift in relative demand causes the ratio $s^c_t/u^c_t$ to move countercyclically, so that the fall in skilled hours is proportionally smaller than the fall in unskilled hours.

In order to try to explain our pre and post-1984 stylized facts, it is convenient to derive an analytical expression for the volatility of skilled hours. To do so, first equalize relative supply to relative demand at the business cycle frequency to obtain:

$$\omega^T_t = \frac{(1 - \mu) (1 - \lambda)}{\mu \nu} \left( \frac{s^c_t s^T_t}{u^c_t u^T_t} \right)^{\sigma - 1} \left[ \lambda \left( \frac{k^c_t k^T_t}{s^c_t s^T_t} \right)^{\rho} + 1 - \lambda \right]^{\sigma - \rho}.$$

(6)

Then, assume for simplicity that there are no low frequency variations in the variables that enter this equation: $\omega^T_t = \omega$, $s^T_t = s$, $u^T_t = u$, $k^T_t = k$. Last, linearize equation (6) to obtain $s^c_t$ as function of $u^c_t$ and $k^c_t$:

$$s^c_t = \frac{1}{1 + Q} u^c_t + \frac{Q}{1 + Q} k^c_t.$$

(7)

where the constant $Q$ is defined as:

$$Q \equiv \frac{\sigma - \rho}{1 - \sigma} \frac{\lambda \left( \frac{k}{s} \right)^{\rho}}{\lambda \left( \frac{k}{s} \right)^{\rho} + 1 - \lambda}.$$

(8)

Under the assumption that the covariance between $u^c_t$ and $k^c_t$ is zero, it follows from equation (7) that\footnote{In the data the correlation between $u^c_t$ and $k^c_t$ is equal to 0.36. Here, we set it equal to zero to simplify our explanation. Of course, in the empirical section of the paper, we allow $u^c_t$ and $k^c_t$ to be positively correlated.}

$$\frac{\text{var} (s^c_t)}{\text{var} (u^c_t)} = \left( \frac{1}{1 + Q} \right)^2 + \left( \frac{Q}{1 + Q} \right)^2 \frac{\text{var} (k^c_t)}{\text{var} (u^c_t)}.$$

(9)

This equation contains our main insights concerning the volatility of skilled labor relative to unskilled labor. In what follows we first describe our hypothesis in a qualitative way. In Section 4, we calibrate the model and evaluate each mechanism quantitatively.

**Pre-1984 period.** In the data the variance of $s^c_t$ is lower than the variance of $u^c_t$. From equation (9), we know that our simple model can qualitatively account for this fact under two
conditions: 1) capital-skill complementarity in production \((\sigma > \rho)\), implying \(Q > 0\); 2) the capital stock is less volatile than unskilled labor: \(\text{var} (k^c_t) < \text{var} (u^c_t)\). Notice that, \textit{ceteris paribus}, the relative volatility of skilled labor declines with an increase in \(Q\). In turn \(Q\) increases with the degree of capital skill complementarity, measured by \(\sigma - \rho\). With a Cobb-Douglas production function, the term \(Q\) would be equal to zero and our model would predict that \(\text{var} (s^c_t) = \text{var} (u^c_t)\). The mechanism we emphasize here has been first pointed out by Oi (1962) and Rosen (1968) to explain the lower cyclicality of skilled labor, but, to our knowledge, it has not been quantitatively evaluated.

\textbf{Post-1984 period.} In the post-1984 period, the variance of \(s^c_t\) increases significantly relative to the variance of \(u^c_t\). The variances of these two variables are approximately equal after 1984. In what follows we focus on three effects that can potentially explain this change.

1. \textit{Variation in the level of volatility for unskilled labor.} The absolute volatility of GDP, at the cyclical frequency, has declined substantially around 1984. This fact has been emphasized by many (see e.g. Stock and Watson (2002)). In Section 2.2.1 we have shown how \(u^c_t\) closely tracks the behavior of the cyclical component of GDP. Thus, around 1984, the volatility of \(u^c_t\) has declined substantially. As equation (9) suggests, for given \(Q\) and \(\text{var} (k^c_t)\), a reduction in \(\text{var} (u^c_t)\) tends to increase the relative volatility of skilled labor. The intuition for this result is simple: with capital-skill complementarity, cyclical variations in skilled hours are not only related to cyclical variations in unskilled hours, but also to variations in capital. A decline in the absolute volatility of unskilled hours, therefore, tends to reduce the absolute volatility of skilled hours less than proportionally, leading to an increase in its relative volatility.

