Accounting for the Rise in College Tuition
Web Appendix

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A Additional Data and Estimation Information

This appendix describes the data sources we use and some details omitted in the main text.

A.1 NLSY97

For the National Longitudinal Sample of Youth 1997 (NLSY97), we restrict attention to the representative sample. We drop waves after 2012. We also drop any observations that report annual work hours in excess of 6000. Apart from that, every observation is included when possible (when possible meaning, e.g., that if zero earnings were reported, they are not included when measuring log earnings).

A.2 IPEDS and Delta Cost Project

For our sample selection in the Delta Cost Project (DCP), we require that the institution be present from 1987 to 2010, that they be a four-year, non-specialty institution according to the Carnegie Classification, that they be either public or private, non-profit, and that they have non-missing data on FTEs and net tuition. Additionally, we drop observations that had fewer than 100 FTE students or had net tuition per FTE outside of the 1-99th percentile range. To be included in the fixed effects regression, we additionally require that observations have cost per FTE inside of the 1-99th percentile range. Without trimming, the R^2 measures in the fixed effects regression are about 50% smaller (i.e., the within R^2 measure falls to around 0.1 and the overall measure falls to around .06).

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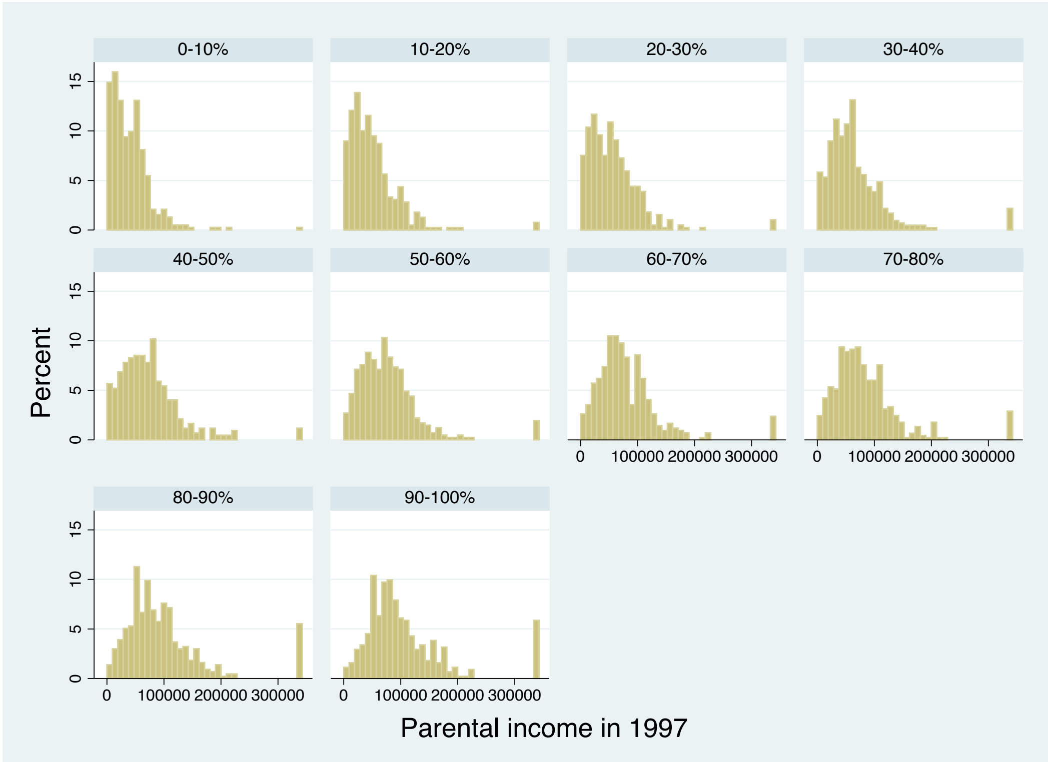

Figure 1: Distribution of Parental Income by Ability Decile

The college budget constraint has custodial costs, an endowment, investment, and tuition. The corresponding data measures are as follows:

- Endowment: all non-tuition revenue, which is the sum of appropriated federal (non-Pell) grants, appropriated state and local grants, and a auxiliary revenue (all per student).
- Investment: total education and general expenditures including sponsored research but excluding auxiliary enterprises.
- Tuition: net tuition and fees revenue.
- Custodial costs: a residual computed as the endowment plus tuition less investment.

As with Epple, Romano, and Sieg (2006), we compute custodial costs as a residual. Our investment measure is perhaps too broad as it includes all education costs, rather than just minimal ones. However, it is unclear exactly what minimal expenditures on education should be.

A significant shortcoming in the DCP database is that financial variables that are reported as zero are converted to missing values (p. 14 DCP11). Moreover, there are a large number of missing values for certain measures, including the appropriated state and local grants measure. For this measure in particular, one could imagine that many schools actually had zero appropriations.

For the estimation of the cost function, we of course require that a cost observation be non-missing. Since costs are computed as a residual, this also requires the endowment, investment, and tuition measures to also be non-missing. This results (after trimming) in 23,718 observations for costs (as well as endowment). Investment and net tuition have a total of 30,517 observations. The other variable we take from IPEDS, federal plus state government grants to students, has 23,047 observations (which may be a result of incorrectly missing values).

A.3 PSID

For the Panel Study of Income Dynamics (PSID), we restrict the sample to heads of households (not necessarily male), aged 18 to 65, in the representative SRC (Survey Research Center) sample. For waves prior to 1991, we compute an estimate of the heads years of education using the education bucket variable (e.g., we treat "some college" as 14 years of education and "college" as 16 years) since actual years of education are not available.

A.4 Unreported Model Parameters from the Calibration/Estimation

Table 1 presents the cost function estimates. Table 2 gives how parameters vary over the transition.

B Additional Transition Information

This appendix provides estimates of how earnings have changed over the past few decades and provides historical information on the student loan programs.

