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By

Brant Abbott, Giovanni Gallipoli, Costas Meghir, and Giovanni L. Violante

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COWLES FOUNDATION FOR RESEARCH IN ECONOMICS
YALE UNIVERSITY
Box 208281
New Haven, Connecticut 06520-8281

http://cowles.econ.yale.edu/

Education Policy and Intergenerational Transfers in Equilibrium†

Brant Abbott
Queen's University
brant.abbott@queensu.ca

Giovanni Gallipoli
University of British Columbia
gallipol@mail.ubc.ca

Costas Meghir
Yale University, IFS and NBER
c.meghir@yale.edu

Giovanni L. Violante
New York University, CEPR, and NBER
glv2@nyu.edu

Abstract
This paper examines the equilibrium effects of alternative financial aid policies intended to promote college participation. We build an overlapping generations life-cycle, heterogeneous-agent, incomplete-markets model with education, labor supply, and consumption/saving decisions. Driven by both altruism and paternalism, parents make inter vivos transfers to their children. Both cognitive and non-cognitive skills determine the non-pecuniary cost of schooling. Labor supply during college, government grants and loans, as well as private loans, complement parental resources as means of funding college education. We find that the current financial aid system in the U.S. improves welfare, and removing it would reduce GDP by 4-5 percentage points in the long-run. Further expansions of government-sponsored loan limits or grants would have no salient aggregate effects because of substantial crowding-out: every additional dollar of government grants crowds out 30 cents of parental transfers plus an equivalent amount through a reduction in student's labor supply. However, a small group of high-ability children from poor families, especially girls, would greatly benefit from more generous federal aid.

JEL Classification: E24, I22, J23, J24.

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1 Introduction

Investment in human capital is a key source of aggregate productivity growth and a powerful vehicle for social mobility. However, imperfections in insurance and credit markets can distort skill investment choices and lead to less than socially optimal educational attainment. Motivated by these considerations, governments promote the acquisition of education through a variety of interventions. Financial aid for college students is a pillar of education policy in many countries. For example, in 2012 the US Federal government spent 150 billion dollars on loans and grants for college students.[1] Given their magnitude and scope, it is important to quantify the effects of policies intended to advance college attainment and understand the way they interact with private financing of education.

In this paper we build a life-cycle, heterogeneous-agent model with incomplete insurance and credit markets of the type popularized by Ríos-Rull (1995) and Huggett (1996), featuring intergenerational links in the tradition of Laitner (1992) and set in an overlapping generations context. Throughout their life cycles parents make savings and labor supply decisions and, when their children are old enough, they make financial transfers to them. These transfers depend on the policy environment, such as the availability of financial aid, and are motivated by both altruism and a paternalistic preference for children's education. Both cognitive and non-cognitive skills determine the non-pecuniary cost of education for students. Government grants and loans, private loans, as well as labor supply during college complement parental resources as means of funding the financial cost of college education. Workers of different gender and education are imperfect substitutes in production. The government redistributes through a progressive tax system.

With this rich structure in hand, we study the impact of financial aid policies on college attainment, welfare, and the aggregate economy. Central to our analysis are the role of market incompleteness, heterogeneity and selection, and general equilibrium feedbacks.

Since Becker (1964) the potential importance of liquidity constraints on education attainment is well understood. The extent to which credit market imperfections can distort college attendance

[1] See Trends in Student Aid, College Board, 2012.

depends on the capacity and willingness of parents to fund education for their children, the availability of government-sponsored grants and loans, and the earnings potential of students.[2] Gale and Scholz (1994) show that inter vivos transfers (IVTs) for education are sizable.[3] However, studies using data from the 1980s and 1990s concluded that family income played a small role in college-attendance decisions, after controlling for child ability and several family background characteristics (Cameron and Heckman, 1998; Keane and Wolpin, 2001; Carneiro and Heckman, 2002; Cameron and Taber, 2004). More recently, though, Belley and Lochner (2007) found that parental financial resources matter significantly for college attendance in the 2000s. In turn, Heckman and Mosso (2014) argue that much of the family income effect estimated in the 2000s results from low ability children, while high ability children were already in school.[4]

Earnings risk is pervasive and only partially insurable.[5] It can affect individual decisions as well as the impact of policy, including the relative benefit of grants versus loans.[6] Thus, we model earnings as a stochastic Roy model with a separate process for each education group, different for males and females. We explicitly account for alternative channels of consumption insurance, including spousal labor supply as in Blundell et al. (2016b).

In the model we allow for heterogeneity in both the returns to education and the psychic costs of schooling, which depend on both cognitive and non-cognitive ability.[7] Modeling psychic costs is necessary because pecuniary returns can only account for part of the observed college attendance patterns

[2]Garriga and Keightley (2015) show that omitting the labor supply margin of college students may lead to large overestimates in the effects of tuition subsidies.

[3]Winter (2014) also argues that ignoring parental transfers may lead to wrong inference about the extent of credit constraints. Keane and Wolpin (2001) and Johnson (2013) estimate parental IVTs as a function of observable characteristics from the NLSY79. Brown et al. (2012) show that while parental contributions are assumed and expected in financial aid packages they are not legally enforceable nor universally given, implying substantial heterogeneity in access to resources for students with observationally similar families.

[4]Carneiro et al. (2011) show that returns to college are in fact negative for low ability children.

[5]Blundell et al. (2008); Low et al. (2010); Heathcote et al. (2014)

[6]See for example Johnson (2013). As originally emphasized by Levhari and Weiss (1974), college education is a multi-period investment requiring an ex-ante commitment of resources and time. Uncertainty in its return is a key determinant of education decisions. Hence, students may be unwilling to finance college using loans when risk about their future earnings and ability to repay is high.

[7]The first studies linking human capital investment to life cycle earnings (Mincer, 1958; Becker, 1964; Ben-Porath, 1967) sidestepped the important issue of self-selection into education, as described in the seminal contributions of Rosen (1977) and Willis and Rosen (1979).

by ability (see Cunha et al., 2005; Heckman et al., 2006a). From a policy perspective accounting for such heterogeneity allows a meaningful examination of the importance of targeted interventions. The way cognitive and non-cognitive skills are transmitted across generations, as well as their effects on education choices and returns, are estimated from data. In particular, since in the model parents' education affects children's non-cognitive skills, expanding schooling for the current generation reduces the cost of human capital accumulation for future generations, an original insight of T.W. Schultz that was relevant then as it is now.[8]

To complete our understanding of how government policy can affect educational attainment and wages we follow Heckman et al. (1998b,c), Lee (2005) and Lee and Wolpin (2006), amongst others, and set the model in a general equilibrium context, which allows wages to adapt to changes in the supply and composition of educated workers.[9] In our model the aggregate production function depends on inputs from three types of education and allows for imperfect substitutability between males and females of the same skill.