2. \textit{Variation in the level of capital equipment relative to skilled labor.} The third effect we consider has to do with the dramatic increase in the level of \(k^T_t/s^T_t\) that occurred during the sample period. To understand the implications of this trend, consider the effect of a higher \(k/s\) level in equation (8). If \(\rho < 0\) and \(\sigma > \rho\), a higher \(k/s\) leads to a decline in the term \(Q\) in (8), and thus to a higher relative volatility of skilled labor over the business cycle. The intuition for this result

\[\text{While the stock of physical capital does not display large variations at the business cycle frequency, the flow of services per unit of time provided by this stock might be significantly procyclical, as firms can adjust the workweek of capital along the business cycle. The reason why we did not allow for cyclical capital utilization in our model has to do with the nature of complementarity between skilled workers and capital equipment that we would like to formalize. If skilled workers are needed in order to setup and supervise the work of equipment capital, then variations in the workweek of capital will only have limited influence on the demand for skill workers, while possibly exerting some influence on their average weekly hours.}\]
is as follows. With \( \sigma > \rho \), a higher capital stock leads to an increase in the demand for skilled labor (capital-skill complementarity effect). The sign of \( \rho \) determines whether a higher level of \( k/s \) tends to amplify or reduce the marginal effect of higher capital on the demand for skilled labor. If \( \rho = 0 \) (the Cobb-Douglas case), there is no such level effect. In the empirically relevant case in which \( \rho < 0 \), capital and skilled labor are relatively more complements in production than in the Cobb-Douglas case. This relatively high complementarity implies that, when capital is already abundant relative to skilled labor, a further increase in \( k_t/s_t \) at the business cycle frequency (induced by a drop in \( s_t \)) induces a smaller increase on the demand for skilled labor. The dramatic increase in \( k_t^T/s_t^T \) that occurred over the sample period implies that capital in the 1990’s was very abundant relative to skilled labor. Consequently, in this period, cyclical fluctuations in the demand for skilled labor became relatively more related to cyclical variations in the demand for unskilled labor.

3. Variation in degree of capital-skill complementarity. The second candidate explanation for the increase in the relative volatility of skilled hours is represented by a reduction in the degree of capital-skill complementarity. Mechanically, a reduction in \( \sigma - \rho \) leads to a reduction in \( Q \), which tends to increase \( \text{var}(s_t^c)/\text{var}(u_t^c) \). The key question is, of course, whether and when such decline in the degree of capital-skill complementarity took place. As we discuss in more detail in the next section, this hypothesis is consistent with the long-run behavior of the skill premium \( \omega_t^T \) and the relative inputs \( s_t^T/u_t^T \) and \( k_t^T/s_t^T \) since the late 1980’s. During this period, and relative to the early 1980’s, the growth rate of the skill premium slows down considerably. This deceleration is accompanied by a higher growth rate of the stock of capital equipment relative to skilled hours, and by a slowdown in the growth rate of \( s_t^T/u_t^T \). In order to reconcile these facts with the capital skill-complementarity hypothesis it is necessary to postulate a decline in \( \sigma - \rho \) that occurred sometime in the late 1980’s.

The quantitative assessment of these mechanisms is obviously of great interest, and we turn to them in the next section.

\(^{34}\)This is consistent with the estimates of Krusell, Ohanian, Ríos-Rull, and Violante (2000).
4 Quantitative Analysis

In this section we calibrate the model and undertake a quantitative analysis of the three mechanisms illustrated in Section 3. In Section 4.1 we consider two of these mechanisms: the lower volatility of unskilled hours and the higher capital-skilled labor ratio that characterize the post-1984 period. To do so, the parameters of the equilibrium relationship (6) are calibrated using data for the whole 1979:1-2002:4 period. For this reason, we label this exercise “Constant Parameters”.

In Section 4.2 we evaluate the effect of the third mechanism, a reduction in the degree of capital-skill complementarity, on the relative volatility of skilled hours. This “Changing Parameters” exercise is also motivated by the difficulty faced by the version of the model with constant parameters in reconciling the lower growth rate of the skill premium in the 1990’s with the simultaneous acceleration in the growth rate of the capital-skilled hours ratio.

