

# SKILL-BIASED TECHNICAL CHANGE AND THE COST OF HIGHER EDUCATION: AN EXPLORATORY MODEL

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January 6, 2012

## Abstract

We document trends in higher education costs and tuition over the past 50 years. To explain these trends, we develop and simulate a general equilibrium model with skill- and sector-biased technical change. We assume that higher education suffers from Baumol's (1967) service sector disease, in that the quantity of labor and capital needed to educate a student is constant over time. Calibrating the model, we show that it can explain the rise in college costs between 1959 and 2000. We then use the model to perform a number of numerical experiments. We find, consistent with a number of studies, that changes in the tuition discount rate have little long-run effect on college attainment.

## 1 Introduction

For most American families, the cost of a college education is a significant expense. College tuition has grown faster than inflation for decades. Attendance rates have slowed

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\*We are grateful to Cristina De Nardi, Eric French, Suqin Ge, Hui He, Michael Sattinger, Chris Taber, Gian Luca Violante, and seminar participants at McMaster University and the University at Albany for helpful comments and discussions.

even as the college wage premium has soared (Goldin and Katz, 2008). Many observers fear that, in the words of a recent CNN headline (Censky, 2011), “surging college costs price out [the] middle class”. In this paper, we develop a simple model that explains why college costs have risen so dramatically, and consider its implications.

We begin by documenting trends in higher education costs and tuition over the past 40 years. The data show that the total cost of educating a student has risen at roughly the same rate as per capita GDP. Since 1950, listed or “sticker price” tuition has grown more quickly than GDP, while tuition net of grant aid has risen at the same rate. To explain the cost trend, we develop and simulate a general equilibrium model with skill- and sector-biased technical change. In our model, higher education suffers from the service sector disease (Baumol and Bowen, 1966; Baumol, 1967). In particular, we assume that the quantity of skilled labor needed to produce a college degree is constant across time, even as it becomes more productive in other sectors. The data appear consistent with such an assumption. For example, in 1976 there were 16.6 students for each college faculty member; in 2009 the number had fallen to 16.0.<sup>1</sup> As potential college professors and administrators become more productive in other sectors, their wages, and the cost of college education, will rise. Our model successfully replicates the dramatic increase in higher education costs.

Our paper straddles two areas of research. The first is the industry-level analysis of higher education costs and tuition. There are a number of explanations for the increase in college costs and tuition: Archibald and Feldman (2011) provide a lucid review. One explanation is the service sector disease discussed above. An alternative explanation is that institutions of higher education have become increasingly inefficient. The inefficiencies arise from market power and public subsidies that allow colleges to pad their expenses (e.g., Bowen, 1980), or costly “arms races.” Harris and Goldrick-Rab (2010) argue that because higher education practices are not objectively analyzed, significant inefficiencies almost surely exist. Other explanations focus on the tuition colleges charge, rather than the costs they incur. One such explanation is increased price discrimination. Many institutions, especially private ones, post a “sticker price” well in excess of the discounted tuition most students actually pay. Increasing the sticker price has allowed colleges to offer a broader menu of net prices, increasing their ability to price discriminate. Although some students may face the full sticker price, the prices most students pay have risen more slowly. Yet another explanation is that decreased public funding has forced schools to raise tuition.

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<sup>1</sup>2010 *Digest of Education Statistics*, Table 254. Ratios expressed in full-time equivalent terms.

In their recent book, Archibald and Feldman (2011) conclude that the service sector disease plays a central role. They show that the cost trajectory of higher education is similar to that of other high-skill services, and that costs have risen rapidly at community colleges as well as at Ivy-league institutions. We show that in a general equilibrium model, this form of biased technical change generates an increase in college costs similar to those actually observed. We believe our model can make quantitative predictions of college tuition.

The second area of research consists of general equilibrium analyses of human capital accumulation and earnings dynamics. Ljungqvist (1993) argues that because the cost of providing education depends on the cost of skilled labor, education may be particularly expensive in countries where the current level of educational attainment is low. In contrast to Ljungqvist (1993), who uses theoretical arguments, most of this literature is quantitative. In an influential paper, Heckman, Lochner and Taber (1998a) show that sustained skill-biased technological change can explain the changes in education and earnings observed over the past few decades. Lee and Wolpin (2006, 2010) consider similar topics. Akyol and Athreya (2005) emphasize that investments in college are risky: drop-out rates are high. Gallipoli, Meghir and Violante (2010) analyze tuition schedules that vary with income and ability. Our contribution is to determine the cost of higher education within the model, allowing it to adjust to economic events.

The paper most similar to ours is Castro and Coen-Pirani (2011), who also allow the cost of college to be a direct function of the wage for skilled labor. The two papers differ along a number of modelling dimensions,<sup>2</sup> and more important, in emphasis: we focus on college costs, while Castro and Coen-Pirani focus on educational attainment.

In addition to explaining the cost trends, our model allows us to assess the effect of higher tuition on college attainment. The model suggests that the long-term effects of changing tuition subsidies are small. Increasing the tuition discount rate by 1% increases enrollment by only 0.07%. Although many micro-level estimates, such as Dynarski (2003), suggest a much higher elasticity, our findings are consistent with the structural literature. As Heckman, Lochner and Taber (1998b) emphasize, once the price of skilled labor is allowed to adjust in general equilibrium, the effects of policy changes are often muted.

The rest of the paper is organized as follows. In Section 2, we summarize historical patterns of higher education costs and pricing. In Section 3, we describe our model. In Section 4 we discuss how we calibrate the model. In Section 5, we use the model to

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<sup>2</sup>Most notably, our model includes physical capital, while Castro and Coen-Pirani use a richer model of human capital.

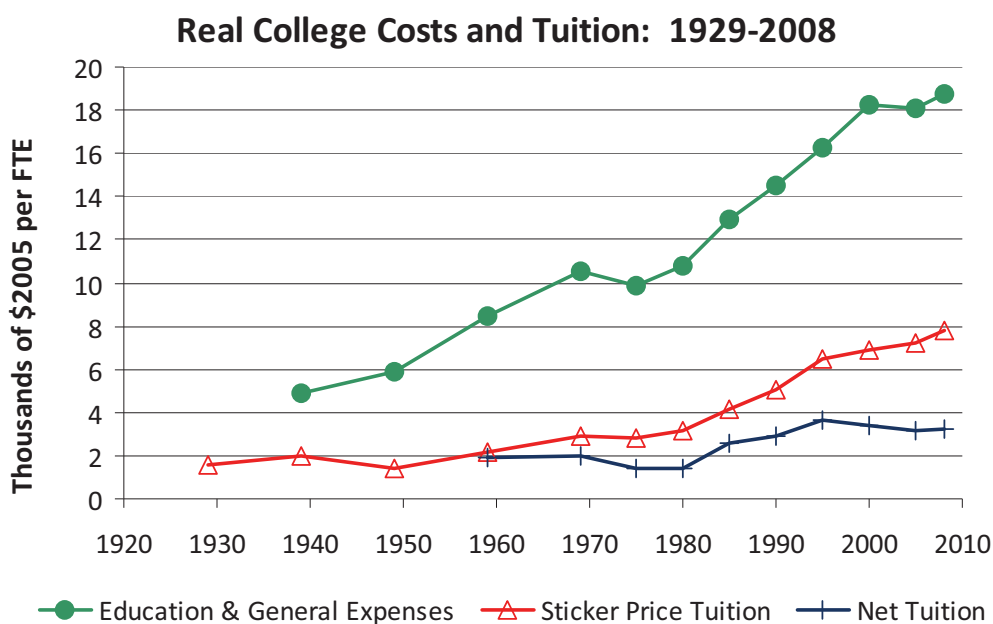


Figure 1

perform a few policy experiments. In Section 6 we discuss some extensions to the model and conclude.

## 2 Higher Education Data

In this section, we present data related to higher education: costs, prices, enrollment, and returns. We use these data to motivate the structure of our model, and as calibration targets for our quantitative exercises.