B.1 Model Units and Growth in Earnings

Since we focus on steady states with only real variables, we need a way to convert dollar measures into our model. We do this by expressing all variables relative to average earnings in 2010. A natural concern is that average earnings have grown substantially over the sample period.

Indeed, earnings have grown substantially over the sample period. For instance, using the PSID, we compute four measures of real average family income: (1) head and wife labor

t	$\mathfrak{c}_t^0$		$\mathfrak{c}_t^2/1000$		F_t	C_t^2
1987	17.6	(2.3)	0	(95)	17417	1
1988	18.4	(2.3)	23	(97)	18657	79
1989	19.4	(2.2)	31	(94)	20630	101
1990	19.0	(2.2)	68	(92)	20700	218
1991	18.7	(2.2)	28	(89)	20229	89
1992	19.9	(2.2)	66	(88)	22032	206
1993	19.5	(2.2)	53	(88)	21872	162
1994	19.0	(2.1)	81	(87)	21537	249
1995	18.8	(2.1)	100	(83)	21243	314
1996	14.7	(2.2)	201	(89)	16208	629
1997	18.7	(2.3)	155	(92)	18665	503
1998	22.1	(2.3)	167	(96)	21729	544
1999	21.0	(2.3)	181	(101)	20399	584
2000	22.9	(2.3)	232	(107)	22701	737
2001	22.0	(2.3)	200	(105)	21993	631
2002	29.9	(2.3)	592	(105)	29810	1851
2003	31.1	(2.3)	582	(96)	30869	1841
2004	36.3	(2.3)	695	(92)	35649	2211
2005	38.5	(2.3)	707	(89)	37802	2251
2006	39.6	(2.3)	776	(89)	38929	2475
2007	41.9	(2.3)	886	(87)	41465	2821
2008	41.5	(2.3)	757	(84)	41207	2407
2009	40.1	(2.3)	640	(79)	39301	2080
2010	44.1	(2.3)	610	(72)	42756	2019

R-squared: within 0.118; overall 0.068.
Observations: 24641.
Note: standard errors are in parentheses; millions of 2010 dollars.

Table 1: Cost Curve Estimates

year	λ	i	ϕ	$\bar{\zeta}$	$\bar{l}^s$	$\bar{l}^u$	$\bar{l}$
1987*	0.46	4.7	3072	488	12500	0	12500
1988	0.52	4.9	3253	462	17250	0	17250
1989	0.53	4.4	3411	495	17250	0	17250
1990	0.54	3.9	3593	683	17250	0	17250
1991	0.55	5.2	3852	606	17250	0	17250
1992	0.57	5.9	4006	804	23000	0	23000
1993	0.58	5.5	4177	757	23000	23000	23000
1994	0.59	6.0	4337	842	23000	31510	31510
1995	0.59	6.1	4544	893	23000	31510	31510
1996	0.60	5.8	4722	941	23000	31510	31510
1997	0.61	6.4	4927	1372	23000	31510	31510
1998	0.62	6.9	5166	1238	23000	31510	31510
1999	0.62	6.1	5309	1245	23000	31510	31510
2000	0.63	5.4	5551	1237	23000	31510	31510
2001	0.64	4.3	5853	1329	23000	31510	31510
2002	0.64	3.9	6131	1212	23000	31510	31510
2003	0.65	2.3	6477	1396	23000	31510	31510
2004	0.65	1.8	6804	1236	23000	31510	31510
2005	0.65	2.4	7173	1455	23000	31510	31510
2006	0.66	4.1	7540	1344	23000	31510	31510
2007	0.66	4.0	7909	1305	23000	31510	31510
2008	0.66	0.7	8364	1361	23000	40805	40805
2009	0.66	4.1	8722	1357	23000	40805	40805
2010	0.66	3.0	9129	1779	23000	40805	40805

Note: Except for ζ, all dollar values are nominal but converted to real in the computation. [a]The "1987" borrowing limits correspond to the limits in place from 1981 to 1986. The "1987" college premium corresponds to the average from 1981 to 1987. [b]The interest rates here correspond to five-year averages. See B for details. The notation l^u ($l^u = 0$ prior to 1993 and then $l^u = \bar{l}$ afterward) represents the aggregate unsubsidized loan limit.

Table 2: Transition Parameter Summary

income; (2) head and wife labor income plus transfers; (3) family income (which includes asset income); and (4) OECD-equivalized labor plus transfer income. Our preferred measure is (4), and the averages over time for all measures are displayed in figure 2. In figure 3, we also report the time series for average log values for our preferred measure.