4.1 The Lower Volatility of Unskilled Hours and the Higher Capital-Skilled Labor Ratio

Our quantitative analysis follows Krusell, Ohanian, Ríos-Rull, and Violante (2000) in employing a version of the production function (4) that allows for a distinction between capital equipment, $k_{et}$, and capital structures, $k_{st}$. This distinction is important from a quantitative standpoint: the two capital stocks have been growing at significantly different rates, and equipment is likely to exhibit the higher degree of complementarity with skilled labor. Specifically, in this section we consider the following aggregate technology with constant parameters:

$$y_t = z_t k_{st}^\alpha \left[ \mu u_t^\sigma + (1 - \mu) (\lambda k_{et}^\vartheta + (1 - \lambda) s_t^\rho) \right]^{(1 - \alpha)/\sigma},$$

(10)

The resulting relative demand function has exactly the same form as in (5). Once we impose the equality between the relative demand and the relative supply for skilled labor, we obtain the analog of equation (6)

$$\omega_t^T = (1 - \mu) (1 - \lambda) \frac{s_t}{u_t} \left[ \lambda \left( \frac{k_{et}}{s_t} \right)^\vartheta + 1 - \lambda \right]^{\frac{\sigma - \vartheta}{\rho}}.$$

(11)

Equation (11) is the center of our quantitative analysis. In Figure 5 we plot the variable $\omega_t$, and
in Figure 6 the variables $s_t/u_t$ and $k_{et}/s_t$. The series for capital equipment is from Cummins and Violante (2002). We interpolate their yearly data to obtain quarterly observations, by imposing a constant quarterly rate of growth within each year.

![Figure 5: Skill premium](image)

Figures 5 and 6 are to be interpreted jointly in terms of equation (11). Over the entire sample period 1979:1-2002:4, the skill premium and the ratio of skilled to unskilled hours display an upward trend. Given the increase in the ratio of the stock of capital equipment to skilled hours, these two trends can only be reconciled, within our framework, by the existence of capital-skill complementarity in production. For our quantitative exercise we need to specify values for the parameters $\sigma, \alpha, \rho, \lambda$ and $\mu$ in equation (11). We set $\sigma = 0.4$ and $\alpha = 0.13$. The value for $\sigma$ has been estimated by Krusell, Ohanian, Ríos-Rull, and Violante (2000). Other papers have provided estimates of this parameter,

---

35 The key feature of these series that we wish to emphasize for the purposes of the exercise in this section is that they all display upward trends. In the next section we will explore the fact that these trends have in fact changed over time.

36 The capital equipment series was kindly made available by Gianluca Violante. It is based upon the Cummins and Violante (2002) series of quality-adjusted equipment prices. The latter extrapolates Gordon (1990)’s quality-adjusted series, which span only the 1947-1983 period, until 2000. We extrapolate the Cummins-Violante series to the year 2002. In order to compute the growth rate of the stock of equipment from 2000 to 2003, we compute the growth rate of the series published by the BEA and add to it the average amount by which the growth rate of the Cummins-Violante series exceeds the published data over the period 1979-2000.

37 Using data for the 1963-1992 period, Krusell, Ohanian, Ríos-Rull, and Violante (2000) find evidence for the existence of capital-skill complementarity. The latter allows them to be able to account for the increase in the skill premium in the early 1980s.
most of them tending to be fairly concentrated around 0.4 (see Autor, Katz, and Krueger (1998) for a review). The parameter $\alpha$ represents the share of capital structures in GDP and has also been taken from Krusell, Ohanian, Ríos-Rull, and Violante (2000). We select $\mu$ and $\lambda$ in order to match the average wage bill ratio and aggregate labor share over the entire period 1979:1-2002:4. Unlike the case of $\sigma$, estimates of $\rho$ in the literature tend to be more dispersed. We pick the substitution parameter $\rho$ in order to match the average growth rate of the skill premium in the entire sample, computed by regressing the logarithm of the skill premium on a constant and time trend. Regarding the computation of the data moments, the aggregate labor share of income is set at 0.70, consistently with NIPA data. In addition, we use the CPS data to construct the average wage bill ratio and the average growth rate of the skill premium.

Table 8 summarizes our calibration exercise under a constant production structure. It contains the values of the calibrated parameters together with the data moments that they match.
Relative volatility & Comovement

<table>
<thead>
<tr>
<th>Total Hours</th>
<th>Relative Volatility</th>
<th>Comovement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>skilled</td>
<td>unskilled</td>
</tr>
<tr>
<td>1979:1-1983:4 Data</td>
<td>0.37</td>
<td>0.97</td>
</tr>
<tr>
<td>Benchmark</td>
<td>0.61</td>
<td></td>
</tr>
<tr>
<td>1984:1-2002:4 Data</td>
<td>1.05</td>
<td>0.91</td>
</tr>
<tr>
<td>Benchmark</td>
<td>0.79</td>
<td></td>
</tr>
<tr>
<td>Constant $k_{et}/s_t$ after 1984</td>
<td>0.76</td>
<td>0.69</td>
</tr>
</tbody>
</table>

Table 9: Quantitative Results under Constant Parameters

To evaluate the performance of our model, we use the series $u_t, k_{et}$ and $\omega_t^T$ (computed as the HP-filter trend of $\omega_t$) together with the calibrated parameters (Table 8) in equation (11), to obtain a predicted series $\hat{s}_t$ for skilled hours. We then HP-filter $\hat{s}_t$ to extract its cyclical component $\hat{s}_c^c$. Figure 7 plots $s_t$ together with $\hat{s}_t$. Figure 8 reports $\hat{s}_c^c$, together with the the cyclical components of output and actual total skilled hours. Figure 9 represents the rolling standard deviations.