### 2.1 Expenditures and Tuition

In considering “college costs”, it is useful to distinguish between three distinct objects: (1) expenditures, the costs incurred in educating students; (2) the listed or “sticker” price for tuition; and (3) the net tuition students pay after receiving financial aid.

The top line in Figure 1 shows real expenditures per full-time-equivalent (FTE) student for the higher education sector, including 2-year, 4-year and graduate students. These data are drawn from the U.S. Department of Education’s Digest of Education Statistics, and converted to 2005 dollars with the GDP deflator. The data are measured over

academic years, July 1 - June 30, which we index by the initial calendar year. Constructing the full series requires several splices: prior to 1967, costs are measured on a per-fall-enrollee basis, and after 1995 the data definitions were modified. We consider the subset of costs included in the education and general category. Among the costs excluded from this category are auxiliary operations such as dormitories.<sup>3</sup> Average expenditures have more than trebled over time, from under \$5,000 in 1939 to over \$18,000 today. Perhaps the most notable feature of the series is that between 1969 and 1975 costs actually fell slightly, before returning to their upward trend. Archibald and Feldman (2011) stress that during this time period the U.S. was still in what Goldin and Margo (2005) call the “Great Compression”, during which relative wages for educated workers fell.

The second line in the figures shows sticker price tuition per FTE over the same time period. Consistent with the cost measures, we calculate sticker price tuition as tuition revenues divided by FTE, again using data from the Digest of Education Statistics.<sup>4</sup> This series also requires splicing per-FTE and per-enrollee data. After falling between 1939 and 1949, sticker price tuition has risen more rapidly than expenditures. Most college students, however, receive some form of grant aid, either from the institution itself, or some external source such as the Federal government. Using data from the College Board (2010), we calculate average student grant aid, exclusive of veterans benefits.<sup>5</sup> Subtracting aid from sticker price tuition yields net tuition. The bottom line in Figure 1 shows net tuition. Net tuition has grown more slowly over time than sticker prices, suggesting that the increase in sticker prices is at least partly intended to increase the scope for price discrimination. A striking feature of sticker price and especially net tuition is that they are quite low relative to expenditures. Although state aid to public institutions has not increased over time (in real per FTE terms), it is still significant. Federal grants are also a major source of income, even at private institutions.

Figure 2 shows the same costs and tuition as fractions of per capita GDP, which is constructed from the national accounts and Census data (Council of Economic Advisors, 2010).<sup>6</sup> These data show that, with the exception of 1939, education and general expen-

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<sup>3</sup>One quirk of education and general expenditures is that they include institutional “scholarships and fellowships”: rather than being deducted from tuition revenue, institutional aid is treated as an expense. In the cost series shown in Figure 1 we deduct these expenses: the effects of this adjustment are discussed in the data appendix.

<sup>4</sup>The Digest of Education Statistics also includes undergraduate tuition indices, which begin in 1964-65. We compare the tuition measures in the data appendix.

<sup>5</sup>Our calculations also omit tax benefits. In recent years, the Federal income tax credits for higher education have grown rapidly (College Board, 2010). Aid data for 1959 are found by extrapolating backward from 1963.

<sup>6</sup>Consistent with the model below, our measure of population consists of people aged 16-64. Calculat-

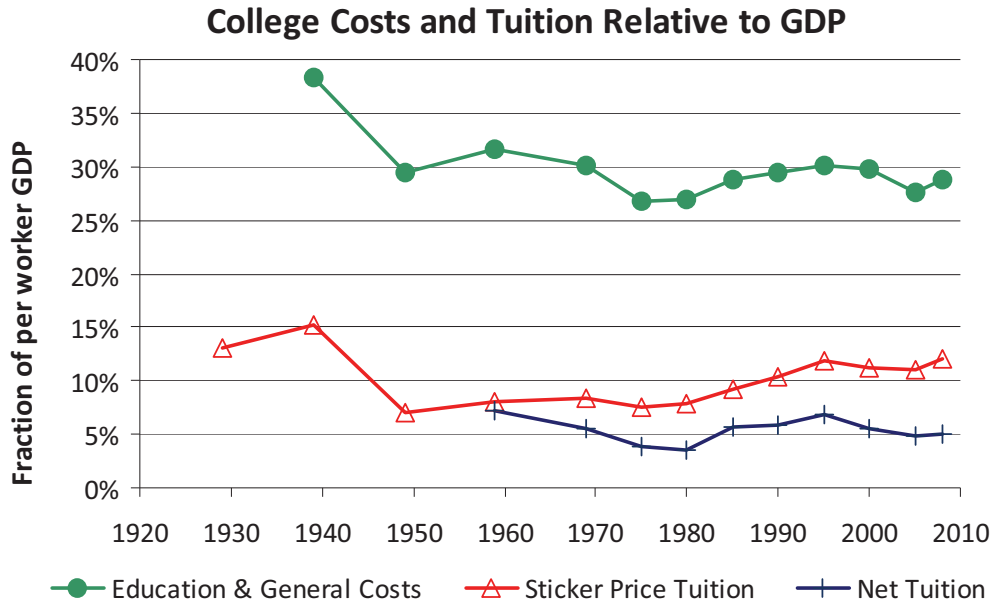


Figure 2

ditures have stayed between 28 and 32 percent of per capita GDP. This is consistent with the hypothesis that higher education has enjoyed few, if any, productivity gains over the past few decades. After falling dramatically between 1929 and 1949, sticker price tuition has grown faster than GDP, while net tuition has grown at the same rate. The net tuition ratio, being a function of averages, need not imply that higher education is as “affordable” today as it was in the past. Median income has grown far more slowly than per capita GDP, and tuition varies widely across students (Leonhardt, 2009).

The data in Figures 1 and 2 are averages taken across both public and private institutions, with the latter including for-profit institutions as well as traditional non-profit schools. These averages also combine data for 2-year and 4-year institutions. Figure 3 shows disaggregated expenditure data, expressed as a fraction of GDP. Perhaps the most notable feature of the data is the sharp decline in private sector expenditures between 1995 and 2000. Given that the public sector shows no such decline, the break in the series probably reflects changes in the Department of Education’s data measures. Figure 3 also shows expenditures for non-profit private institutions. In the recent decade for-profit institutions have grown rapidly, from 4 percent of private enrollment in 1980 to 29 percent

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ing per capita GDP total population makes the series in Figure 2 more variable, but does not change their general properties. To be consistent with academic years, we use averages of consecutive calendar-year values.

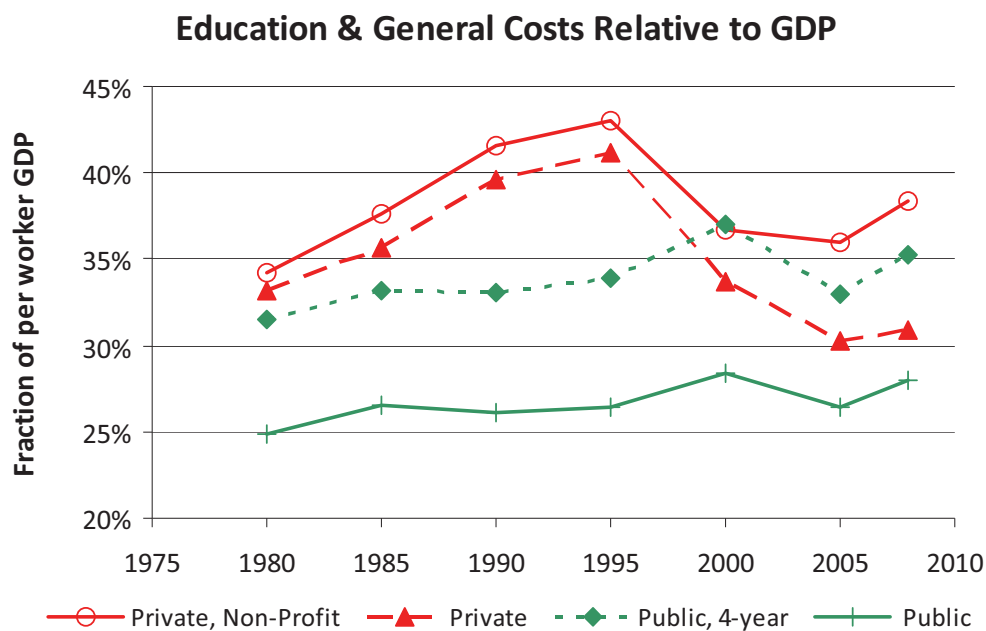


Figure 3

in 2008. Because for-profit institutions tend to have lower costs, their growth has pulled down average expenditures in the private sector. Although separate cost data for 2-year and 4-year institutions are available only for public institutions, about 90 percent of 2-year students are in public colleges. Figure 3 reveals that once 2-year public institutions are excluded, public and private institutions have fairly similar levels of expenditure. Figure 3 also shows that the expenditures at 2-year colleges follow a trajectory similar to that at 4-year institutions; Archibald and Feldman (2011) view this as evidence against the “arms race” hypothesis.