Finally, to shed light on the welfare effects of education policy, we build on Benabou (2002) and develop a decomposition of welfare gains into aggregate productivity improvements, lower inequality in initial conditions, and reduced consumption uncertainty.

Our data is drawn from various US sources, including the Current Population Survey (CPS), the Panel Study of Income Dynamics (PSID), the National Longitudinal Survey of Youth (NLSY, 79 and 97), the National Center for Education Statistics (NCES), and the National Accounts. The model is estimated in stages. We first estimate the wage processes, for each education group and gender, as well as the intergenerational transmission of ability and the aggregate production function. Then, having set few parameters based on the literature, we use the simulated method of moments to estimate the rest of the model's parameters. The US federal system of grants and loans is represented in detail,

[8]Parental investments may also affect cognitive skills - see Cunha and Heckman (2007); Cunha et al. (2010) for example. However we do not model this here. Our estimates include the effect of parental investments since we measure cognition at late teenage years, but our counterfactuals do not allow the intergenerational transmission of cognitive skills to change.

[9]For a similar approach, see also the work of Bohacek and Kapicka (2012), Krueger and Ludwig (2016), Johnson and Keane (2013), and Garriga and Keightley (2015).

allowing for the existing amount of means testing, to ensure that we capture the main sources of public funding for education and the way they are targeted in practice.

We establish that the model fits the data along a number of crucial dimensions that are not targeted in estimation. For example, cross-sectional life-cycle profiles of the mean and dispersion of hours worked, earnings, consumption, and wealth are consistent with their empirical counterparts. We are careful to match numerous statistics about student borrowing, including their average cumulative loans upon graduation.[10] The implied intergenerational correlation of income between parents and children is around 0.4, close to the value documented by Solon (1999) for the US, while the income-rank mobility implied by the model is well within the range estimated by Chetty et al. (2014). Our modeling choices for federal financial aid imply marginal effects of parental wealth on college attainment, controlling for child's ability, that are similar to those estimated by Belley and Lochner (2007) from the NLSY97. The role of paternalism is key in explaining these facts. Moreover, when we use the model to simulate an artificial randomized experiment in which a (treated) group of high-school graduates receives an additional $1,000 in yearly tuition grants and another (control) group does not, the simulated treatment effect on college attainment that is consistent with the outcomes of quasi-randomized policy shifts surveyed by Kane (2003), and Deming and Dynarski (1995).

We conduct a number of different policy experiments, in which we change the size and nature (need-based/merit-based) of the federal grant program and government-sponsored loan limits. We find that crowding out effects due to public financing are a very important feature and mitigate the effects of policy: every additional dollar of government grants crowds out 20-30 cents of parental IVTs on average, and a $1,000 reduction in tuition fees lowers annual hours worked by college students by 3-4%, or roughly $300-400 in earnings. The amount of crowding out varies across the wealth distribution, with poorer parents reacting considerably less. Overall, however, the current level of federal aid (grants and loans) is welfare improving and accounts for 4.5% of GDP, with the loans being particularly important (since they are self-targeting, to an extent) and accounting for nearly 3%

[10] Lochner and Monje-Naranjo (2011) stress that models may imply too little borrowing relative to data.

of GDP. However, there does not seem to be much benefit of expanding the program further, with the important caveat that a small group of high-ability children from poor families, especially girls, would still greatly benefit from more generous federal aid. Consistent with the literature, the general-equilibrium response of wages, together with crowding out, implies that the aggregate long-run effect of tuition reductions is less than half the immediate response.

The remainder of the paper is organized as follows. Section 2 outlines the model and defines equilibrium. Section 3 describes estimation. Section 4 explores the empirical implications of the model by assessing its behavior along several key dimensions not explicitly targeted in the parameterization. Section 5 presents all the policy experiments. Section 6 provides a general discussion of the main findings. Section 7 concludes. The Appendix contains additional details on the parametrization and on the results of the policy experiments, as well as a sensitivity analysis.

2 Model

We begin by describing the model's demographic structure, preferences, production technology, financial markets, and government policies. Next, we outline the life cycle of agents and define a competitive equilibrium. We abstract from aggregate shocks, and thus describe the economy in steady state. For this reason, to lighten notation, we omit time subscripts whenever possible. When discussing the choice of parameter values requires no detour, we do it as we present the model. This subset of the model's parameters that are externally specified based on the literature is summarized in the tables in Appendix G. The rest of the parameterization is outlined in Section 3.

2.1 Preliminaries

Time is discrete, indexed by t and continues forever. A period in the model corresponds to two years. The economy is populated by a continuum of individuals, equally many males and females. Gender is indexed by $g \in \{m, f\}$ and age by $j \in \{0, 1, ..., J\}$. At each date a new cohort of measure one of each gender enters the economy. The first period of life in the model $(j = 0)$ corresponds to age 16 and the last one $(j = J)$ to age 100. Individuals survive from age j to $j + 1$ with probability ζ_j (strictly less than 1 only after retirement). Since cohort size and survival probabilities are time-invariant, the model's age distribution is stationary.

The life cycle of individuals comprises four stages: education from age $j = 0$ to a maximum of age j^{CL}, marital matching at age $j^{CL}+1$, work until age $j^{RET}-1$, and retirement from age j^{RET} to J. In the first stage the decision unit is the individual. In the last two, the decision unit is the household, i.e. a husband and wife pair.

Preferences. The consumption and leisure of an individual with gender $g \in \{m, f\}$ at age j are denoted by c_j^g and ℓ_j^g, respectively. We will minimize/suppress subscripts wherever possible in the following discussion to improve readability. Individuals have gender and age specific preferences over consumption c and leisure ℓ

$$u_{gj}(c, \ell) = \frac{c^{1-\gamma}}{1-\gamma} + \vartheta_j^g \frac{\ell^{1-\nu_j^g}}{1-\nu_j^g}. \tag{1}$$

The preference parameters above are pre-set, based on existing literature: the coefficient of relative risk aversion γ is set to 2.[11] For males, ν^m and ϑ^m do not depend on age; ν^m is set so that the (average) Frisch elasticity of labor supply is 1/3, and ϑ^m is set so that average hours worked by men are 35% of their time endowment.[12] For women each of these parameters takes two values: one for when they have no children in the household —the same values they take for men— and one for when they do (ages 30-45). The Frisch elasticity for women with children is 2/3, following Blundell et al. (2016a). Their weight on non-market time ϑ_j^f at ages when children are present is set so that women work in the market on average 40% less than men (as in the CPS 2000 data). Individuals discount future

[11] See Attanasio and Weber (1995).