![Figure 7: Model Fit for the Total Skilled Hours under Constant Parameters](image)

Table 9 contains the cyclical properties of skilled hours predicted by our model, before and after 1984. This is our “benchmark” exercise under constant parameters, when both effects considered in this section are at work.

In interpreting these results, it is convenient to think of a situation in which there is no capital-skill complementarity in production ($\sigma = \rho$). In this case, the ratio of the standard deviations of
skilled and unskilled hours would equal one in both subperiods.\textsuperscript{38} The existence of capital-skill complementarity in production, by itself, explains why the relative standard deviation of skilled hours is significantly smaller than one before 1984.

After 1984, the relative standard deviation of skilled hours increases by 17 percentage points (from 0.61 to 0.79), which is about a quarter of the increase observed in the data. This change is due to the two effects considered in this section. First, the absolute volatility of the cyclical component of unskilled hours ($\Delta u_c^t$) has declined dramatically after 1984, while the volatility of the cyclical component of capital equipment ($\Delta k_c^t$) did not change in a significant way over the sample period. In the data, \( \text{std}(\Delta k_c^t)/\text{std}(\Delta u_c^t) \) increased from 0.50 before 1984:1 to 0.91 after this date. This fact in conjunction with capital-skill complementarity implies that, as explained in Section 3, the volatility of skilled hours will drop proportionally less than the volatility of unskilled hours and GDP. Second, the ratio $k_{c\ell}/s_t$ has increased over the sample period, especially in the 1990’s, when its growth rate more than doubled. If $\rho < 0$, as in our benchmark calibration, this increase should have increased the relative volatility of skilled hours.

In order to get a sense of the relative contribution of each of these two effects, we have performed a simple experiment with equation (7). For given coefficient $Q$, and for given series for the

\textsuperscript{38}As a consequence, the volatility of skilled hours relative to GDP would also be approximately equal to one in both subperiods.
cyclical components of unskilled hours and capital equipment, this equation can be used to obtain a predicted series for the cyclical component of skilled hours. We have computed the value of the coefficient $Q$ such that the predicted series for skilled hours displays a relative standard deviation for the period 1979:1-1983:4 equal to the one predicted by the benchmark case (i.e., 0.61). The relative standard deviation of skilled hours after 1983:4 obtained using this procedure is reported in Table 9 under the label “Constant $k_{ct}/s_t$ after 1984”. This figure, 0.76, represents the relative volatility of skilled hours in the subperiod following 1984, under the assumption that the coefficient $Q$, and therefore the ratio $k_{ct}/s_t$, stays constant at its pre-1984 value. This result suggests that most of the increase in the relative volatility of skilled hours explained by the constant parameter model can be attributed to the lower volatility of unskilled hours over the business cycle.

4.2 The Decline in Capital-Skill Complementarity

In this section we evaluate the magnitude of the third mechanism described in Section 3. We have argued that the increase in the relative volatility of skilled hours might be attributed, at least in part, to a reduction in the degree of capital-skill complementarity in the economy. In what follows we first provide some empirical evidence in favor of this hypothesis and discuss how the
latter might be justified from a theoretical point of view. We then evaluate its contribution to the cyclical behavior of skilled hours.

**The decline in capital-skill complementarity.** Our starting point is the observation that assuming a constant set of parameters for the whole sample period (the benchmark case of the previous section) implies that the model is not able to replicate very closely the long-run behavior of the skill premium, as Figure 10 suggests.

![Figure 10: Model Fit for the Skill Premium under Constant Parameters](image)

The principal reason for this failure is that the trends in the skill premium and the input ratios appear to change sometime around the late 1980’s. Figure 5 shows a decline in the average growth rate of the skill premium between the 1979:1-1989:3 and 1989:4-2002:4 subperiods (the reason for splitting the sample around 1989:4 will become clear later in this section).