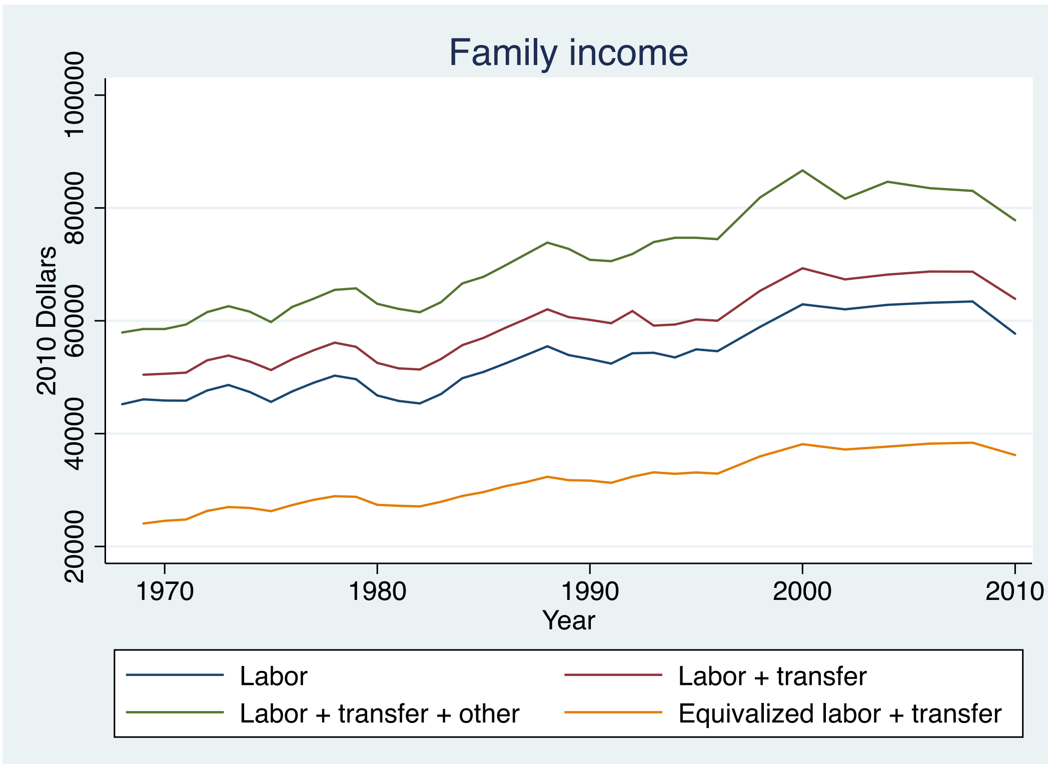

Figure 2: Average Income (2010 dollars)

While in every measure there has been this substantial earnings growth over time, other factors have been changing as well. Most importantly, college attainment has changed substantially over the last few decades. These changes could explain most or all of the changes in average earnings. To investigate this, we regressed our preferred income measure on age, age squared, and age cubed (results for age dummies are similar) and an education measure equal to $(\min(\max(educ, 12), 16) - 12)/4$ where educ is the heads years of education (the measure corresponds closely to our model). We restrict the sample to heads aged 18 to 65. The regression results are reported in table 3.

The results reveal that, after controlling for education attainment and age, almost all the growth in earnings is orthogonal to time. Because of this result, we restrict attention to steady states in the true sense of the word with average earnings growing over time only because of changes in educational attainment. It is worth noting that our implied college earnings premia is 0.70, which is a bit higher than what Autor, Katz, and Kearney (2008)

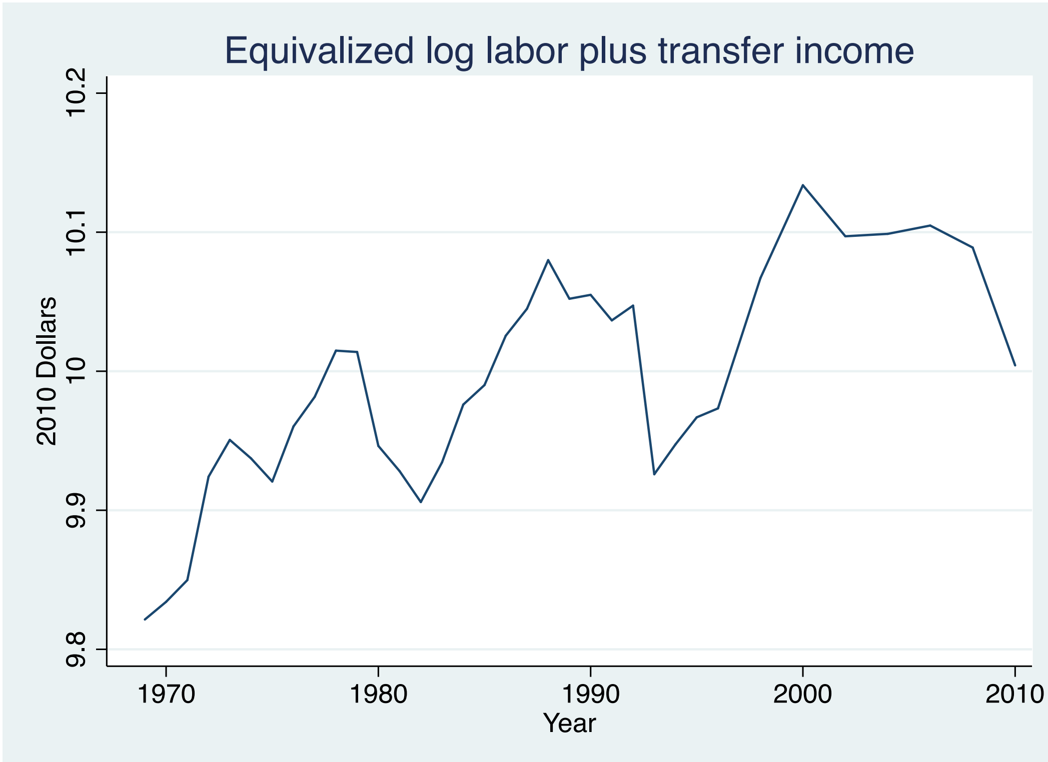

Figure 3: Average Log Equivalized Income (2010 Dollars)

	Equivalized income
Year	0.000359
	(0.000211)
Years of college education / 4	0.704
	(0.00578)
Age / 10	0.316
	(0.0652)
Age squared / 100	0.00546
	(0.0164)
Age cubed / 1000	-0.00546
	(0.00131)
Constant	8.254
	(0.425)
Observations	116092
R^2	0.143

Standard errors in parentheses

Table 3: Estimates from Regression on Log Equivalized Labor Plus Transfer Income

would suggest. However, one should note that their earnings premia is restricted to full-time workers, while our measure has hours worked varying with characteristics.

Our model units are expressed as a fraction of average log equivalized income in 2010. Rounding slightly, this amount was \$36,200. In 1987, this value was \$31,400, which is our target for averages earnings in 1987.

B.2 Earnings Premium

The estimates in Autor et al. (2008) only go until 2005. As stated in the main text, we fit a quadratic polynomial from 1987-2005 and use that to recover λ_t values both in and out of sample. Figure 4 plots the actual and fitted college premium. Since the steep rise in the earnings premium began in 1981, we try to obtain something more akin to an initial steady state value by taking the seven-year average from 1981 to 1987. We treat this average, 0.46, as the "1987" value.