[12] See Meghir and Phillips (2009) for estimates of Frisch elasticities for men.

utility at the rate $\beta = 0.944$. We choose this value to replicate an annual capital-output ratio of 4.[13]

We assume full ex-ante commitment within the marriage. Married couples have household preferences

$$u_j(c^m, c^f, \ell^m, \ell^f) = u_{mj}(c^m, \ell^m) + u_{fj}(c^f, \ell^f) + x^m + x^f \tag{2}$$

where x^g denotes transfers of utility between spouses (with $x^m + x^f = 0$) that allow the initial commitment to be fulfilled ex-post.[14]

We follow Voena (2015) by modeling economies of scale in consumption as dependent on the sharing of resources. That is, total expenditure to consume c^m and c^f is $c = [(c^m)^{\tilde{\rho}} + (c^f)^{\tilde{\rho}}]^{\frac{1}{\tilde{\rho}}}$. The optimal allocation of consumption within the marriage requires $c^m = c^f$. Hence we have that $c = 2^{\frac{1}{\tilde{\rho}}} c^g$, where $\tilde{\rho} = 1.4$, as estimated by Voena (2015), implies sizable economies of scale for couples.

Production. All final goods are produced by a representative firm using aggregate physical capital K and an aggregate human capital input $\mathcal{H}$ according to the production technology $Y = F(K, \mathcal{H})$, where F is Cobb-Douglas with capital's share of output $\alpha = 0.33$. Capital depreciates at rate $\delta = 0.07$ per period.

We follow Katz and Murphy (1992) and Heckman et al. (1998a) in modelling aggregate labor input $\mathcal{H}$ as a constant elasticity of substitution aggregator of six types of labor inputs, $H^{e,g}$, indexed by gender g and education attainment $e \in \{LH, HS, CL\}$, where LH denotes high-school dropouts, HS high-school graduates, and CL college graduates:

$$\mathcal{H} = \left[s^{LH}\left(H^{LH}\right)^{\rho} + s^{HS}\left(H^{HS}\right)^{\rho} + s^{CL}\left(H^{CL}\right)^{\rho}\right]^{\frac{1}{\rho}}, \tag{3}$$

[13]Because one model-period represents two calendar years, this corresponds to a model-period capital-output ratio of 2.

[14]This specification is consistent with the transferable utility model described in Weiss (1997), pp.89-90.

where

$$H^e = \left[s^{f,e}(H^{f,e})^\chi + s^{m,e}(H^{m,e})^\chi\right]^{\frac{1}{\chi}}, \quad e \in \{LH, HS, CL\} \tag{4}$$

Both ρ and χ are in $(-\infty, 1]$. Each labor market is assumed to be competitive. The estimation of the elasticities of substitution and the CES weight parameters $s^{g,e}$, based on data from the Current Population Survey (CPS) for 1968-2001, is discussed in Section 3.

Financial Markets. Markets are incomplete. Agents trade claims to physical capital and risk-free bonds in zero net supply, but cannot buy state-contingent insurance against individual labor-income risk. All financial contracts are transacted by competitive intermediaries (banks). Claims to capital and bond holdings pay the same return in equilibrium because of no-arbitrage. Households with positive savings receive from banks an equilibrium interest rate which equals r. Banks lend the funds to other households with borrowing needs at the rate $r^- = r + \iota$, where the wedge $\iota > 0$ is the cost of overseeing the loan per unit of consumption intermediated. We set the unsecured wedge ι to reproduce the fraction of US households, with heads between age 22 and 65, who have negative net worth. From the SCF 2001 we estimate this fraction to be 6.7%, which we replicate by setting $\iota = 0.097$ (recall that each model period is two-years, thus the annualized wedge would be 0.048). Individuals face debt limits that vary over the life-cycle. High-school students, young (i.e. before marriage) workers, and retired households cannot borrow. Credit access for the college students is explained in detail below. Working-age married households are subject to a borrowing constraint $\underline{a}^e$. The value of $\underline{a}^e$ is set to $-\$75,000$ if the most educated spouse is a college graduate, $-\$25,000$ if the most educated spouse is a high school graduate, and $-\$15,000$ if both spouses are high school dropouts. These values are based on self-reported limits on unsecured credit by family type from the SCF.[15] All retired households can buy annuities at actuarially fair rates, which allows us to abstract

[15]The lifetime natural borrowing limit may be more restrictive for some households, particularly those approaching retirement.

from bequests.[16]

Government. The government levies flat taxes $\tau_w = 0.27$, $\tau_k = 0.40$ and $\tau_c = 0.05$ on labor income, asset income and consumption, respectively (see McDaniel, 2014).[17] The government refunds a lump-sum amount of tax revenue ψ to each individual, which we parameterize such that the ratio of the variance of disposable income to the variance of pre-government income is 0.61 (see Heathcote et al., 2010). This feature attributes to the model's tax/transfer system the same degree of progressivity as in the US. The government also runs a public pension system which pays an education specific benefit p^e to retirees. The pension replacement rate is set to 33% of average earnings within each respective education group (Mitchell and Phillips, 2006). Once the education and pension systems have been financed, excess tax revenues are spent on non-valued government consumption G.

2.2 Life cycle

The life cycle of an individual consists of four phases —education, marital matching, work, and retirement— which we describe in this same order.

2.2.1 Education

The education stage lasts three periods and includes two decisions. At the onset of the first period of adult life $(j = 0)$ individuals choose whether to finish high school or enter the labor market. In the second period those who completed high school decide whether to attend college, which lasts for two periods if chosen.[18]

[16] As explained, one reason why financial markets are incomplete is that there are no state-contingent insurance markets for (i) individual labor-income risk. As it will be clear from the description of the rest of the model, there are also missing markets to insure (ii) the risk of being born with disadvantaged initial conditions (e.g. poor or low-ability parents), (iii) the shocks affecting the psychic cost of education, and (iv) adverse outcomes at the marital matching stage.

[17] The tax τ_k is levied only on positive capital income. We use τ_k throughout with the convention that if $a < 0$ then $\tau_k = 0$.