In the first subperiod, the skill premium has grown, on average, at a rate of 1.36% per year, while in the second period it has grown at an average rate of 0.74% per year. Figure 6 depicts the evolution of the relative inputs $k_{et}/s_t$ and $s_t/u_t$. This figure shows a substantial acceleration after 1989:3 in the growth rate of $k_{et}/s_t$ (from 2.69% to 6.19% per year) and a contemporaneous slowdown in the growth of $s_t/u_t$ (from 2.89% to 1.89% per year).40 These observations accord well

---

40The increase in the growth rate of $k_{et}/s_t$ can be traced back to a substantial decline in the relative price of equipment in terms of consumption, brought about by a significant acceleration in the technological progress specific
with the empirical evidence presented by Card and DiNardo (2002) and Beaudry and Green (2002), who also notice that the skill premium has grown at significantly smaller rates after about 1987 with respect to the previous seven years, despite an acceleration in the growth rate of the stock of capital equipment.

The evolution of $k_{et}/s_t$ and $s_t/u_t$ since the late 1980’s represents a challenge to the view that the long-run behavior of the skill premium in the 1980’s and 1990’s can be explained using a production structure characterized by capital-skill complementarity and constant parameters. The latter would have predicted a faster, rather than a slower, increase in the skill premium since 1989, because the faster growth in $k_{et}/s_t$ and the slower growth in $s_t/u_t$ should have made skilled labor relatively more productive than in the first sub-period (see also Figure 10). Instead, Figure 5 clearly tells otherwise.\textsuperscript{41}

Our view is that this evidence can, in principle, be reconciled with the capital-skill complementarity hypothesis, by postulating that the degree of complementarity in production between skilled labor and capital equipment has decreased sometime during the late 1980’s. The lower degree of capital-skill complementarity would then contribute to explain the increase in the relative volatility of skilled hours over the business cycle.

To evaluate the importance of this effect for the cyclical behavior of skilled hours, we follow a simple approach, and assume a once-and-for-all decline in $\sigma - \rho$ in the production function (10). In reality, of course, this decline is likely to have been a slowly-evolving process spanning several years, presumably due to the diffusion and routinization of computers and information technologies, and reaching maturity around the late 1980’s. Katz (1999) (page 17) has interpreted the slowdown in the growth of the relative demand for skill since the late 1980’s, as reflecting a “maturing of the computer revolution”, whereby “as technologies diffuse and become more routinized the comparative advantage of the highly skilled declines.” This view is in fact consistent with the theoretical model proposed by Greenwood and Yorokoglu (1997) to describe the effects of the

\textsuperscript{41}Figure 10 and Figure 7 are obviously closely related, as they are two different ways of conveying the same information. In the constant production structure model, the sharp increase in capital equipment that took place during the 1990s induces a significant increase in relative productivity of skilled labor, all else constant. Since the actual $s/u$ ratio does not grow any faster in the 1990s, this must lead to a faster growth in the predicted skill premium (Figure 10). Similarly, since the actual skill premium does not grow any faster in the 1990s, this must lead to a faster growth in predicted skilled employment (Figure 7).
### Table 10: Calibration under Changing Parameters

<table>
<thead>
<tr>
<th>Period</th>
<th>Parameters</th>
<th>Values</th>
<th>Target Moments</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979:1-1989:3</td>
<td>$\lambda_1$</td>
<td>0.92</td>
<td>Average labor share in GDP</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>$\mu_1$</td>
<td>0.57</td>
<td>Average wage bill ratio</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>$\rho_1$</td>
<td>-2.21</td>
<td>Average yearly growth rate of skill premium</td>
<td>1.36%</td>
</tr>
<tr>
<td>1989:4-2002:4</td>
<td>$\lambda_2$</td>
<td>0.56</td>
<td>Average labor share in GDP</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>$\mu_2$</td>
<td>0.52</td>
<td>Average wage bill ratio</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>$\rho_2$</td>
<td>-0.40</td>
<td>Average yearly growth rate of skill premium</td>
<td>0.74%</td>
</tr>
</tbody>
</table>

faster decline in the price of equipment since 1974 on the relative demand for skilled labor. Along the same line, Blanchard (2003) (page 281) conjectures that “it is likely that computers will become easier and easier to use in the future, even by low skill workers. Computers might even replace high-skill workers, those workers whose skills involve primarily the ability to compute or to memorize.” We argue that this phenomenon might have already begun since the late 1980’s.

**Business cycle implications.** In order to evaluate the importance of the evidence described above for the cyclical properties of skilled labor, we recalibrate the model allowing for a different degree of capital-skill complementarity after a certain break date in the late 1980’s.