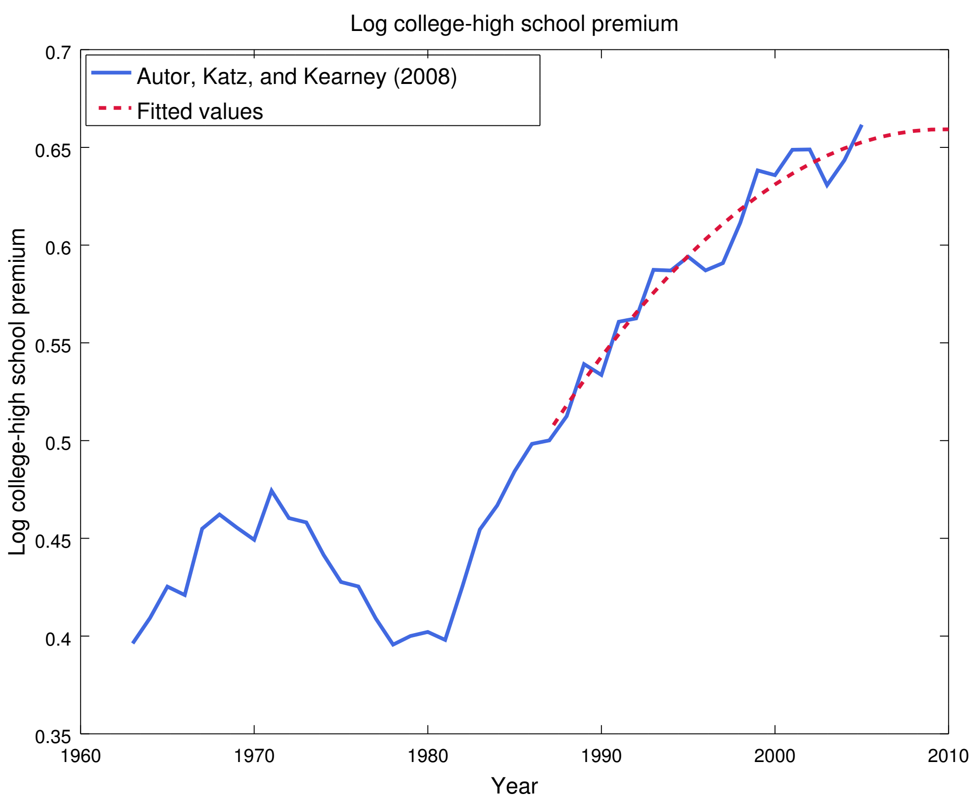

Figure 4: Log College Premium

B.3 Student Loan Programs

Government guaranteed loans have been available to students through two programs, the William D. Ford Federal Direct Loan (DL) and Federal Family Education Loan (FFEL) (Smole, 2012). The DL program has loan capital provided by the government while the FFEL has loan capital provided privately (Smole, 2012). In either case, losses due to default, death, or permanent disability have been paid for by the government (Smole, 2012).

Unsubsidized loans were introduced by the Higher Education Amendments of 1992 Title IV, Part B, §428H.[1] The loan limit was a combined subsidized and unsubsidized limit (i.e., students who were not eligible or only partly eligible for subsidized loans would be allowed to borrow the remainder via unsubsidized loans) (§428H(d)).

Beginning in 1994, independent undergraduate students were able to borrow more than the combined subsidized/unsubsidized limit for dependent undergraduates (Smole, 2012). Then in 2008, the ability to borrow in unsubsidized loans was increased for dependent and independent undegraduates (Smole, 2012). Table 4 summarizes the historical loan limits, both the aggregate loan limits and the year-by-year limits.

To map these limits into our model, where we do not distinguish between dependent and independent students, we need to make an assumption. Choy (2002) shows that in 1999-2000, 37.6% (36.7%) of students at public (private) 4-year schools were financially independent. So, we create a combine dependent/independent limit by placing 37% of weight on the independent limit and 63% of weight on the dependent limit. The values are given in table 2.

For our terminal steady state, we take the limits associated with 2010. For our initial steady state, we take the limits not associated with 1987, which were new that year, but rather with the limits in 1986 (which had been in place since 1981). The complete list of limits we use, in nominal terms, is given in table 5

Interest rates have also varied historically. From 1992 to 2006, the interest rates were given as a 91-day T-bill plus a spread while capped at a specified rate. In other years, interest rates have had a fixed rate between 3.4% and 10%. Since 2008, there have also been separate interest rates for subsidized and unsubsidized loans. For completeness, these are reproduced from Smole (2012) in table 6.

In mapping these interest rates into the model, we first compute what the real student loan interest rate in period τ would be for a loan originated at time t, and call it $i_{t,\tau}$.[2] We

[1] The content is available at https://www.govtrack.us/congress/bills/102/s1150/text. Retrieved: June 1, 2015.

[2] We measure this as the statutory rate minus the CPI inflation rate. For the statutory rate, we take the rate corresponding to November 1st in year τ. For 1988 to 1992, we use a rate of $9.6\% = 0.8 * 10\% + 0.2 * 8\%$. Prior to 1988, we use 8.5%. For 2008 and beyond, we take the numerical average of the subsidized and

	Aggregate Limit		Annual limit					
			Subsidized			Combined		
	Subsid.	Comb.	Yr. 1	Yr. 2	Yr. 3+	Yr. 1	Yr. 2	Yr. 3+
10/1/81-12/31/86								
Dependent	12,500	-	2,500	2,500	2,500	-	-	-
Independent	12,500	-	2,500	2,500	2,500	-	-	-
1/1/87-9/30/92								
Dependent	17,250	-	2,625	2,625	4,000	-	-	-
Independent	17,250	-	2,625	2,625	4,000	-	-	-
10/1/92-6/30/93								
Dependent	23,000	-	2,625	3,500	5,500	-	-	-
Independent	23,000	-	2,625	3,500	5,500	-	-	-
7/1/93-6/30/94								
Dependent	23,000	23,000	2,625	3,500	5,500	2,625	3,500	5,500
Independent	23,000	23,000	2,625	3,500	5,500	2,625	3,500	5,500
7/1/94-6/30/07								
Dependent	23,000	23,000	2,625	3,500	5,500	2,625	3,500	5,500
Independent	23,000	46,000	2,625	3,500	5,500	6,625	7,500	10,500
7/1/07-6/30/08								
Dependent	23,000	23,000	3,500	4,500	5,500	3,500	4,500	5,500
Independent	23,000	46,000	3,500	4,500	5,500	7,500	8,500	10,500
7/1/08-								
Dependent	23,000	31,000	3,500	4,500	5,500	5,500	6,500	7,500
Independent	23,000	57,500	3,500	4,500	5,500	9,500	10,500	12,500

Note: A "-" means unsubsidized loans were not yet available; all values are in nominal terms. Source: Tables B-2 and B-3 in Smole (2012).