[18] Individuals can therefore enter the labor force either at age $j = 0$ as high-school dropouts, or at age $j = 1$ as high-school graduates, or at age $j = 3$ as college graduates. To avoid further complexity, we abstract from modeling the college drop-out decision. The vast majority of dropouts occur in the freshman year, and dropout rates are far higher for part-time

As analyzed by Cunha et al. (2005) and Heckman et al. (2006a), psychic costs —reflecting preparedness or taste for education— are an important component of schooling decisions. In our model an individual's utility cost κ^e of attaining education level e depends on cognitive skills θ_{cog}, non-cognitive skills θ_{non}, gender, and an idiosyncratic preference shock κ_ϵ. Specifically, we assume the linear relationship

$$\kappa^e = \varsigma_0^e + \varsigma_1^e \mathbf{1}_{\{g=f\}} + \varsigma_2^e \log(\theta_{non}) + \varsigma_3^e \log(\theta_{cog}) + \varsigma_4^e \kappa_\epsilon. \tag{5}$$

The education specific coefficients ς_k^e will be estimated, and the idiosyncratic education preference shock κ_ϵ, common to high school and college (but with a different loading), is drawn from a standard normal distribution. This estimation is illustrated in Section 3. In what follows, we let the vector $\boldsymbol{\theta}$ summarize the pair $(\theta_{non}, \theta_{cog})$.

Parental resources matter for the education decision of the child in two ways. First, during the education period a child receives education-conditional cash transfers from their parents. That is, a child receives $\hat{a}_0$ from their parents unconditionally at age $j = 0$, and receives an additional amount $\hat{a}^{CL}$ —chosen by the parents at the same time as $\hat{a}_0$— conditional on going to college. We let $\hat{\mathbf{a}}$ denote the pair $\left(\hat{a}_0, \hat{a}^{CL}\right)$. Parental resources also matter because various federal aid policies depend on parental means: the relevant parental wealth classes that determine the extent to which college students qualify for federal aid are denoted by the index $q = \{1, 2, 3\}$.

Let the value of entering the workforce with education e be $V_{gj}^e(\cdot)$, and the value of continuing in school for a person of gender g and age j be $V_{gj}(\cdot)$. This latter value includes all costs and benefits of education except for the psychic cost. We define the value function V_{gj}^* to be the upper envelope of the education and work values. At age 0 this value function implicitly defines the high school

than full-time students. Thus, for the most part, very little commitment has been made among the vast majority of those who choose not to complete college, and the absence of outlays of time and money by dropouts in our model of high school graduates is likely to be of little substance. When relating to the data we count only those who complete college as having attended.

continuation decision:

$$V_{g0}^{*}\left(\hat{\mathbf{a}},\boldsymbol{\theta},q,\kappa_{\epsilon}\right)=\max\left\{V_{g0}\left(\hat{\mathbf{a}},\boldsymbol{\theta},q,\kappa_{\epsilon}\right)-\kappa^{HS}(g,\boldsymbol{\theta},\kappa_{\epsilon}),\,\mathbb{E}_{z}[V_{g0}^{LH}\left(\hat{a}_{0},\boldsymbol{\theta},z_{0}\right)]\right\}. \tag{6}$$

The initial draw on the productivity process is not known prior to entering the labor force, hence the expectation in the second argument of the $\max$ operator.

Individuals who choose to enter the labor force at age $j=0$ with $e=LH$ (or at age $j=1$ with $e=HS$) solve the follow problem:

$$\begin{aligned}
V_{gj}^{e}\left(a_{j},\boldsymbol{\theta},z_{j}\right) &= \max_{c_{j},\ell_{j},a_{j+1}} u_{g}\left(c_{j},\ell_{j}\right)+\beta\mathbb{E}_{z}\left[V_{g,j+1}^{e}\left(a_{j+1},\boldsymbol{\theta},z_{j+1}\right)\right] \\
& \quad s.t. \\
(1+\tau_{c})c_{j}+a_{j+1} &= \left(1-\tau_{w}\right)w^{g,e}\varepsilon_{j}^{g,e}\left(\boldsymbol{\theta},z_{j}\right)\left(1-\ell_{j}\right)+\psi+\left[1+r\left(1-\tau_{k}\right)\right]a_{j} \\
a_{j+1} &\geq 0, \quad c_{j}\geq 0, \quad \ell_{j}\in[0,1] \\
z_{j+1} &\sim \mathit{\Gamma}_{z}^{g,e}\left(z_{j+1}\mid z_{j}\right).
\end{aligned} \tag{7}$$

where a_j denotes assets at age j, ψ is the lump-sum government transfer, and $w^{g,e}$ is the gender and education specific price for a unit of human capital. The gender, age and education specific function $\varepsilon_j^{g,e}$ relates ability $\boldsymbol{\theta}$ and idiosyncratic productivity shocks z_j to productive efficiency per unit of labor supply. The exact dependence of $\varepsilon_j^{g,e}$ on $\boldsymbol{\theta}$ and z_j and the Markov process of the productivity shock $\mathit{\Gamma}_{gz}^{e}$ are described in detail in Section 3.

The value of completing high-school is defined by

$$\begin{aligned}
V_{g0}\left(\hat{\mathbf{a}},\boldsymbol{\theta},q,\kappa_{\epsilon}\right) &= \max_{c_{0},a_{1}} u_{g}\left(c_{0},1-\bar{t}\right)+\beta V_{g1}^{*}\left(a_{1},\hat{a}^{CL},\boldsymbol{\theta},q,\kappa_{\epsilon}\right) \\
& \quad s.t. \\
a_{1} &= \left[1+r\left(1-\tau_{k}\right)\right]\hat{a}_{0}-c_{0}(1+\tau_{c}) \\
a_{1} &\geq 0, \quad c_{0}\geq 0.
\end{aligned} \tag{8}$$

High-school students are permitted neither to borrow nor to work. They study for a fraction $\bar{t} = 0.3$ of their time endowment, and consume the rest as leisure.