In order to set values for the model’s parameters and determine a precise break date, we proceed as follows. First, for a given break date $T$, we assume that while the parameters $\rho$, $\mu$ and $\lambda$ of the production function (10) may take on different values before and after $T$, the parameters $\alpha$ and $\sigma$ remain instead unchanged over the entire sample period. The value of $\rho$, $\mu$ and $\lambda$ for the subperiod preceding $T$ are set exactly as in Section 4.1, in order to match the average labor share, the average wage bill ratio, and the average growth rate of the skill premium between 1979:1 and $T$. The value of $\rho$, $\mu$ and $\lambda$ for the subperiod following $T$ are set in an analogous way. For given set of parameters, we then select the break date $T$ that minimizes the sum of squared errors between the trend in the actual skill premium, $\omega^T$, and the skill premium predicted by the model. This procedure yields $T = 1989:3$ as the break date.

This calibration exercise is summarized in Table 10. Notice, in particular, how the calibrated elasticity of substitution between skilled labor and capital equipment is now much lower before 1984, and much higher after 1984, compared to the benchmark case of Table 8.

Before proceeding, a few observations are in order. First, the assumption that the decline in $\sigma - \rho$
is due to an increase in $\rho$, rather than a decrease in $\sigma$, is motivated by the idea that, as computers and information technologies become more routinized, it is the degree of complementarity of skilled labor with capital equipment that might decline. This assumption turns out to be quite innocuous as similar results can be obtained by keeping $\rho$ the same across subperiods and letting $\sigma$ adjust. Second, after the break date, it is necessary to change $\mu$ and $\lambda$ together with $\rho$, in order to avoid jumps in the predicted series for the skill premium and to guarantee that the model is consistent with the evidence on the average labor income shares in both subperiods. Third, our break date for the model’s parameters (1989:3) occurs a few years after the date (1983:4) in which we break the data series to analyze their cyclical properties. While in a literal sense, it would be more consistent to have these two dates closer, it is unreasonable to interpret the reduction in the volatility of GDP or in the degree of capital-skill complementarity as having occurred in a specific quarter or even year. Instead, we think of both of these phenomena as processes occurring over time.

Figure 11: Model Fit for the Skill Premium under Changing Parameters

Figure 11 plots the data series for the HP-trend in the skill premium, $\omega^T$, and its value predicted by the model. The key feature illustrated by this figure is the ability of the model to reproduce the slowdown in the growth rate of the skill premium, in spite of the underlying behavior of the relative input ratios.

Figure 12 plots the data series for skilled hours $s_t$ together with the series $\hat{s}_t$. The model
Table 11 contains the cyclical properties of skilled hours predicted by our model and compares them both with the data and with results of Section 4.1. This table illustrates how the change in the degree of capital-skill complementarity is quantitatively important. In particular, the fact that the degree of capital-skill complementarity before 1984 is higher than in the benchmark calibration, allows this version of the model to predict a lower relative volatility of skilled hours in the first
subperiod (0.55 against 0.61). Similarly, the higher degree of capital-skill complementarity in the 1990’s generates a larger increase in the relative volatility of skilled hours. The latter is 0.95 in the version of the model with changing parameters against 0.79 in the model with constant parameters.

In summary, the three effects we have discussed in Section 4.1 can jointly account for almost sixty percent \((0.95 - 0.55) / (1.05 - 0.37)\) of the increase in the relative standard deviation of skilled hours observed in the data. Most of the explanatory power of the model comes from the change in the production function parameters (about 55 percent), followed by the decline in the relative standard deviation of unskilled hours (about 37 percent), and the increase in the ratio of capital equipment relative to skilled hours (about 8 percent).

5 Summary and Conclusion

Using CPS data for the period 1979-2003, we have documented a dramatic increase in the cyclical volatility of aggregate skilled hours relative to GDP, starting from the late 1980’s. Aggregate skilled hours display little cyclicality in the 1981-82 recession relative to unskilled hours and GDP. Starting from the mid-1980’s, instead, aggregate skilled hours become more volatile than both unskilled hours and GDP. In the paper, we have evaluated the extent to which a simple supply/demand
model for skilled and unskilled labor based on the hypothesis of capital-skill complementarity in production can help explain these stylized facts. In particular, within this framework, we have considered the impact of the following three effects on the relative volatility of skilled hours: a reduction in the absolute volatility of GDP and unskilled hours since 1984, an increase in the level of capital equipment relative to skilled labor over the sample period, a reduction in the degree of capital-skill complementarity since the late 1980’s. We have provided empirical in support of each of these effects. Our conclusion is that the three mechanisms reviewed above can jointly explain about sixty percent of the observed increase in the relative volatility of skilled labor. The reduction in the degree of capital-skill complementarity plays a key role in accounting for this result.
A Detailed Data Appendix

The data set we use is the Merged Outgoing Rotation Groups (MORG) extracts from 288 Monthly Current Population Surveys (CPS), prepared by the NBER and covering the period from 1979 through 2003. Monthly observations are obtained by using information on each individual’s interview month. Each monthly sample contains about 30,000 individuals which are representative of the U.S. population aged between 16 and 65 years. Each representative individual is associated with a sample weight, which allows us to estimate actual monthly cross-sectional distributions.