Figure 4 displays disaggregated sticker price tuition. The data break in the late 1990s appears to have an effect here as well. However, the distinction between non-profit and for-profit private institutions is modest. Although for-profit institutions have lower costs, they rely more heavily on tuition revenue. Since 1992, the first year disaggregated revenue data are available, tuition for 4-year public institutions has risen relative to tuition for 2-year public institutions; we use the 1992 tuition ratio to infer 4-year tuition for earlier years.

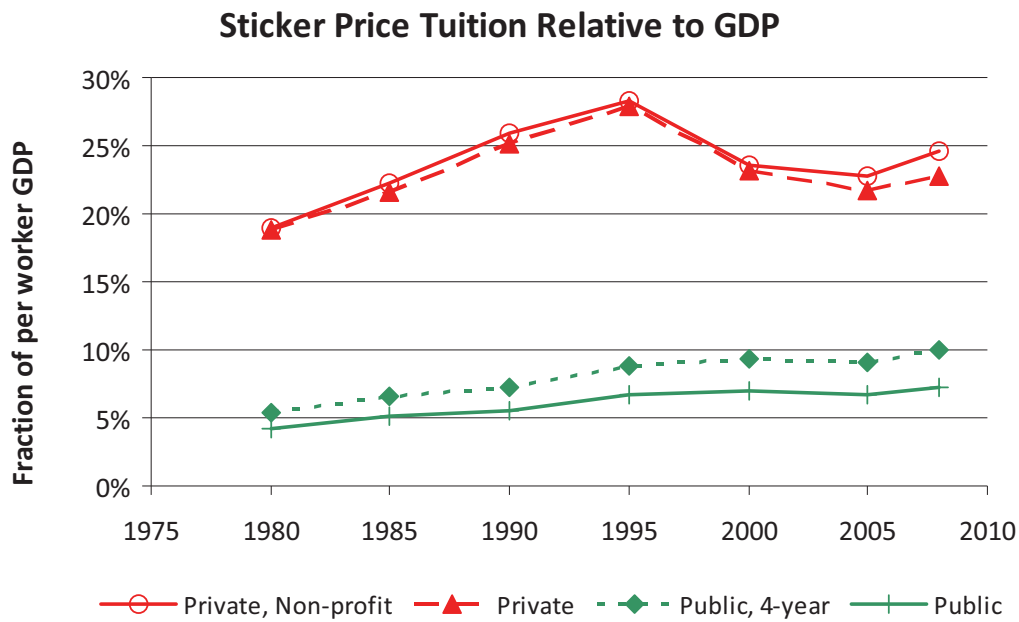


Figure 4

## 2.2 Staffing and Compensation

Table 1 shows staffing levels, measured as the ratio of students (in FTE) to employees (in FTE), as shown in the Digest of Education Statistics. Both overall and faculty staffing levels have remained roughly constant during the past three decades. The most notable change has been a reduction in non-professional staff in favor of non-faculty professionals. Assuming that worker quality has stayed constant as well, these constant staffing levels are consistent with our hypothesis that higher education has not enjoyed any efficiency gains.

Turning to costs per worker, data from the Digest of Education Statistics shows that faculty compensation has grown very slowly. Figure 5 shows that salaries for full-time instructional faculty have in fact fallen relative to GDP. Controlling for faculty rank and including benefits (not rank-differentiated) does not change the trend. Figure 6 reveals ongoing changes in faculty composition. The fraction of instructional faculty that are full-time employees has fallen steadily, from 78% in 1970 to 51% in 2007. Figure 6 also shows that during the 1960s and 1970s, the share of faculty and students associated with 2-year colleges increased.



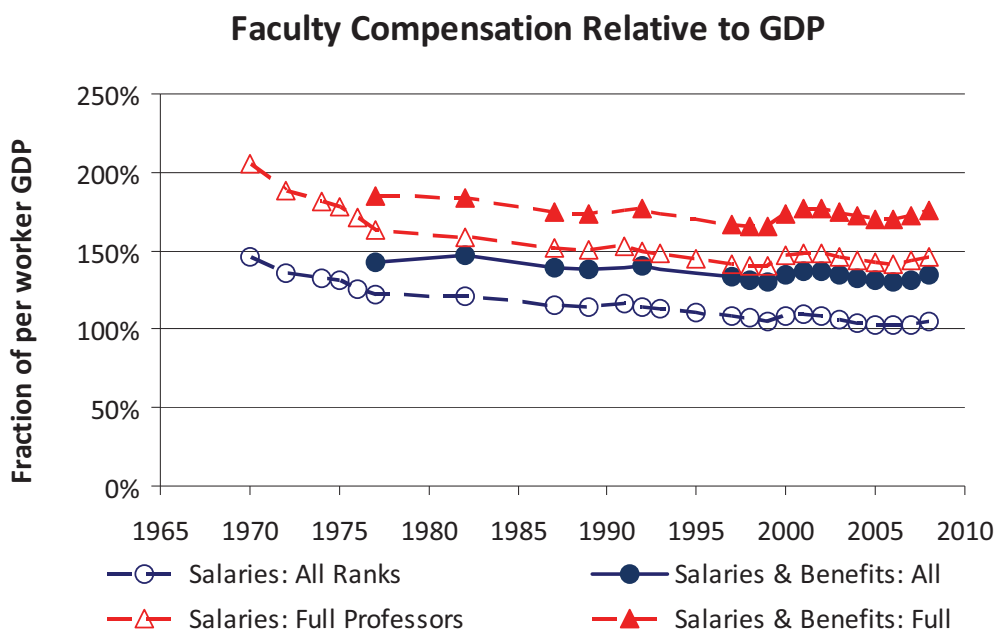


Figure 5

	1976	1999	2009
All	5.4	4.8	5.4
Professional staff	9.8	7.5	7.6
Administrative	84.0	69.9	68.5
Faculty	16.6	14.9	16.0
Graduate assistants	100.5	110.4	109.1
Other professionals	50.9	23.0	21.7
Non-professional staff	11.9	13.4	18.6

Note: All quantities in FTE terms.