The continuation value V_{g1}^{*} is the maximum of the value of attending college and the value of entering the labor market as a high school graduate. Specifically,

$$V_{g1}^{*}\left(a_1, \hat{a}^{CL}, \boldsymbol{\theta}, q, \kappa_{\epsilon}\right) = \max\left\{V_{g1}\left(a_1 + \hat{a}^{CL}, \boldsymbol{\theta}, q\right) - \kappa^{CL}(g, \boldsymbol{\theta}, \kappa_{\epsilon}), \mathbb{E}_z[V_{g1}^{HS}\left(a_1, \boldsymbol{\theta}, z_1\right)]\right\}. \quad (9)$$

College lasts for two (two-year, $j = 1$ and $j = 2$) periods. In each period, college students face tuition costs ϕ and may take up student debt b. The values of being in college in the initial and final period are, respectively

$$V_{g1}\left(a_1 + \hat{a}^{CL}, \boldsymbol{\theta}, q\right) = \max_{c_1, \ell_1, a_2, b_2} \; u_g\left(c_1, \ell_1\right) + \beta V_{g2}\left(a_2, b_2, \boldsymbol{\theta}, q\right) \quad (10)$$

and

$$V_{g2}\left(a_2, b_2, \boldsymbol{\theta}, q\right) = \max_{c_2, \ell_2, a_3, b_3} \; u_g\left(c_2, \ell_2\right) + \beta V_{g3}^{CL}\left(a_3, b_3, \boldsymbol{\theta}, q\right) \quad (11)$$

These two maximization problems are subject to a number of constraints. First, the non-negativity of consumption $c \geq 0$. Second, the time allocation constraint $\ell_j \in [0, 1 - \bar{t}]$: labor supply in college is flexible, but the time endowment available for work is reduced by $\bar{t}$ units to reflect the time required for learning. Working students supply high-school equivalent labor.[19][20]

We now turn to college students' budget constraints, which also illustrates how government programs affect schooling choices. All students have access to unsubsidized student loans up to a value $\underline{b}$.

[19]Our model generates average hours worked by students approximately equal to the average 20 hours per week reported by Garriga and Keightley (2015). In addition to this, our model fits reasonably well to the numbers of full-time and part-time working students observed in the data. For example, in the NCES Baccalaureate and Beyond data for graduating seniors 2007-8, 19% of students reported not working , 56% worked part-time, and 25% worked full-time. In our model 19% do not work, 43% work less than 0.25 of their time endowment, and 37% work more than 0.25 of their time endowment.

[20]For simplicity their labor productivity, $\varepsilon_j^{g,HS}$ in the budget constraint below is allowed to depend only on gender, age j and ability $\boldsymbol{\theta}$. Implicitly, we are assuming every college student has idiosyncratic productivity value equal to the population mean $(z = 0)$.

Unsubsidized loans cumulate interest at rate r^u both during and after college. Students with financial need, measured by their parents' wealth ($q=1$), have access to subsidized loans up to a limit $\underline{b}^s$. Interest on subsidized loans is forgiven during college. Those with wealthy parents ($q=3$) have access to private loans at the rate r^p. Because $r^p < r^u$, and because the credit limit on private loans $\underline{a}^p$ allows them to fully fund college through private credit, students with $q=3$ always choose this option.[21] Federal grants $\mathfrak{g}$ are awarded by the government through a formula that makes them a function of both parental wealth and student abilities. Hence, we allow grants to be both need-based and merit-based. To simplify notation, we refer to $\phi(q,\boldsymbol{\theta})$ as tuition fees ϕ net of grants $\mathfrak{g}(q,\boldsymbol{\theta})$. Next, we state the college students' budget constraints.

A student with wealthy parents ($q=3$) has the option to borrow privately and faces the following budget constraint:

$$\begin{aligned}&(1+\tau_c)c_j + a_{j+1} - (1-\tau_w)\, w^{g,HS}\varepsilon_j^{g,HS}(\boldsymbol{\theta}, z_j=0)\,(1-\bar{t}-\ell_j) + \phi(q,\boldsymbol{\theta}) = \\ =\;&\begin{cases}[1+r(1-\tau_k)]\,a_j & \text{if } a_j \geq 0, \\ (1+r^p)\,a_j & \text{otherwise}\end{cases} \\ &a_{j+1} \geq -\underline{a}^p\end{aligned} \tag{12}$$

A student who qualifies only for unsubsidized government loans ($q=2$) faces the budget constraint:

$$\begin{aligned}&(1+\tau_c)c_j + a_{j+1} + b_{j+1} - (1-\tau_w)\, w^{g,HS}\varepsilon_j^{g,HS}(\boldsymbol{\theta}, z_j=0)\,(1-\bar{t}-\ell_j) + \phi(q,\boldsymbol{\theta}) = \\ =\;&\begin{cases}[1+r(1-\tau_k)]\,a_j & \text{if } a_j \geq 0, \quad b_j = 0 \\ (1+r^u)\,b_j & \text{if } a_j = 0, \quad b_j < 0\end{cases} \\ &a_{j+1} \geq 0 \quad b_{j+1} \geq -\underline{b}\end{aligned} \tag{13}$$

[21] Implicitly, interest rates on private education loans depend on credit scores. See Ionescu and Simpson (2016). As a result, poor families with low credit scores face high borrowing rates on private education loans. Implicitly, we assume that these rates are so high that poor families choose not to use the private market to finance their children's education.

A wealth-poor student who qualifies for a subsidized government loan $(q = 1)$ faces the budget constraint:

$$
\begin{aligned}
& (1+\tau_c)c_j + a_{j+1} + b_{j+1} - (1-\tau_w)\, w^{g,HS} \varepsilon_j^{g,HS}(\boldsymbol{\theta}, 0)\,(1-\bar{t}-\ell_j) + \phi\,(q, \boldsymbol{\theta}) = \\
= & \begin{cases} [1 + r\,(1-\tau_k)]\, a_j & \text{if } a_j \geq 0, \quad b_j = 0 \\ b_j & \text{if } a_j = 0, \quad 0 > b_j \geq -\underline{b}^s \\ -\underline{b}^s + (1+r^u)\,(b_j + \underline{b}^s) & \text{if } a_j = 0, \quad b_j < -\underline{b}^s \end{cases} \\
& a_{j+1} \geq 0 \quad b_{j+1} \geq -\underline{b}
\end{aligned}
\tag{14}
$$

We parameterize grants and student loans using data published by the NCES for the year 2000 (source: Student Financing of Undergraduate Education: 1999-2000, Statistical Analysis Report). Federal student loans were taken out by 62.1% of graduating seniors, and of these federal loans 84.1% were at least partially subsidized. To qualify for a subsidized loan $(q = 1)$ a child's family must pass two tests. The first is a potential income test, which stipulates that the higher earning parent would earn less than \$85,000 if they work fulltime (35% of their time endowment).[22] The second test is a wealth test, and we find that replicating the percentage of students with subsidized loans $(q = 1)$ requires a family wealth threshold of $a^* = \$113{,}000$. To replicate the fraction of students with any type of federal loans ($q = 2$ as well as $q = 1$) requires a second wealth threshold of $a^{**} = \$151{,}000$ above which students prefer private loans. Note that if family wealth is below a^*, but potential income exceeds \$85,000, then the student will qualify for $q = 2$ financial aid. Cumulative borrowing limits for federal loans to (dependent) students were \$23,000 in year 2000, of which a maximum \$17,250 could be subsidized if the student qualified. We use these values to set $\underline{b}$ and $\underline{b}^s$ and we specify $\underline{a}^p$ so that cumulative private and federal borrowing limits are equal. The interest rate on federal student loans was prime (r^- in our model) plus 2.6% in 2000, thus we set $r^u = r^- + \iota^u$, where $\iota^u = 0.053$ (recall that a model period is two years). For private student loans we set the borrowing rate to

[22] The NCES data indicate that very few subsidized loans are given to children from families with income over \$85,000, but that below this threshold there is not much influence of income.