Table 4: Historical Loan Limit Information

year	$\bar{l}^{sub}$	$\bar{l}^{uns}$	$\bar{l}$	$\bar{b}_1^{sub}$	$\bar{b}_2^{sub}$	$\bar{b}_{\geq 3}^{sub}$	$\bar{b}_1^{uns}$	$\bar{b}_2^{uns}$	$\bar{b}_{\geq 3}^{uns}$	$\bar{b}_1$	$\bar{b}_2$	$\bar{b}_{\geq 3}$
1987*	12500	0	12500	2500	2500	2500	0	0	0	2500	2500	2500
1988	17250	0	17250	2625	2625	4000	0	0	0	2625	2625	4000
1989	17250	0	17250	2625	2625	4000	0	0	0	2625	2625	4000
1990	17250	0	17250	2625	2625	4000	0	0	0	2625	2625	4000
1991	17250	0	17250	2625	2625	4000	0	0	0	2625	2625	4000
1992	23000	0	23000	2625	3500	5500	0	0	0	2625	3500	5500
1993	23000	23000	23000	2625	3500	5500	2625	3500	5500	2625	3500	5500
1994	23000	31510	31510	2625	3500	5500	4105	4980	7350	4105	4980	7350
1995	23000	31510	31510	2625	3500	5500	4105	4980	7350	4105	4980	7350
1996	23000	31510	31510	2625	3500	5500	4105	4980	7350	4105	4980	7350
1997	23000	31510	31510	2625	3500	5500	4105	4980	7350	4105	4980	7350
1998	23000	31510	31510	2625	3500	5500	4105	4980	7350	4105	4980	7350
1999	23000	31510	31510	2625	3500	5500	4105	4980	7350	4105	4980	7350
2000	23000	31510	31510	2625	3500	5500	4105	4980	7350	4105	4980	7350
2001	23000	31510	31510	2625	3500	5500	4105	4980	7350	4105	4980	7350
2002	23000	31510	31510	2625	3500	5500	4105	4980	7350	4105	4980	7350
2003	23000	31510	31510	2625	3500	5500	4105	4980	7350	4105	4980	7350
2004	23000	31510	31510	2625	3500	5500	4105	4980	7350	4105	4980	7350
2005	23000	31510	31510	2625	3500	5500	4105	4980	7350	4105	4980	7350
2006	23000	31510	31510	2625	3500	5500	4105	4980	7350	4105	4980	7350
2007	23000	31510	31510	3500	4500	5500	4980	5980	7350	4980	5980	7350
2008	23000	40805	40805	3500	4500	5500	6980	7980	9350	6980	7980	9350
2009	23000	40805	40805	3500	4500	5500	6980	7980	9350	6980	7980	9350
2010	23000	40805	40805	3500	4500	5500	6980	7980	9350	6980	7980	9350

*The "1987" limits correspond to the limits in place from 1981 to 1986.

Table 5: Borrowing Limit Transitions

	Subsidized	Unsubsidized
1/1/81-6/30/88		
All	9% or 8%*	-
7/1/88-9/30/92		
First 48 months	8%	8%
Remaining payment period	10%	10%
10/1/92-6/30/94		
All	min{T-bill+3.1%, 9%}	min{T-bill+3.1%, 9%}
7/1/94-6/30/95		
All	min{T-bill+3.1%, 8.25%}	min{T-bill+3.1%, 8.25%}
7/1/95-6/30/98		
In-school, grace, deferment	min{T-bill+2.5%, 8.25%}	min{T-bill+2.5%, 8.25%}
Repayment periods	min{T-bill+3.1%, 8.25%}	min{T-bill+3.1%, 8.25%}
7/1/98-6/30/06		
In-school, grace, deferment	min{T-bill+1.7%, 8.25%}	min{T-bill+1.7%, 8.25%}
Repayment periods	min{T-bill+2.3%, 8.25%}	min{T-bill+2.3%, 8.25%}
7/1/06-6/30/08		
All	6.8%	6.8%
7/1/08-6/30/09		
All	6.0%	6.8%
7/1/09-6/30/10		
All	5.6%	6.8%
7/1/10-6/30/11		
All	4.5%	6.8%

Note: A "-" means unsubsidized loans were not yet available.
*9% if 12-month average of; 91-day T-bill>9%; 8% otherwise.
Source: Table B-4 in Smole (2012).

Table 6: Historical Interest Rate Information

take i_t to be the numerical average of $\{i_{t+j,t}\}_{j=-13}^{0}$. This average interest rate reflects that, in a standard 10-year repayment plan, cohorts from 13 years ago will be affected by the current interest rate alongside the current cohort: Along the transition, payments in period t on a loan of size l with remaining duration d are $p_t(l,d) = l\frac{i_t(1+i_t)^{d-1}}{(1+i_t)^d-1}$. Table 7 gives both the cohort specific interest rate $i_{\tau,\tau+j}$ at various lags along with the average across the 14 cohorts i_τ.