While these trends have almost surely reduced the growth in college costs, interpreting them is difficult. The trends may well reflect a decline in the human capital embodied in college instructors. Alternatively, they may reflect idiosyncratic features in the specialized academic job market. Moreover, it is not clear whether reductions in human capital imply reductions in educational quality, as assumed by Castro and Coen-Pirani (2011), or simply reductions in costs. In the model below, our identifying assumption will be that providing a college education requires a fixed amount of skilled labor, with no changes in

### Faculty and Student Composition: Full-time vs. Part-time and Four-year vs. Two-Year

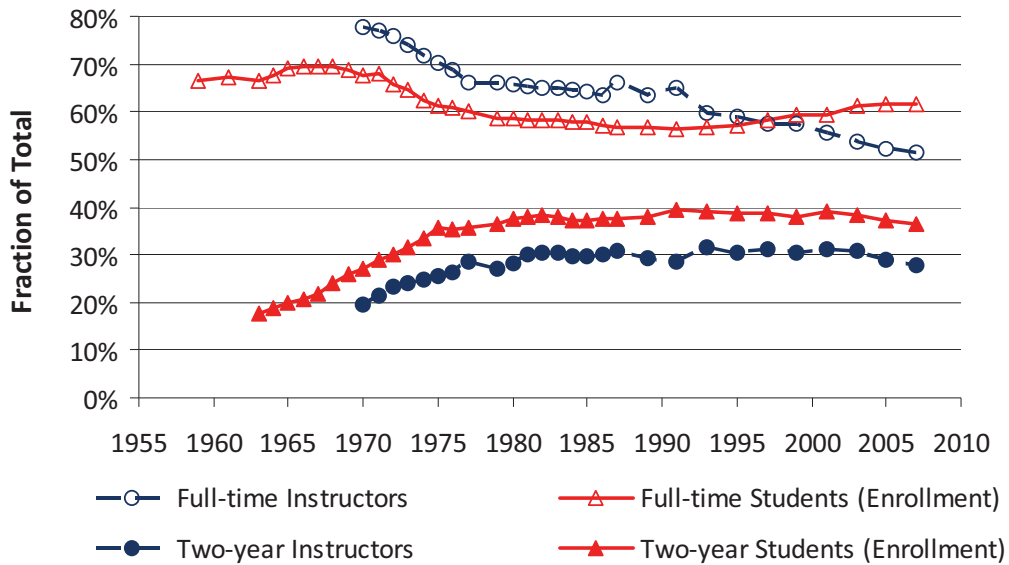


Figure 6

either efficiency or quality.

The reduction of non-professional staff in favor of non-faculty professionals has probably raised staffing costs. Unfortunately, the data do not provide compensation information for non-instructional employees.

## 2.3 Capital

The Digest of Education Statistics reports total physical plant in the higher education sector for the years 1929-30 through 1989-90. Unfortunately, these data do not divide capital between “education and general uses”, as opposed to auxiliary “current fund” uses such as dormitories. Table 2 shows real physical plant per FTE. While it varies greatly from decade to decade, over the long-term physical plant is more or less constant. The data show that because capital use is constant, while real wages are rising, user costs (here calculated as 12 percent of plant) are a shrinking fraction of total current fund expenditures.

Table 2. Expenditures and Physical Plant				
	Expenditures			
	Current Fund	Education & General	Physical Plant	User Cost / CF Expenses
1929-30	5.59	4.16	22.76	48.9%
1939-40	6.60	5.11	26.95	49.0%
1949-50	7.97	6.06	17.04	25.6%
1959-60	10.53	8.81	25.47	29.0%
1969-70	14.02	11.22	28.04	24.0%
1979-80	14.66	11.47	21.57	17.6%
1989-90	19.43	15.23	23.75	14.7%

Note: Costs are measured in 1,000s of \$2005 per FTE.

## 2.4 College Attainment and Earnings

Moving to the demand side of the higher education market, Table 3 presents college attainment for the past 70 years, using Census data.<sup>7</sup> In any given decade, the educational achievement of workers less than 25 years old is projected by the achievement of 30- to 34-year-olds in the *next* decade. This means, for example, 27.8% of the 20- to 24-year-olds in 1960 attended college in the following decade. Because most people have completed their undergraduate studies by the time they reach 30, this is a good projection of ultimate educational attainment. Table 3 shows that the growth in college attendance is diminishing. For example, the fraction of people aged 25 or older that attended college rose from 32 percent in 1980 to 45 percent in 1990, an increase of 13 percentage points. Between 2000 and 2010, attendance grew by only 4 percentage points. In contrast, the fraction of people completing at least a Bachelor's degree continues to grow.<sup>8</sup>

Another piece of the puzzle is earnings. Census data indicate that in 1961, men who had attended college earned 46 percent more than high school graduates. By 2000, the premium had risen to 65 percent. During the same period, the earnings premium among those with least a Bachelors degree (relative to a high school diploma) rose from 65 percent to 107 percent. This rise in college premia is well-known. While the premia reflect differences in ability as well as human capital accumulation, they suggest that the

<sup>7</sup>Data through 2000 are from the Decennial Censuses. Data for 2010 are from the Current Population Survey.

<sup>8</sup>Table 1 shows that the fraction of college attendees receiving a Bachelors degree has grown modestly, from 46 percent in 1940 to 54 percent in 2010.

returns to college are at a minimum not decreasing.

Table 3. College Attainment Rates (percent)

	Attended College		Bachelors+	
	25+	30-34	25+	30-34
1940	10.1	NA	4.6	6.3
1950	13.6	16.3	6.2	7.4
1960	16.5	21.5	7.7	10.9
1970	21.3	27.8	10.7	14.4
1980	31.9	46.7	16.2	24.6
1990	45.2	55.1	20.3	24.3
2000	51.8	57.9	24.4	27.9
2010	55.9	61.1	29.9	34.1

## 2.5 Key Findings

Our review of the data reveals several trends:

- Expenditures per college student tend to grow at the same rate as per capita GDP.
- Since World War II, sticker price tuition has grown faster than GDP, while tuition net of grant aid has grown at the same rate.
- Since at least 1976, staffing at institutions of higher education has remained constant, although there have been changes in its composition.
- Capital per student has remained more or less constant over time.
- Between 1940 and 2010, educational attainment, whether measured by attendance or 4-year degrees, more than quintupled.
- Since 1960, the earnings premium for college-educated workers has grown significantly.

## 3 Model

### 3.1 Goods sector

We consider an economy with two sectors: the goods-producing sector and an education sector. The goods sector produces output ( $Y$ ) using two skill categories of workers,

white-collar and blue-collar, and homogeneous capital. Specifically, production is given by the following nested CES form

$$Y = AK^\alpha[\omega W^{1-\varsigma} + (1-\omega)B^{1-\varsigma}]^{(1-\alpha)/(1-\varsigma)} \quad (1a)$$

$$= AK^\alpha L^{1-\alpha}, \quad (1b)$$

$$L \equiv [\omega W^{1-\varsigma} + (1-\omega)B^{1-\varsigma}]^{1/(1-\varsigma)}, \quad (1c)$$

where  $B$  denotes total units of blue-collar skill,  $W$  denotes white-collar skill,  $L$  denotes total labor inputs,  $K$  denotes capital, and  $A$  indexes aggregate productivity. The parameter  $\varsigma$  governs the substitutability between white- and blue-collar labor (the elasticity of substitution is  $1/\varsigma$ ). Heckman, et al. (1998a) estimate a version of this model where  $K$  and  $L$  are also nested in a CES aggregator, but find the elasticity of substitution for these two factors is close to 1. To capture skill-biased and skill-neutral technical change, we allow the weight  $\omega$  and the shifter  $A$  to vary over time.

Firms are perfectly competitive. The equilibrium pricing conditions are:

$$r + \delta = \alpha \frac{Y}{K} = \alpha A \left( \frac{K}{L} \right)^{\alpha-1}, \quad (2)$$

$$w^B = (1-\alpha)(1-\omega) \frac{Y}{L} \left( \frac{B}{L} \right)^{-\varsigma}, \quad (3)$$

$$w^W = (1-\alpha)\omega \frac{Y}{L} \left( \frac{W}{L} \right)^{-\varsigma}, \quad (4)$$

where  $r$  is the real interest rate,  $\delta$  is the depreciation rate, and  $w^B$  and  $w^W$  are the unit prices of blue-collar and white-collar skill, respectively. The skill price ratio is:

$$\frac{w^W}{w^B} = \frac{\omega}{1-\omega} \left( \frac{W}{B} \right)^{-\varsigma}. \quad (5)$$

## 3.2 Individuals

Individuals live from ages 18 to 64, for a total of  $T = 47$  periods. Each individual is endowed with the ability level  $h$ . At the beginning of their lives, individuals choose whether to spend 4 periods attending college. If the individual chooses not to go to college, he works as a unskilled labor with human capital  $h$ . If the individual chooses to

attend college, he becomes a “skilled” agent and his human capital is

$$\gamma(h) = \gamma_0[h + \gamma_1(h - \gamma_2)^3].$$

The shape of this transformation draws on Heckman et al.’s (1998a, Tables I and II) estimates of how earnings vary by ability and education. Assume unskilled workers work  $L^B$  hours per year on average, and skilled workers work  $L^W$  hours. Let  $y_h^B$  denote the earnings of an individual of type  $h$ , with “raw” human capital  $h$ , if she works as unskilled worker:  $y_h^B = h \cdot w^B \cdot L^B$ . Let  $y_h^W$  denote the earnings of the same individual when she works as skilled worker:  $y_h^W = \gamma(h) \cdot w^W \cdot L^W$ .