$r^p = r^- + \iota^p$. The private loan premium $\iota^p = 0.048$ reproduces the observation that around 8% of graduates have borrowed from non-federal sources. We think of these two additional wedges as higher intermediation costs, over and above the unsecured credit wedge ι defined above, associated with screening of applications.

We define the cost of college as tuition fees plus the cost of books and other academic material net of institutional and private grants, and we compute an average across all full-time, full-year dependent students enrolled in private not-for-profit and public 4-year colleges in the year 2000. We obtain an average annual cost ϕ of \$6,710. Federal and state grants $\mathfrak{g}$ are means-tested, with children of low ($q = 1$), middle ($q = 2$) and high ($q = 3$) income parents receiving \$2,820, \$668 and \$143 per year, respectively. Thus, net annual tuition $\phi(q, \boldsymbol{\theta})$ is \$6,710 minus the applicable federal grant, depending on q. In Appendix F we provide a detailed description of the federal system of financial aid to college students (as in the year 2000) that we aim to reproduce in estimation.

To simplify the computation we assume that at the end of college all student debt (private and federal loans) is refinanced into a single private bond that carries the interest rate r^-. Hence, with a slight abuse of notation, we can write the value of a college student upon entering the marital matching stage as

$$V_{g3}^{CL}\left(\tilde{a}_3, \boldsymbol{\theta}\right) = V_{g3}^{CL}\left(a_3, b_3, \boldsymbol{\theta}, q\right), \tag{15}$$

where $\tilde{a}_3$ is the student net asset position based on a_3, b_3 and q. For those students with $a_3 < 0$ (borrowing from the private sector) or $a_3 = 0$ and $b_3 > 0$ (borrowing from the government), $\tilde{a}_3$ is computed as the present value of all future payments that must be made on student loans, depending on the amount borrowed and applicable interest rates, discounted at rate r^-. When making this calculation we assume that fixed payments would have been made for 10 periods following graduation. We adopt this approach —which provides a close approximation to a setting where fixed installments are required for a given number of periods, but households can use unsecured debt to make these payments if necessary— in order to simplify the computation.[23] Appendix F illustrates this conversion

[23]This approach reduces the high-dimensional state space of married couples by four variables: debt and parental wealth

scheme in more detail.

2.2.2 Marital Matching

Although individuals are heterogeneous in several dimensions upon entering the matching stage, we assume that probabilistic matching between men and women is based only on education. Where e^f and e^m are the matched female's and male's education levels, the ex-post value of the match is:

$$W_3(a_3^f + a_3^m, z_3^f, z_3^m, \boldsymbol{\theta}^f, \boldsymbol{\theta}^m, e^f, e^m), \tag{16}$$

which is the present discounted utility that this household will generate. Individuals entering the matching stage value their prospects as the expectation over potential outcomes, conditional on their own education. Let $Q^f\left(e^f, e^m\right) \in [0,1]$ be the probability that a woman in education group e^f meets a man belonging to group e^m. Symmetrically, matching probabilities for men are denoted $Q^m\left(e^m, e^f\right)$. Then, for example, for a college educated female, the expected value of marriage is:

$$V_{f3}^{CL}\left(a_3^f, \boldsymbol{\theta}^f\right) = \frac{1}{2}\sum_{k\in\{LH,HS,CL\}} Q^f(CL,k)\mathbb{E}_{a^m,z^f,z^m,\boldsymbol{\theta}^m}\left[W_3(a_3^f + a_3^m, z_3^f, z_3^m, \boldsymbol{\theta}^f, \boldsymbol{\theta}^m, CL, e^m = k)\right] \tag{17}$$

where the $1/2$ is the assumed sharing rule, constant because of full commitment.[24]

The conditional expectation is taken over the remaining state variables for the man (ability, wealth, and productivity) —which may be correlated with his education— and over productivity draws for the wife herself. For those who have not completed college, their match value also depends on their own past labor market productivity z_2, but we retain the assumption that productivity of the partner is not observed. Matching rates are based on observed CPS data, for which educational match frequencies

of each spouse.

[24]There are no singles in the model. Consequently there is no well defined outside option to marriage. If there was an alternative to marriage, then the sharing rule would be defined as a share of *surplus* based on outside options. This would add the complexity of a heterogeneous and age-varying Pareto weight in the state space, complicating an already difficult computational problem.

Husband's Edu	Wife's Edu HSD	HSG	CLG
HSD	0.107	0.030	0.002
HSG	0.027	0.498	0.042
CLG	0.002	0.056	0.236

Notes: Cell frequencies are the percentage of all marriages involving a particular match, i.e. these frequencies sum to one. Source: CPS 2000

Table 1: Husband-Wife Matching on Education

are provided in Table 1. The heavy weight on the diagonal is a manifestation of the pronounced assortative matching.

Our policy experiments modify the shares of men and women in each education group which requires us to take a stand on how these changes affect the conditional matching probabilities. We choose to vary these probabilities so as to keep the correlation between cognitive skills of husbands and wives constant across steady-states. We use this correlation, as opposed to the correlation across education levels, because the measure of cognitive skills is a cardinal variable, unlike educational attainment.

2.2.3 Working-Age Families

In this stage each family solves a standard life-cycle problem as in equation (7); the difference is that the choice variables include the consumption and labor supply of both members of the household. The structure of the shocks is the same, with uncertainty over efficiency units of human capital for both man and wife, as specified before. Total household expenditure on goods allows for economies of scale, as specified in Section 2.1. The couple's value function $W_j(a_j, z_j^f, z_j^m, \boldsymbol{\theta}^f, \boldsymbol{\theta}^m, e^f, e^m)$, together with the relevant budget constraint, is shown in Appendix A.