	$i_{\tau,\tau+j},\ j=$														
τ	0	1	2	3	4	5	6	7	8	9	10	11	12	13	i_τ
1987	4.9	4.4	3.7	3.1	4.3	5.5	5.5	5.9	5.7	5.6	6.2	7.0	6.3	5.1	4.9
1988	5.5	4.8	4.2	5.4	6.6	6.6	7.0	6.8	6.7	7.3	8.1	7.4	6.2	6.8	4.9
1989	4.8	4.2	5.4	6.6	6.6	7.0	6.8	6.7	7.3	8.1	7.4	6.2	6.8	8.0	4.4
1990	4.2	5.4	6.6	6.6	7.0	6.8	6.7	7.3	8.1	7.4	6.2	6.8	8.0	7.3	3.9
1991	5.4	6.6	6.6	7.0	6.8	6.7	7.3	8.1	7.4	6.2	6.8	8.0	7.3	6.9	5.2
1992	3.5	3.1	4.8	5.8	5.2	5.8	6.3	5.5	5.6	3.7	3.1	1.8	1.8	2.9	5.9
1993	3.1	4.8	5.8	5.2	5.8	6.3	5.5	5.6	3.7	3.1	1.8	1.8	2.9	4.6	5.5
1994	4.8	5.4	5.2	5.8	6.3	5.5	4.9	3.7	3.1	1.8	1.8	2.9	4.6	4.6	6.0
1995	5.4	5.2	5.8	6.3	5.5	4.9	3.7	3.1	1.8	1.8	2.9	4.6	4.6	0.7	6.1
1996	5.2	5.8	6.3	5.5	4.9	3.7	3.1	1.8	1.8	2.9	4.6	4.6	0.7	3.6	5.8
1997	5.8	6.3	5.5	4.9	3.7	3.1	1.8	1.8	2.9	4.6	4.6	0.7	3.6	1.6	6.4
1998	5.5	4.7	4.8	2.9	2.3	1.0	1.0	2.1	3.8	3.8	-0.1	2.8	0.8	-0.8	6.9
1999	4.7	4.8	2.9	2.3	1.0	1.0	2.1	3.8	3.8	-0.1	2.8	0.8	-0.8	0.3	6.1
2000	4.8	2.9	2.3	1.0	1.0	2.1	3.8	3.8	-0.1	2.8	0.8	-0.8	0.3	0.9	5.4
2001	2.9	2.3	1.0	1.0	2.1	3.8	3.8	-0.1	2.8	0.8	-0.8	0.3	0.9	0.7	4.3
2002	2.3	1.0	1.0	2.1	3.8	3.8	-0.1	2.8	0.8	-0.8	0.3	0.9	0.7	1.3	3.9
2003	1.0	1.0	2.1	3.8	3.8	-0.1	2.8	0.8	-0.8	0.3	0.9	0.7	1.3	1.3	2.3
2004	1.0	2.1	3.8	3.8	-0.1	2.8	0.8	-0.8	0.3	0.9	0.7	1.3	1.3	1.3	1.8
2005	2.1	3.8	3.8	-0.1	2.8	0.8	-0.8	0.3	0.9	0.7	1.3	1.3	1.3	1.3	2.4
2006	3.6	3.9	3.0	7.1	5.2	3.7	4.7	5.3	5.2	4.8	4.8	4.8	4.8	4.8	4.1
2007	3.9	3.0	7.1	5.2	3.7	4.7	5.3	5.2	4.8	4.8	4.8	4.8	4.8	4.8	4.0
2008	2.6	6.7	4.8	3.3	4.3	4.9	4.8	4.4	4.4	4.4	4.4	4.4	4.4	4.4	0.7
2009	6.5	4.6	3.1	4.1	4.7	4.6	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.1
2010	4.0	2.5	3.6	4.2	4.0	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	2.3

Note: Values having $\tau + j \geq 2015$ are predicted assuming a nominal interest rate of 1% and inflation rate of 2%.

Table 7: Historical Interest Rate Information

While these give interest rates for some of the years along the transition path, the actual transition from steady state to steady state may take several decades. In this case, it is unclear what i_τ should be. To illuminate this, figure 8 plots i_τ for $\tau = 1987, \ldots, 2010$. While

unsubsidized rates.

the average interest rate early on is around 5%, it increases to a peak of around 7% before falling for a decade and finally hovering around 3%. To obtain our initial steady state interest rate, we use the average of the rates from 1987 to 1991. Likewise, to obtain our final steady state rate, we use the average from 2006 to 2010.[3] These average values are 4.7% and 3.0%, and they are plotted alongside the historical interest rates for comparison.