We assume that an individual’s preferences are given by the discounted value of her lifetime earnings, net of college costs. This implies that  $U_h^W$  and  $U_h^B$ , the returns from going to college and not going to college, respectively, are

$$\begin{aligned} U_h^B &= N^B y_h^B; & U_h^W &= N^W y_h^W, \\ N^B &\equiv \sum_{t=0}^{T-1} \beta^t; & N^W &\equiv \sum_{t=4}^{T-1} \beta^t, \end{aligned} \quad (6)$$

where  $\beta$  is the discount factor.

Individuals can borrow and lend freely at the rate  $r$ . The decision to go to college thus depends only on the cost and the expected returns to college. Let  $c$  denote annual cost, and  $C = c \sum_{t=0}^3 \beta^t \equiv N^C c$  the lifetime cost, of college. Suppose that students pay the fraction  $d$  of this cost, with the remainder funded by lump-sum taxes.<sup>9</sup> An individual is indifferent between going to college and not if the expected utility gain from going to college is equal to 0. This gives us a threshold ability level  $h^*$  which satisfies the following equation:

$$\begin{aligned} 0 &\equiv (U_{h^*}^W - dC) - U_{h^*}^B \\ &= N^W \gamma(h^*) w^W L^W - N^C dc - N^B h^* w^B L^B. \end{aligned} \quad (7)$$

Therefore an individual chooses to go to college if and only if  $h > h^*$ .

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<sup>9</sup>Given our assumptions of linear preferences and full credit access, we will ignore these transfers in our discussion.

### 3.3 Higher education sector

Converting a blue-collar worker into a white-collar worker requires skilled labor and capital. The cost of these inputs are their outside opportunity costs, namely the wage  $w^W$  and the user cost  $(r + \delta)$ . The cost of going to college per year for an individual is thus

$$c = E^W w^W + E^K (r + \delta), \quad (8)$$

where  $E^W$  is the number of skilled labor units devoted to each student in a year, and  $E^K$  is the amount of capital. Combining equations (8) and (7) allows us to restate the college skill threshold:

$$N^W \gamma(h^*) \frac{w^W}{w^B} L^W = N^C d \left[ E^W \left( \frac{w^W}{w^B} \right) + E^K \left( \frac{r + \delta}{w^B} \right) \right] + N^B h^* L^B. \quad (9)$$

### 3.4 Ability distribution

Each individual begins life with a draw of human capital,  $h$ , from a log-normal distribution:  $\ln(h) \sim \mathcal{N}(\mu, \sigma^2)$ . Let

$$e = 1 - F(h^*), \quad (10)$$

denote the fraction of the population that attends or has attended college.

### 3.5 Equilibrium

We will work with an open economy framework, taking the interest rate  $r$  as given.

**Definition 1** *A steady-state equilibrium is given by: the capital stock  $K$  and the labor quantities  $W$  and  $B$ ; the skill threshold  $h^*$ ; the wage rates  $w^B$  and  $w^W$ ; and a distribution of people from age 18 to 64,  $m(h)$ , such that the following conditions hold:*

- (i) *Given the interest rate and the wages,  $h^*$  is consistent with equation (7).*
- (ii) *All markets clear:*

$$W = \frac{43}{47} \cdot L^W \cdot \int_{h > h^*} \gamma(h) m(dh) - \frac{4}{47} E^W e, \quad (11)$$

$$B = L^B \cdot \int_{h \leq h^*} h m(dh). \quad (12)$$

- (iii) *The price of each factor equals its marginal product. That is, equations (2), (3), (4) hold.*

An important equilibrium statistic is  $mwr$ , the ratio of the average wage for college-educated workers to the average wage for blue-collar workers:

$$mwr = \frac{w^W [W + \frac{4}{47}E^W e] / [\frac{43}{47}e]}{w^B B / (1 - e)}. \quad (13)$$

### 3.6 Transition Adjustment

Because the parameters of the model are shifting over time, the actual economy is in a transition path where the fraction of the population enrolled is increasing over time. This can be crudely approximated in our model by distinguishing between the current enrollment rate  $e_1$  and the education attainment rate of older workers,  $e_0$ . Associated with these enrollment rates are the skill cutoffs  $h_1$  and  $h_0$ . We proceed as follows:

1.  $h_1$  is found by solving equation (9); we are assuming agents are myopic.  $h_0$  is found by inserting  $e_0$  – which is taken as given – into equation (10).
2. The overall enrollment rate is  $e$ :

$$e = \frac{4}{47}e_1 + \frac{43}{47}e_0 = \frac{4}{47}[1 - F(h_1)] + \frac{43}{47}[1 - F(h_0)]. \quad (14)$$

3. The new supplies of white and blue collar skill are:

$$W = \frac{43}{47} \cdot L^W \cdot \int_{h>h_0} \gamma(h) m(dh) - \frac{4}{47} \cdot E^W \cdot \int_{h>h_1} m(dh), \quad (15)$$

$$B = \frac{43}{47} \cdot L^B \cdot \int_{h \leq h_0} h m(dh) + \frac{4}{47} \cdot L^B \cdot \int_{h \leq h_1} h m(dh). \quad (16)$$

4. The equilibrium is defined much as before, replacing (10), (11) and (16) with (14), (15) and (16), respectively. The mean wage ratio is adjusted slightly:

$$mwr = \frac{w^W [W + \frac{4}{47}E^W e_1] / [\frac{43}{47}e_0]}{w^B B / [1 - \frac{43}{47}e_0 - \frac{4}{47}e_1]}.$$

## 4 Calibration

### 4.1 Procedure

We calibrate the model assuming the economy is in transition, taking the enrollment of the older cohort,  $e_0$ , as given. Our target years are 1959-60 and 2000-01.



We pick the following parameters from the data described above or from other studies:  $\delta = 0.08$ ;  $r = 0.04$ ;  $\beta = 1/(1+r)$ ;  $L^W = L^B = 1$ ;  $\varsigma = 0.7$  (Heckman et al., 1998, Table III, OLS);  $d^{1959} = 0.2363$ ;  $d^{2000} = 0.2426$ ;  $e_0^{1959} = 0.077$  (1960 value);  $e_0^{2000} = 0.244$ ; and  $E^K = 18,573$ . The capital requirement  $E^K$  is found by scaling the capital figures in Table 3 by the ratio of education and general to current-fund expenditures, and taking the average. We are measuring college attainment as the fraction of the population with at least a 4-year degree. We assume that the capital-output ratio is constant at 2.666, its average value since 1929.