The household problem becomes slightly different when the children (a pair) are born because parents know the gender of children right away, which adds a state variable from then on. Parents do not know exactly what a child's cognitive and non-cognitive skills will turn out to be yet, only what they can forecast based on parental skills and education. It is at the stage when inter vivos transfers to the children are chosen that the final abilities and education preferences of a child are revealed to their parents. The household problem in the period of the inter vivos transfers is described in detail in Section 2.3 below.

2.2.4 Retirement

After inter vivos transfers have been given, parents continue working until retirement age $j^{RET} - 1$. When they retire, from period j^{RET} onwards, they solve a simplified problem with labor supply fixed at zero. Their income is augmented by social security payments, which depend on the level of education. Retirees may die at age j with probability equal to the empirical mortality rates (US Life Tables, 2000). We assume perfect annuity markets during retirement, thus the return to assets is increased in line with the mortality rate for the relevant age because the assets of expiring households are redistributed within cohorts. We show the household problem during retirement in Appendix A.

2.3 Intergenerational Linkages

The two crucial mechanisms for intergenerational linkages in our model are (i) the transmission of skills from parents to children and (ii) inter-vivos transfers from parents to children.

Transmission of Abilities At the age of 16 ($j = 0$), when inter vivos transfers take place, and just before education choices are made, the cognitive and non-cognitive skills are crystalized. These may be a result of parental investments (which we do not model here) and of genetics. Our modelling choices are in part determined by the available data. Thus child cognitive skills are drawn from a discrete distribution which depends on the mother's cognitive skills.

A child's non-cognitive skills are drawn from a distribution that depends on their mother's education and the child's own cognitive skills. By allowing non-cognitive skills to depend on parental education, which itself is a choice, we endogenize in part the intergenerational transitions of skills.

In counterfactual simulations we assume that the relationship of non-cognitive skills with parental education, *conditional* on child cognitive skills, can be taken as causal; hence as the parents change their education choices as a result of policy, they affect the child non-cognitive skills, based on our estimated relationship. Details on these transition matrices, and their estimation using the NLSY79, are reported in Section 3.

Intervivos Transfers Individuals start their life with some wealth and funding for their education, which is the result of parental transfers. Utility from children and the resulting transfers, arises from both altruism and paternalism. In what follows, we denote variables for the child with the ˆ symbol.

The altruistic weight parents put on their child's expected lifetime utility is $\omega_{\hat{g}}$. Beyond altruism, parents may enjoy a utility gain ξ if their child goes to college. This is an important feature which may explain why, in the data, lower ability children of wealthier parents attend college. It is also relevant for the extent to which private transfers are (or are not) crowded out by government programs. The additional value that parents obtain from their children at the age where the latter are about to start making their own choices is given by

$$\omega_{\hat{g}} V^*_{\hat{g}0}(\hat{\mathbf{a}}, \hat{\boldsymbol{\theta}}, \hat{q}, \hat{\kappa}_\epsilon) + \xi \cdot \mathbf{1}_{\{\hat{e}=CL\}}, \tag{18}$$

where $\mathbf{1}_{\{\hat{e}=CL\}}$ indicates whether the child attends college. Note that, at the time of the transfer, the parents know both the abilities of the child ($\hat{\boldsymbol{\theta}}$) and her random shock to education preferences ($\hat{\kappa}_\epsilon$). We allow altruism to depend on gender because we observe gender differences in inter vivos transfers; however, we restrict paternalism to be the same across genders because we do not observe gender differences in the influence of parental wealth on education.

To reduce the computational burden, we posit that each family has two identical children. Hence, the family makes the same transfers to each of them. The unconditional transfers $\hat{a}_0$ are paid to the child immediately, whereas the college-conditional transfers are committed to a trust account when the child is 16, and then paid to the child upon entering college at 18.

Transfers are determined by augmenting the parent's value function by the value defined in (18) and maximizing with respect to the conditional and unconditional transfers. The cost of the transfer to the parent is the reduction in their wealth. Gains from transfers accrue to the parents for two reasons. First, the children's value $V^*_{\hat{g}0}$ is increasing in $\hat{\mathbf{a}}$, and parents are altruistic. Second, a large enough conditional transfer $\hat{a}^{CL}$ can induce the child to choose to attend college, and since parents are paternalistic they experience an extra utility gain ξ from this choice. Because of the fixed nature of the utility gain, this paternalistic motive is stronger for wealthy parents whose marginal utility from consumption is low.

The formal structure of the dynamic problem of the family in the period of the inter vivos transfers is presented in Appendix A and details of the estimation of altruism and paternalism parameters are contained in Section 3.

2.4 Equilibrium

The model is solved numerically to characterize the stationary equilibrium allocation. Given age heterogeneity and finite lives, this model entails $J + 1$ overlapping generations. Stationarity implies that we study an equilibrium such that the cross-sectional allocation for any given cohort of age j is invariant over the sequence of time periods $t \in \{t_0, t_1, ...\}$. A detailed definition of the stationary equilibrium and its numerical computation is presented in Appendix A. The equilibrium allocation implies that households choose their education level, consumption, labor supply, and inter-vivos transfer plans to maximize expected lifetime utility, firms maximize profits, prices clear all markets, and the government budget constraint is balanced period by period.

3 Estimation Results

There are three sets of parameters in the model: those that are estimated separately from the model, namely the production function and the income process; those that are estimated within the model using the method of moments. These include parameters determining the costs of education, some preference parameters (including altruism and paternalism) and several others, listed in the appendix. Finally there are some parameters that we fix based on the literature.

3.1 Aggregate Production Function

Under the assumption that all labor markets are competitive, we estimate the technology parameters and test the iso-elasticity assumptions using CPS data on wage bills and hours worked for the different gender-education groups for the years 1968-2001. Details of our estimation and tests, including robustness checks using different instruments and specifications, are presented in Appendix B. In the numerical analysis we set the elasticity of substitution between education aggregates to 3.3 (i.e. $\rho = 0.7$). This is within the range of our estimates and in line with values reported in the literature.[25] Our specification of technology also allows for imperfect substitutability of male and female efficiency units.[26] We use a baseline value of $\chi = 0.45$ in the numerical simulations, corresponding to an 'education-conditional' elasticity of roughly 1.8 between men and women, a number within our range of estimates. The values of the gender/education CES weights $s^{g,e}$ are reported in the appendix.[27]

This specification of aggregate technology, together with the equilibrium selection mechanism of the model, yields college and high school wage premia that are consistent with the data. Applying the estimation approach of Goldin and Katz (2007) to data simulated from our model, the

[25]Many estimates in the literature are based on a coarser two-type skilled/unskilled classification for labor, with no gender differences. Katz and Murphy (1992) estimate the elasticity of substitution to be 1.41; Heckman et al. (1998a) report a favorite estimate of 1.44. Card and Lemieux (2001) obtain an elasticity of substitution between college and high school workers of about 2.5; however, their estimated elasticity, when accounting for imperfect substitutability across age groups, ranges between 4 and 6. Finally, using a nested specification with three human capital types Goldin and Katz (2007) suggest a preferred elasticity between college and non-college workers of 1.64.