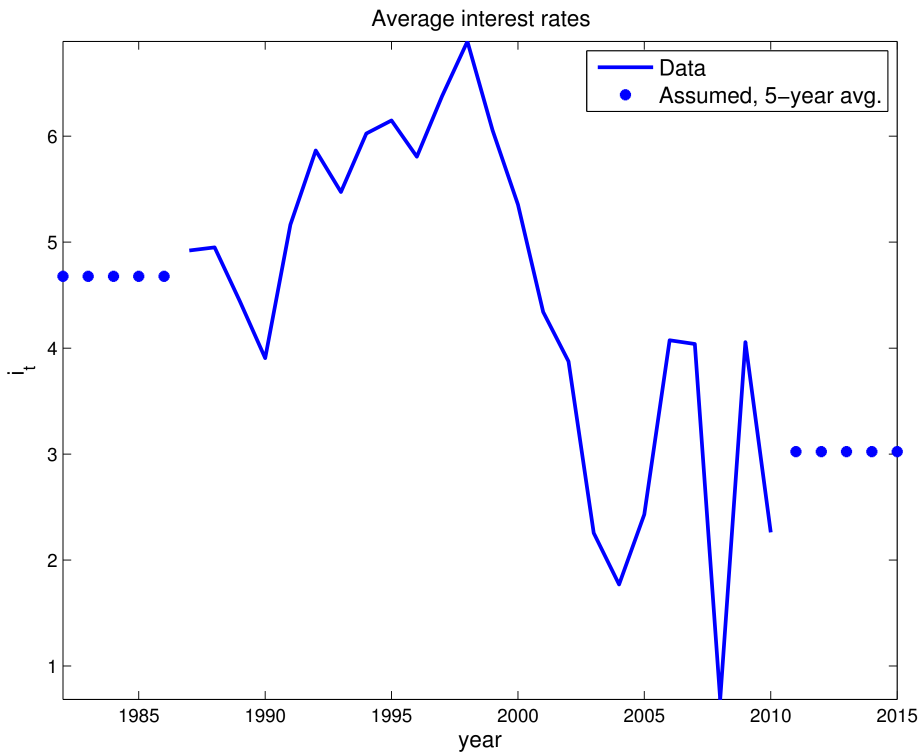

Table 8: Historical Interest Rates with Assumed Steady State Rates

C Computation

This appendix describes some of the less trivial details of the computation. The worker and youth problems are mostly standard except that we use "binary monotonicity," a technique described in Gordon and Qiu (2015), to solve the worker problem very quickly.[4] We focus the remaining discussion on the solution of the college problem and the transition.

[3]Hence, in the computation, we replace the 1987 and 2010 values with those 5-year averages (so that our initial steady state corresponds to "1987" and terminal corresponds to "2010."

[4]In particular, the asset policy function is monotone in assets, so we can solve for the working problem in $O(n_A \log n_A)$ time (where n_A is the number of asset grid points) else equal.

C.1 Solving the College Problem

Computing the solution of the college problem is challenging. Since our value function for attending college takes into account many different features of the model, including borrowing limits, default, kinks, and a lack of feasibility of certain regions of the state space, it is not always smooth and is not well-defined in certain regions of the state space. Because of this, we found working with first order conditions (FOCs) untenable (which is the approach in Epple et al., 2006), at least for calibration/estimation where the model must be solved thousands of times for a wide range of parameter values.

Instead of working with FOCs, we directly maximize the college's quality function by choosing tuition. Specifically, we parameterize tuition as a bilinear function of the students ability and parental income. We construct a tensor product grid of ability and parental income. We then specify the value of tuition at those tensor-grid points, which implicitly defines a tuition function (via the bilinear interpolant) for the entire space. Given a particular guess on the tuition function, we must solve for enrollments, college investment, and college quality jointly. Specifically, we "guess" (i.e., solve a root-finding problem) on what the equilibrium college quality is, compute youth utility from attending (taking into the account the tuition they will pay and the utility they receive from college quality), compute enrollment probabilities, compute investment as a residual in the college budget constraint, and produce an implied college quality. We then check if the guess on quality and the implied quality are close enough. If not, we update the guess (in particular, we use bisection).[5]

The equilibrium tuition functions for 1987 and 2010 are displayed in figure 5. There is a great deal of variation in the tuition function. Some of the variation is immaterial: For the lowest ability youths, enrollment probabilities are virtually zero. Hence, any higher tuition level for them should generate essentially the same enrollment for this group (zero) and hence the same college quality. However, the tuition function also has substantial variation where youths do attend. In our discussion of figure **??**, we described the main mechanism for why enrollment in 1987 is low for high ability, medium parental income youths. This discussion carries over almost directly to why tuition plummets for these students. In particular, colleges want the high ability students, but they have very little ability to pay. So tuition falls to accomodate some of them.

Given the variation in the tuition function, we decompose the process of finding the equilibrium tuition into a number of steps in an attempt to ensure we get close to the global maximum. To do this, we use three techniques: a multigrid, global search, and local search.

[5]Note that, unfortunately, we have no guarantee that the equilibrium is unique: If college quality is very high, willingness to pay is very high, which may justify the high college quality through higher enrollment of high-paying students.