We use the year-1959 and year-2000 values of  $\{Y, K, e, c, mwr\}$ , and year-1959 values of  $W$  and  $B$  to find the parameter vector  $\{\sigma, \mu, \gamma_0, \gamma_1, \gamma_2, E^W, \alpha^{1959}, A^{1959}, \omega^{1959}, A^{2000}, \omega^{2000}, \alpha^{2000}\}$ . We do this in three steps:

1. Given  $\sigma$  and  $\gamma_2$ , we choose 7 parameters,  $\{E^W, A^{1959}, \gamma_0, \gamma_1, \mu, \alpha^{1959}, \omega^{1959}\}$ , to match the following 7 moments in 1959: aggregate capital  $K$ , aggregate output  $Y$ , cost of higher education  $c$ , fraction enrolled  $e_1$ , mean wage ratio  $mwr$ , and the labor inputs  $W$  and  $B$ , both of which are 1. The final two targets are a normalization; as Lee and Wolpin (2010) point out,  $W$  and  $B$  are not identified separately from  $A$  and  $\omega$ . To evaluate equations (15) and (16), we use formulas for the moments of truncated distributions found in Jawitz (2004).
2. We use the year-2000 values of  $\{Y, K, e\}$ , to find  $h^*$ ,  $K$ ,  $W$ ,  $B$ ,  $w^W$ ,  $w^B$ , and the parameters  $\{A^{2000}, \omega^{2000}, \alpha^{2000}\}$ .
3. Finally, we iterate over  $\sigma$  and  $\gamma_2$  (repeating steps 1 and 2), to minimize the distance between the observed and predicted year-2000 values of  $c$  and  $mwr$ :

$$\begin{aligned} c &= E^W w^W + E^K (r + \delta), \\ mwr &= \frac{[w^W W + \frac{4}{47} E^W w^W e_1]}{w^B B} \cdot \frac{(1 - \frac{43}{47} e_0 - \frac{4}{47} e_1)}{[\frac{43}{47} e_0]}. \end{aligned}$$

Perhaps the most important calibration target in this process is the level of college costs,  $c$ . Our preferred measure of costs excludes both institutional aid and 2-year institutions.<sup>10</sup> Table 4 shows this measure, which appears as Case 4, is an intermediate case.

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<sup>10</sup>Separate cost data for 2-year and 4-year institutions are first available in the Digest of Education statistics in 1977, and then only for public institutions. However, about 90 percent of 2-year students are in public institutions, and if one is willing to assume the ratio of 2-year to 4-year costs is constant over time, one can use attendance data to make an approximate adjustment.

	Institutional Aid	2-year Institutions	$(c/Y)^{1959}$	$(c/Y)^{2000}$
Case 1	Included	Included	32.77%	33.09%
Case 2	Included	Excluded	35.04%	40.13%
Case 3	Excluded	Included	31.56%	29.77%
Case 4	Excluded	Excluded	33.70%	35.74%

## 4.2 Results

Table 5 shows the value of parameters estimated from the model. Between 1959 and 2000, skill-neutral technology,  $A$ , increases by 55%. The weight on white-collar skill in the labor composite,  $\omega$ , increases from 0.1085 to 0.2925. The weight on capital,  $\alpha$ , stays the same, which follows from equation (2) under a constant capital-output ratio and a constant interest rate.

Parameters	Values	
	in 1959	in 2000
$A$ skill-neutral productivity level	749	1,162
$\alpha$ weight on capital	0.3199	0.3199
$\omega$ weight on white-collar skill in composite	0.1085	0.2925
$\gamma_0$ cubic production function of skill	12.382	
$\gamma_1$ cubic production function of skill	46.119	
$\gamma_2$ shifter in production function of skill	1.3515	
$\mu$ mean of log ability	0.0959	
$\sigma$ standard deviation of log ability	0.0688	
$E^W$ skilled labor units per student per year	3.4383	

Table 6 assesses the model's fit of the calibration targets. The model matches all the data moments. The rapid growth in the mean wage ratio suggests that higher education, being skill-intensive, should become increasingly expensive relative to GDP. This tendency is offset by capital costs, which are constant in absolute terms and decreasing relative to GDP. The offsetting forces allow the model to replicate the observed growth in college expenditures, while holding constant the resources devoted to each student.

Table 6. Data and model moments						
		$Y$	$K$	$c$	$mwr$	$e_1$
in 1959	data	26,740	71,280	9,010	1.651	0.144
	model	26,740	71,280	9,010	1.651	0.144
in 2000	data	61,290	163,400	21,890	2.074	0.341
	model	61,290	163,400	21,890	2.074	0.341
Note:	Output and capital per worker and college costs per student are measured in \$2005.					

## 5 Experiments

Between 1959 and 2000, three parameters changed: the skill weight  $\omega$ , the productivity parameter  $A$ , and the tuition discount factor  $d$ . To assess the effects of each parameter, we perform a decomposition exercise, solving the model at its 1959 parameter values, and then changing each of the three parameters in isolation. First we look at skill-biased technological change ( $\omega$ ), then Hicks-neutral technological change ( $A$ ), and finally, change in tuition discount rate  $d$ .

### 5.1 In Transition

We assume that in both 1959 and 2000, the economy is in transition. In each experiment we fix  $e_0^{2000} = 0.244$  as in the data. We can think of each change as an unexpected shock which affects the economy in 2000, but not the enrollment decisions made by previous cohorts. Appendix 7.2 provides a detailed description of the computation procedure.

Table 7 shows how the aggregate moments change in the full model and in each experiment. Enrollment, for both the youngest cohort and for all ages ( $e$ , given by equation (14)), is measured as absolute changes. Everything else is measured as the ratio of year-2000 values to year-1959 values. Notice that the enrollment of the existing cohort in 2000,  $e_0^{2000} = 0.244$ , is much higher than enrollment in 1959,  $e_0^{1959} = 0.077$ . Therefore, in the absence of other changes, white-collar skill becomes more abundant, which reduces the skill premium ( $w^W/w^B$ ) in each experiment. Notice from equation (2), capital and output always change in the same proportion, and if  $A$  is fixed, capital, aggregate labor ( $L$ ) and output always change in the same proportion.

Table 7: Effects of parameter changes—Transition					
	data	model	$\omega$ only	$A$ only	$d$ only
$Y$	2.29	2.29	1.20	1.86	0.98
$K$	2.29	2.29	1.20	1.86	0.98
$W$	-	2.72	2.72	2.82	2.82
$B$	-	0.80	0.80	0.83	0.83
$L$	-	1.20	1.20	0.98	0.98
$c/Y$	1.06	1.06	1.16	0.50	0.62
$mwr$	1.26	1.26	1.26	0.37	0.37
$w^W/w^B$	-	1.44	1.44	0.43	0.43
$e_1$	0.197	0.197	0.198	-0.144	-0.144
$e$	0.170	0.170	0.170	0.141	0.141
Note:	Table shows ratio of year-2000 values to year-1959 values, except for enrollment ( $e_1$ and $e$ ), which are expressed as absolute changes.				

An increase in  $\omega$  increases the demand for white-collar workers and decreases the demand for blue-collar workers. The increase in demand is bigger than the increase in supply from the older cohorts ( $e_0$ ) found in the data, and the skill premium rises. As a result, the college enrollment of the youngest cohort increases, by almost the same amount as in the full model. Changing  $\omega$  also reweights  $W$  and  $B$  in the computation of  $L$ . Aggregate labor increases, leading capital and output to increase as well.<sup>11</sup> With an increase in the white-collar wage, college costs also increase.

A skill-neutral increase in  $A$  increases the demand for capital, white-collar skill and blue-collar skill. As indicated in equation (2), capital increases relatively more than aggregate labor. Because  $e_0$  increases, white-collar skill increases relative to its 1959 value, and with  $\omega$  unchanged the skill premium drops. The college enrollment of the youngest cohort drops to zero. Because college students are not yet working, an decrease in enrollment increases the amount of blue-collar skill supplied by young workers without decreasing the immediate supply of white-collar skill. Lower enrollment also releases white-collar skill from the provision of higher education. The aggregate supply of both blue-collar and white-collar labor thus increase relative to the full model. Capital and output both increase a lot. With an excess of white-collar skill depressing white-collar wages, and

<sup>11</sup>Holding  $W$  and  $B$  fixed, the effects of changing  $\omega$  on the composite  $L$  depend on the relative sizes of  $W$  and  $B$ , which in turn depend on the normalizations used to scale  $W$  and  $B$  in the calibration. With different scaling, increases in  $\omega$  can cause  $L$  to fall.

output having grown relative to capital needs ( $E^K$ ), college costs drop dramatically.