We organize the data by quarters, ending up with 100 observations for the cross-sectional distribution of individual characteristics. Our key variables of interest are employment status, usual weekly earnings (inclusive of overtime, tips and commissions), usual weekly hours worked, and a series of demographic variables such as age, sex, race and years of education. We also look at the one-digit industry and occupational codes of each individual (more on the coding of sectors and occupations below).

For each quarter, we restrict attention to individuals in the labor force that are not self-employed (to concentrate on paid earnings). For individuals reporting to be employed, we use the following sample selection criterion:

1. Eliminate those with either missing or zero reported earnings.

2. Assign actual hours worked last week to usual hours, if usual hours is missing. This addresses the fact that individuals reporting “hours vary” are declared as having missing usual hours (but not actual hours) after 1993, causing a slight discontinuity in the series for hours between 1993:4 and 1994:1. In fact, it turns out that this imputation of usual hours is applicable only after 1994.

3. Eliminate those with either zero or a missing value for both actual and usual hours.

For each quarter, we end up with a cross-section of about 45,000 representative individuals.

Weekly earnings are top-coded in the CPS. The top-code was revised twice during the sample, at the end of 1988 and at the end of 1997. We imputed top-coded earnings by multiplying every top-code value in the sample by 1.3. This adjustment factor ensures that average earnings in the
top decile remain constant from December 1988 to January 1989 (where a very small number of observations is top-coded). It turns out that the same adjustment factor works for 1997.

For each quarter real weekly earnings are computed by deflating nominal weekly earnings by the Consumer Price Index (CPI). We use the monthly CPI, not seasonally adjusted, from the BLS website. Real hourly wages are computed as real weekly earnings divided by usual weekly hours.

We partition the sample into 240 demographic groups in a way analogous to Katz and Murphy (1992) and, more recently, Krusell, Ohanian, Ríos-Rull, and Violante (2000). First, each individual is either male or female. Second, starting from age 16, we create 10 five-year age groups. Third, we consider three race groups, whites, blacks, and otherwise. Last, we create four education groups, (1) no high school diploma (less than 12 years of completed schooling), (2) high school graduate (12 years of completed schooling), (3) some college (between 13 and 15 years of completed schooling) and (4) college graduate and more (16 years of completed schooling and above). After 1992, consistently with the CPS education classification change from years of schooling to educational categories, education group (1) corresponds to less than a high school diploma, (2) to a high school diploma, (3) to more than a high school degree but less than a B.A., and (4) to a B.A. degree or higher. This adjustment produces time-series for the number of individuals in each education group, as well as for the various variables of interest, that display no significant break in 1992.

In defining skill groups, we assign education groups (1)-(3) to the unskilled category and education group (4) to the skilled category.

A primary reason for recording demographic variables is to allow us to compute adjusted measures of the aggregate labor input, in which actual hours are weighted by some time-invariant base wage rate. This produces series for the labor input in efficiency units, which is more sensible for aggregation across demographic groups. We again proceed in a way analogous to Katz and Murphy (1992) and Krusell, Ohanian, Ríos-Rull, and Violante (2000).42

First, for each quarter and for each demographic group in our partition we compute, for employed individuals, (i) the average hourly wage rate, (ii) the average weekly working hours, and (iii)

42 It may be useful at this point to relate our approach to that of Bowlus, Liu, and Robinson (2002). These authors propose a methodology for constructing labor input series in efficiency units which is based upon a human capital production function with time-varying productivity parameters. Our approach, instead, implicitly assumes no technological progress (the β’s in Bowlus, Liu, and Robinson’s (2002) notation are constant). In reality, however, since our analysis filters out low frequency movements in the data, it is in fact consistent with long-run technical change.
the demographic group’s weight in the population. Formally, and using Krusell, Ohanian, Ríos-Rull, and Violante (2000)’s notation, let $G$ be our population partition, where each demographic group is indexed by $g$. We compute:

$$h_{g,t} = \frac{\sum_{i \in g} \mu_{i,t} h_{i,t}}{\sum_{i \in g} \mu_{i,t}},$$
$$w_{g,t} = \frac{\sum_{i \in g} \mu_{i,t} (w_{i,t} h_{i,t})}{\sum_{i \in g} \mu_{i,t} h_{i,t}},$$
$$\mu_{g,t} = \sum_{i \in g} \mu_{i,t},$$

where $w_{i,t}$ and $h_{i,t}$ are, respectively, the individual’s real hourly wage and usual weekly hours, and $\mu_{i,t}$ is the individual’s population weight.