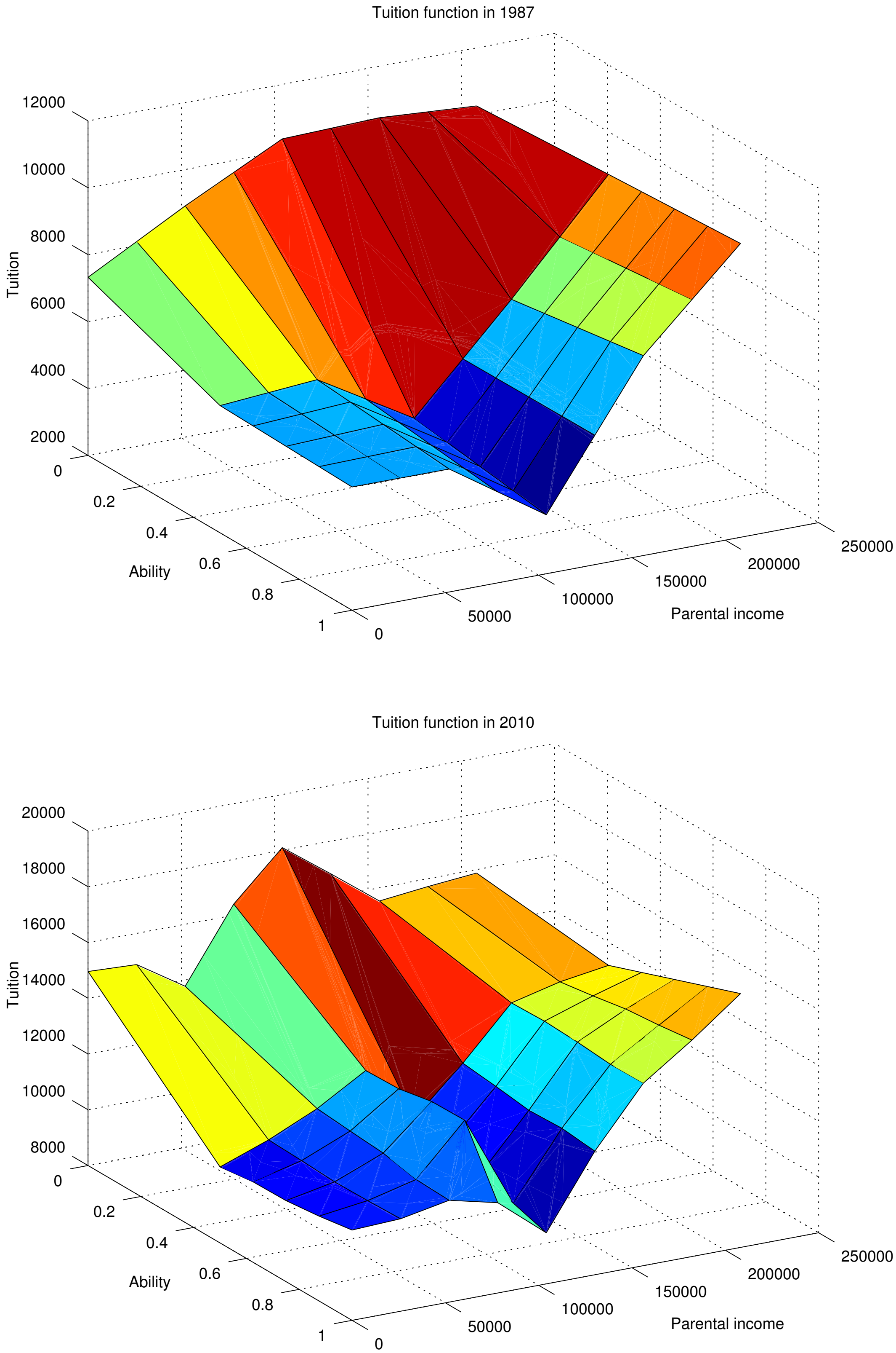

Figure 5: Tuition Functions in 1987 (Top) and 2010 (Bottom)

We begin by specifying tuition on a very coarse grid for ability and parental income, two points in each dimension. We choose one thousand random points in the support of our tuition space.[6] From *each* of these points, we perform a simplex search. We then take the best of these. This the truly global part of our search.

We then do a slightly less global approach. With the best guess on the tuition function from the global step, we take 31 random draws within plus or minus $1000 and perform a simplex search from each (we also do a simplex search from the guess). Taking the best of these, we update our guess. We repeat this process three more times.

Our next step is the multigrid step. In particular, we refine the grid on ability and parental income. Our initial guess on the tuition function is the solution to the previous multigrid step. We then apply the global/local approach just described (32 draws four times). We repeat this multigrid process several times, eventually arriving at our desired grid that has six points in the ability dimension and nine points in the parental income dimension (equilibrium tuition has more curvature in the parental income dimension).

This approach typically yields large increases in quality for the first two multigrids and small increases (on the order of 2% or less) for the remaining five multigrids. Having small grids initially allows for a much more thorough exploration of the search space rather than simply starting with a six-by-nine grid. We tried a number of different approaches and found this one was both reliable and allowed substantial flexibility in the tuition function parameterization.

C.2 Transition

In the transition, the only unknown endogenous object that is needed to solve the household and college problem is the tax rate τ. This is in part because we have taken care to formulate the college problem as static (and made certain other assumptions such as college being a once and for all choice made at time zero): The equilibrium θ, I, N can be determined at each point in time as long as the value function $Y_1(0, s_Y; T)$, is known, and this value function does not depend on θ, I, N, or q.[7]

Our algorithm for computing the transition is as follows:

1. Fix $\underline{t} = 1987 - J + 1$ and some terminal period $\bar{t} \gg 2010$. Guess on $\{\tau_t\}_{\underline{t}}^{\bar{t}}$.

2. For each cohort t in $\underline{t}, \ldots, \bar{t}$, do the following:

[6] We make tuition a state variable and solve for the student value function on a grid (97 points linearly spaced between $0 and $15000 and three points at $20000, $30000, and $50000, converted to model units). The support of the tuition space is $0 to $50000.

[7] Recall that college quality does affect utility, but it shows up at time zero as $Y_1 + q$.

(a) Use backward induction to compute the worker problem for all ages $j = 1, \ldots, J$ (with τ and policies at age j given by $t + j - 1$). For cohorts that are surprised mid-life, the problem must be solved twice, once for before they were surprised (for all ages) and once for after they were surprised (for the age that they are surprised and on).

(b) Use backward induction to compute the student problem for all student ages $j = 1, \ldots, J_Y$ taking tuition as given and with quality separate (don't compute Y yet, just $Y_1, \ldots, Y_{J_Y}$). As in 2(a), the problem may need to be solved more than once.

(c) Compute the college problem solution, guessing θ, I, N, computing q, the value Y, the tuition T, attendance based on EMC, and then updating the θ, I, N guesses until convergence is obtained.

3. For each cohort, simulate a panel. Use it to compute statistics, including the implied $\hat{\tau}_t$ needed to balance the government budget constraint.

4. Determine the supnorm $\max_{t \in \{\underline{t}, \ldots, \bar{t}\}} |\hat{\tau}_t - \tau_t|$. If it is less than .0005, continue to the next stop. Otherwise, update the guess on τ_t according to $\tau_t := (1 - \rho)\tau_t + \rho\hat{\tau}_t$ where $\rho \in (0, 1]$, and go to step (2).

5. Check whether the specified transition length was long enough: If $|\tau_t - \tau^*| < .0005$, where τ^* is the terminal steady state value of τ, then stop. Otherwise, go to (1) and increase $\bar{t}$.

We set $\bar{t} = 2086$. In order to avoid storing policy functions for each cohort, we use Monte Carlo to compute statistics over the transition (this also requires solving for cohorts as far back as $1987 - J + 1$).[8] More precisely, we solve for a cohort's value and policy functions, simulate a panel for just that cohort, and compute statistics (such as means and standard deviations) on a rolling basis.

Students can be surprised by policy changes that can make their current stock of student loan debt infeasible. In particular, a tightening in the real borrowing limits with our $l' \geq l$ assumption can result in infeasibility. To handle this, student borrowing terms and other financial aid variables are fixed for the duration of college.

[8]This technique allowed us to use MPI to much more easily parallelize the transition computation.

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