An increase in  $d$  is a reduction in the tuition discount rate or, equivalently, an increase in net tuition. Higher net tuition discourages college enrollment, and the reduction in the skill premium caused by the increase in  $e_0$  drives enrollment to zero.

## 5.2 In Steady State

In solving the transition model, we assume that agents predict their future earnings myopically. An alternative approach is to assume that the economy is in a steady state, so that myopic expectations are fully rational. We thus revise our experiments, using the same parameter values but assuming that the economy is in a steady-state in both 1959 and 2000. We do so by requiring that all cohorts have the same enrollment rate,  $e_0 = e_1 = e$ , which they choose optimally. We first compute steady-state equilibria for 1959 and 2000, and then conduct the same decomposition as before. We find that when all the parameter changes are considered together, the transition and steady-state versions of the model deliver similar results. The results for the decomposition exercises differ more.

Table 7 shows the results. Notice from equation (2) that capital and output always change in the same proportion, and if  $A$  is fixed, capital, aggregate labor and output always change in the same proportion.

Relative to the benchmark transition model, in the steady state for 1959, enrollment for the older cohorts is higher and enrollment for the youngest cohort is lower. Average enrollment ( $e$ ) is modestly higher in the steady state model. In the transition model,  $e^{1959} = 8.3\%$ ; in the steady state the corresponding value is 8.6%. The total stock of white-collar skill is higher in the steady state because less skill is used in the higher education sector and also because there is a larger existing stock of skill held by older cohorts, due to their higher enrollment. Treating 1959 as a steady state generates a lower stock of blue-collar skill for older cohorts but increases that of the new cohort, who are now less likely to attend college. The second effect dominates the first, and total blue-collar skill increases. Since both blue-collar skill and white-collar skill increase, aggregate labor increases. As a result, the total stock of capital is higher than in the benchmark model. While both types of skill increase, white-collar skill becomes relatively more abundant, so that the cost of college and the mean wage ratio are lower than in the benchmark model. The changes in the relative supply of skills, however, have small effects on total labor inputs ( $L$ ) or output. For example, output for 1959 is \$26,700 in the benchmark model and \$27,000 in the steady state.

Table 8: Effects of parameter changes—Steady state						
	2000/1959 ratios					
	1959	2000	total	$\omega$ only	$A$ only	$d$ only
$Y$	2.70	6.25	2.31	1.21	1.91	1.0000
$K$	7.20	16.65	2.31	1.21	1.91	1.0000
$W$	1.127	3.10	2.75	2.74	1.00	0.9995
$B$	0.996	0.763	0.77	0.77	1.00	1.0001
$L$	1.01	1.23	1.21	1.21	1.00	1.0000
$c/Y$	0.315	0.327	1.04	1.14	0.87	1.0003
$mwr$	1.50	1.77	1.18	1.18	1.00	1.0004
$w^W/w^B$	0.112	0.155	1.39	1.39	1.00	1.0004
$e$	0.086	0.285	0.199	0.199	0.00	-0.000048
Note:	Output and capital are measured in 10,000s of \$2005. Final 4 columns show ratio of year-2000 values to year-1959 values, except for enrollment ( $e$ ), which is expressed as an absolute change.					

The comparison between the year-2000 steady state reported in Table 8 and the year-2000 economy in transition reported in Table 6 is similar to the comparison for 1959. It follows that the changes from the year-1959 steady state to the year-2000 steady state are similar to the changes for the transition model reported in Table 7.

The steady state decomposition shows that the increase in enrollment is almost entirely due to skill-biased technological change. An isolated increase in  $\omega$  reduces the marginal product of blue-collar workers, resulting in a reduction of blue-collar skill and a increase in the skill premium. Enrollment increases and blue-collar skill decreases a lot. The cost of college rises significantly.

A skill-neutral increase of  $A$  increases the demand for capital, and both types of skill. The cost of college drops because output has grown relative to capital inputs,  $E^K$ . In a steady state, this drop in costs has a negligible effect on college attainment. During the transition, the current prices of blue- and white-collar skill affect the enrollment decisions of only the youngest cohort. In a steady state, relative skill prices affect enrollment across all cohorts, making the aggregate quantity of skill much more elastic. As a result, changes in the tuition discount rate are largely offset by changes in skill prices, and have little effect on steady-state attainment. Labor inputs and wages change only slightly. It then follows from equation (2) that the increase in output and capital is almost exactly

$$(A^{2000}/A^{1959})^{1/(1-\alpha)}.$$

If tuition as fraction of cost rises from 0.2363 to 0.2426, enrollment decreases slightly, resulting in more blue-collar skill and less white-collar skill in the steady state. As a result, the skill premium and the relative price increase. The cost of higher education also increases, reinforcing the effect of smaller tuition discounts. The overall effect is very small, however, because of general equilibrium effects. In particular, we find that a 0.825% decrease in the tuition discount rate  $(1 - d)$  results in a 0.056% decrease in enrollment, implying an elasticity of 0.07. The standard price elasticity, based on  $d$  itself, is 0.02.<sup>12</sup> More radical experiments, such as setting  $d = 0$  or  $d = 1$ , produce elasticities of similar magnitudes. As Heckman, Lochner and Taber (1998b) note, changes in wages, which accumulate over an individual's entire working life, almost completely offset the changes in net tuition. In contrast, a number of empirical studies, based on micro-level interventions, find larger effects. (See Dynarski, 2003, and the papers referenced therein.) When wages are held fixed in our model, the enrollment elasticities rise from 0.07 to 0.45, and from 0.02 to 0.14. By way of comparison, Dynarski (2003) finds that the enrollment elasticity to total "schooling costs" is 1.5. Because most of this cost total consists of forgone earnings, Dynarski's estimates imply a tuition elasticity of 0.14, similar to ours.<sup>13</sup>

## 6 Discussion and Conclusions

In this paper, we show that a simple general equilibrium model with skill- and sector-biased technological change can replicate the increase in college costs observed over the past 40 years, along with the increase in college attainment and the increase in the relative wages earned by college graduates. Our model has two key features. The first is the assumption that educating a student requires a fixed amount of capital and skilled labor. The second is skill-biased technological change. We find that in general equilibrium changes in college prices, measured as changes in the tuition discount rate, have little long-run effect on human capital accumulation.

An important limitation to the current analysis is that we model the endpoints of the 1959-2000 transition, rather than the entire trajectory. This restriction also leads us to assume that agents predict the returns to college myopically. Although our expectation is that our main findings do not depend on these assumptions, a full dynamic analysis is

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<sup>12</sup>The exact calculation is  $[-0.000048/0.0859]/[(0.7574 - 0.7637)/0.7637] = 0.068$ . The more standard price elasticity is  $0.00056/[(0.2426 - 0.2363)/0.2363] = 0.021$ .

<sup>13</sup>Dynarski finds tuition and fees to be \$1,900, while foregone earnings are \$18,500, implying that her tuition elasticity is  $1.5 \times (1900/(1900 + 18500))$ .

in order.

Our framework suggests that skill-biased technological change makes a college education more expensive as well as more valuable. The scope for policy intervention is limited, however, if college enrollment is as inelastic to tuition discounts as our model implies. A number of empirical studies suggest that college attendance is sensitive to tuition, at least over the shorter-term. One reason why enrollment may be more price elastic than we predict is that borrowing limits may prevent students from paying higher tuitions. A number of studies, including Cameron and Heckman (1998, 2001) and Cameron and Taber (2004) conclude that borrowing constraints do not significantly restrict college attendance. Keane and Wolpin (2001) argue that although the borrowing constraints that students face are quite strict, students can circumvent them by working. In contrast, Lochner and Monge-Naranjo (2010) find that while credit constraints might not have restricted access in the past, they probably restrict access now. They also stress the importance of modelling these credit constraints in a way consistent with the actual student lending process. Brown, Scholz and Seshadri (2011) find that students not receiving the “expected” amount of parental transfers (as defined in Federal financial aid formulae) are often financially constrained.