Following Kydland and Prescott (1993), we select the time average of the wage rates over the whole sample as the weights to be put on hours.\(^{43}\) Denoting these weights by $\bar{w}_g$, for $g \in G$, we compute the average labor input for a particular population category $j \in G_j$ as:

$$N_{j,t} = \sum_{g \in G_j} \mu_{g,t} \bar{w}_g h_{g,t}.$$

Depending on the question being asked in the main body of the paper, $G_j$ may correspond, for instance, to skilled individuals, or to skilled individuals working in a particular sector, or having a certain occupation.

Similarly, the average wage rate for subgroup $G_j$ is computed as the ratio between total weekly earnings and adjusted weekly hours:

$$W_{j,t} = \frac{\sum_{g \in G_j} \mu_{g,t} w_{g,t} h_{g,t}}{N_{j,t}}.$$

This provides a real hourly wage rate per unit of efficiency supplied by group $j$ individuals.\(^{44}\)

\(^{43}\)We note that, since some demographic groups have no observations in some quarters, the number of observations used to compute average wages may differ from group to group. None of our results would change in any important way if the weights were normalized to sum up to one. Also, similar results obtain if the weights were based on any particular base-period wages.

\(^{44}\)Our analysis implicitly assumes two separate markets for skilled and unskilled workers, each type earning a different wage per efficiency unit of labor supplied.
Table 12: Volatility and co-movement of total hours, employment and average weekly hours per skill group (Household Survey, seasonally-adjusted unfiltered data). Legend: \(a, b, c\) denote correlations significant at 1, 5, and 10 percent level, respectively.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skilled</td>
<td>0.51</td>
<td>1.27</td>
</tr>
<tr>
<td>Unskilled</td>
<td>0.95</td>
<td>0.96</td>
</tr>
<tr>
<td>Aggregate</td>
<td>0.72</td>
<td>0.88</td>
</tr>
<tr>
<td>Hourly wage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skilled</td>
<td>0.77</td>
<td>1.14</td>
</tr>
<tr>
<td>Unskilled</td>
<td>0.61</td>
<td>0.70</td>
</tr>
<tr>
<td>Aggregate</td>
<td>0.64</td>
<td>0.78</td>
</tr>
<tr>
<td>Employment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skilled</td>
<td>0.51</td>
<td>1.33</td>
</tr>
<tr>
<td>Unskilled</td>
<td>0.79</td>
<td>0.29</td>
</tr>
<tr>
<td>Aggregate</td>
<td>0.64</td>
<td>0.33</td>
</tr>
<tr>
<td>Average weekly hours of work</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skilled</td>
<td>0.22</td>
<td>0.45</td>
</tr>
<tr>
<td>Unskilled</td>
<td>0.20</td>
<td>0.29</td>
</tr>
<tr>
<td>Aggregate</td>
<td>0.16</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Table 13: Volatility and co-movement of the skill premium and wages per skill group and in the aggregate (Household Survey, seasonally-adjusted unfiltered data). Legend: \(a, b, c\) denote correlations significant at 1, 5, and 10 percent level, respectively.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly wage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skilled</td>
<td>0.77</td>
<td>1.14</td>
</tr>
<tr>
<td>Unskilled</td>
<td>0.61</td>
<td>0.70</td>
</tr>
<tr>
<td>Aggregate</td>
<td>0.64</td>
<td>0.78</td>
</tr>
<tr>
<td>Skill premium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skilled</td>
<td>0.36</td>
<td>0.94</td>
</tr>
</tbody>
</table>

For the analysis by sector of activity, we use the NBER-created 2-digit industry codes (variable dind) and assign them to the 1-digit 1987 SIC categories (with manufacturing split into durable and non-durable manufacturing).

For the analysis by occupation, one major difficulty is that our data does not provide a time-consistent occupational classification. Until 1982 it is based on the 1970 Census, but from 1983 on it is based on the 1980 Census. We developed an assignment between 2-digit occupational codes (and when necessary 3-digit codes) and 1-digit codes. Both based upon our assignment criteria, and since we do not observe any break in the number of people in each occupational category from 1982 to 1983, our occupational coding seems to be time-consistent. Our assignment rule is available upon request.

B Dealing with Noise in the Data

[TO BE COMPLETED]
References