Another feature missing in our model is drop-out risk. Although 52% of the people aged 25 and older in 2000 had attended college, only 31% had earned a degree of any sort. Akyol and Athreya (2005) find that switching from a full tuition subsidy to none typically reduces the fraction of skilled workers by 5 to 7 percentage points. Ionescu (2009) finds that introducing flexibility in the repayment of Federal student loans significantly increases enrollment.

The model can also be enriched by introducing more heterogeneity in higher education, both in terms of quality and its price. As emphasized by Castro and Coen-Pirani (2011), there are significant quality differences both between public and private institutions, and within each group. Even at a single institution, individuals with different levels of ability and family income usually face different prices.

## 7 Appendix: Background Calculations

### 7.1 Measurement Issues

In this section we consider some alternative versions of our education measures.

Figure 7 shows the effects of excluding scholarships and fellowships from our defi-



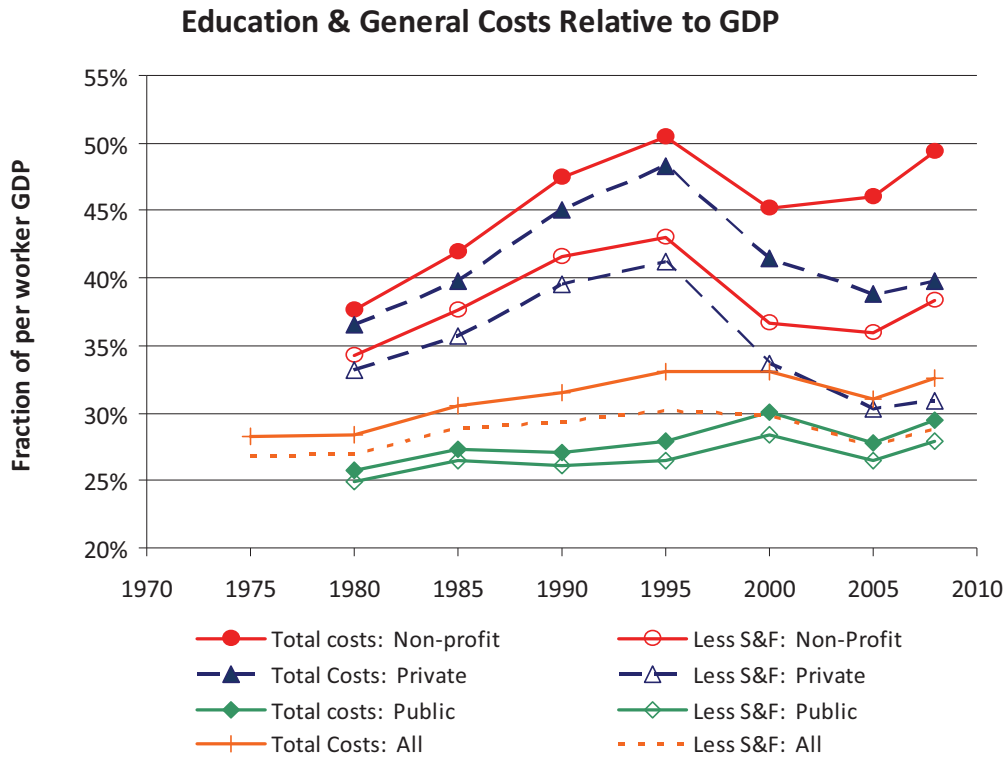


Figure 7

dition of education and general expenditures. Because the revisions in the late 1990s eliminated scholarships and fellowships data for private institutions, we use the College Board’s measure of aggregate institutional grant aid to extrapolate aggregate scholarships and fellowships to the present. Figure 7 reveals that scholarships and fellowships appear to have become increasingly important over time. In 2008, they equalled almost 4 percent of per worker GDP. Their effect appears to be most prevalent in private institutions, although this data is poorly measured.<sup>14</sup> As Table 4 shows, however, excluding scholarships and fellowships from our cost measures has only a modest effect on our calibration targets.

A second data issue involves the measurement of tuition. The tuition data shown in Figures 1 and 4 are found by dividing tuition revenues by FTE. This measure is consistent with our measure of costs, and it can be extrapolated back to 1929. Since 1964, however,

<sup>14</sup>We impute the missing data for private institutions in two steps. First, we use the College Board’s measure of aggregate institutional grant aid to extrapolate aggregate scholarships and fellowships to the present. Second, we subtract from this measure public scholarships and fellowships, which we do observe, leaving us with a residual that we treat as private aid.

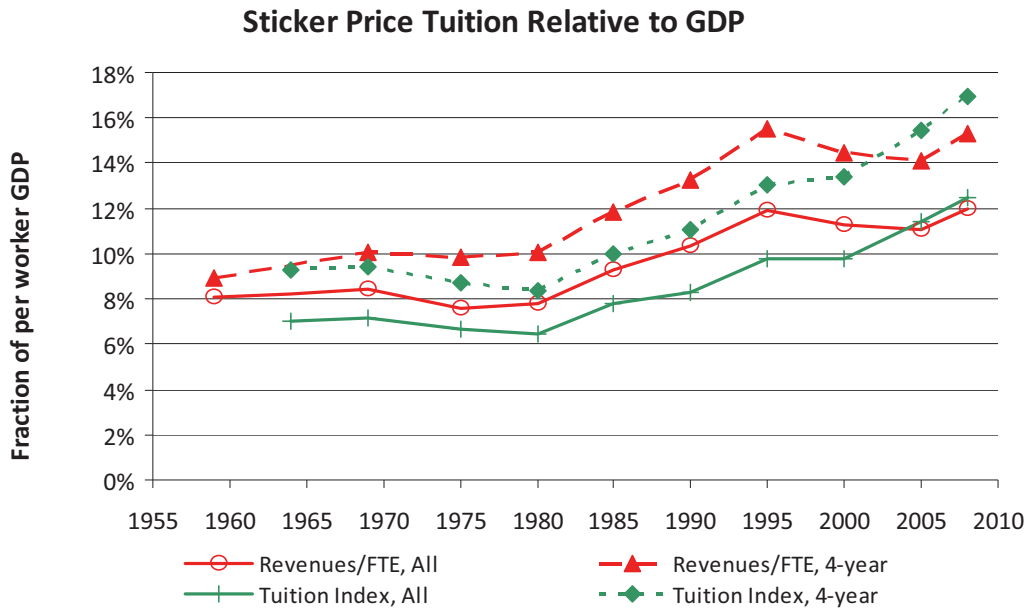


Figure 8

the Department of Education has estimated average undergraduate tuition, and since 1977, it has estimated average undergraduate tuition at 4-year institutions. Figure 8 compares the two measures of tuition. Prior to the data revisions of 1995, the measures moved together, with the revenue-based measures, which included graduate tuition, lying above the tuition index. After 1995, the revenue-based measures have levelled off, while the tuition indices have continued to grow. Over the period 1959-2000, however, the two sets of measures imply similar changes in tuition.

## 7.2 Solving the model—in transition

We assume that the economy is in a transition in 2000. In each decomposition experiment we fix  $e_0^{2000} = 0.244$  as in the data. We find the year-2000 equilibrium  $h_1^*$ ,  $e_1$ ,  $W$ ,  $B$ ,  $K$ ,  $Y$ ,  $w^W$ ,  $w^B$  as follows:

1. Make an initial guess of  $h_1^*$
2. Get  $e_1$  from (10)
3. Get  $W$  from (15) and get  $B$  from (16), thus  $W/B$
4. Get  $L$  from (1c)
5. Get  $K$  from (2)
6. Get  $Y$  from (1a)
7. Get  $w^W$  from (4) and  $w^B$  from (3)
8. Check (9), iterate over  $h_1^*$  until convergence

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