[26]Existing evidence suggests that equally-skilled individuals of different gender are not perfect substitutes, see for example Johnson and Keane (2007).

[27]Our production function specification does not display capital-skill complementarity. Krusell et al. (2000) find evidence of complementarity between equipment capital (but not structure) and college educated workers. Given the richness of the household side of the model, we chose to maintain the production side relatively stylized and opted for one type of capital. In our policy experiments the aggregate capital stock changes very little (policy changes only affect the saving behavior of the wealth-poor, who account for a small share of aggregate wealth). Therefore, the additional effect of changes in capital on the college premium would be fairly small with capital-skill complementarity.

log college/high-school wage differential is estimated to be 0.58, and the log high-school graduate/dropout wage differential is 0.37. These values are close to the estimates presented in Goldin and Katz (2007, Table A8.1) for the year 2000 which place the college premium between 0.58 and 0.61, and the high-school premium between 0.26 and 0.37. When we examine gender gaps, recent work by Goldin (2014) indicates that median earnings of women (in the year 2000) were roughly 74% those of men, and our model generates a corresponding figure of 73%.[28]

3.2 Income Process and the Impact of Ability on Earnings

The wage process is an important ingredient of the model as it determines the career profile as well as the amount of uninsurable uncertainty faced by individuals. We allow individual wage dynamics to depend on age, gender, education and abilities. Heckman et al. (2006b) document that the effects of cognitive skills on earnings are 4-5 times larger than those of non-cognitive skills. In light of this finding, we make the simplifying assumption that only cognitive ability directly affects earnings in the labor market.

We estimate wage processes correcting for selection into work, which provided significant adjustments for women but not for men. In Appendix C we discuss aspects of the estimation and report the resulting deterministic age profile for each education group, which is by now standard: the higher the level of education, the steeper the increases of wages with earnings.

After removing age effects, the idiosyncratic labor productivity process $\varepsilon_j^{g,e}$ is specified as (dropping the individual subscript i):

$$\varepsilon_j^{g,e} = \lambda^{g,e} \log \theta_{cog} + z_j^{g,e}, \tag{19}$$

where

$$z_j^{g,e} = \varrho^{g,e} z_{j-1}^{g,e} + \eta_j^{g,e}, \qquad \eta_j^{g,e} \overset{iid}{\sim} N\left(0, \sigma_\eta^{g,e}\right). \tag{20}$$

[28]Goldin's figure refers to women working 35 hours or more per week, 40 weeks or more per year. In simulated data we consider median full-time female earnings divided by median full-time male earnings, where full-time is defined as 0.3 of time endowment or more.

Education group	Male Gradient	Female Gradient
Less than HS	0.428 (0.054)	0.184 (0.057)
HS Graduate	0.516 (0.030)	0.601 (0.036)
College Graduate	0.797 (0.109)	0.766 (0.099)

Table 2: Estimated ability gradient $\lambda^{g,e}$ (NLSY79)

Less than HS		HS Graduates		College graduates	
ϱ^m	0.955 (0.010)	ϱ^m	0.952 (0.005)	ϱ^m	0.966 (0.015)
σ^m_η	0.015 (0.002)	σ^m_η	0.017 (0.001)	σ^m_η	0.017 (0.005)
σ^m_{z0}	0.037 (0.005)	σ^m_{z0}	0.059 (0.003)	σ^m_{z0}	0.094 (0.009)
ϱ^f	0.852 (0.023)	ϱ^f	0.953 (0.003)	ϱ^f	0.983 (0.016)
σ^f_η	0.025 (0.005)	σ^f_η	0.019 (0.001)	σ^f_η	0.018 (0.004)
σ^f_{z0}	0.035 (0.011)	σ^f_{z0}	0.041 (0.003)	σ^f_{z0}	0.076 (0.007)

Notes: Estimated parameters of the process for individual efficiency units $\varepsilon^{g,e}_j$ (NLSY79). Standard errors in parentheses.

Table 3: Individual Productivity Process Parameters

The initial value of productivity of an agent $z^{g,e}_0$ is drawn from a normal distribution with mean zero and variance $\sigma^{g,e}_{z_0}$. The impact of cognitive skills on wages $\lambda^{g,e}$, the persistence of idiosyncratic productivity shocks $\varrho^{g,e}$, and the variance of idiosyncratic productivity innovations $\sigma^{g,e}_\eta$ all vary by gender and education attainment. This heterogeneity in returns to schooling will in part drive differences in education choices between men and women and across ability groups.

The estimates of the ability gradient and the persistence of the shocks are reported in Tables 2 and 3 respectively. The ability gradient for wages increases with education, implying a strong complementarity between the two. It is also the case that the returns to ability increase by more for

	Children				
Mothers	1	2	3	4	5
1	0.455	0.238	0.197	0.065	0.047
2	0.258	0.242	0.242	0.157	0.110
3	0.160	0.223	0.271	0.190	0.157
4	0.114	0.171	0.257	0.209	0.249
5	0.072	0.076	0.195	0.242	0.415

Notes: Ability transition probabilities, by quintile (NLSY79). Quintile 1 is the lowest ability, quintile 5 is the highest.

Table 4: Ability transition matrix

women than for men, particularly at lower education levels. Shocks are highly persistent, and close to being a random walk for all but females with less than high school. Notably, even for *given ability*, the variance of initial productivity draws increases with education for women, and even more so for men. This uncertainty is particularly difficult to insure against, since at young ages individuals tend to be wealth-poor.

3.3 Intergenerational Transmission of Cognitive and Non-Cognitive Skills

To measure the transmission of cognitive ability θ_{cog} between generations, we use data from the 'Children of the NLSY79' survey, which provides test scores of cognitive skills for both mothers and children. We build pairs of mother and child test-score measurements and estimate an ability transition matrix Γ_θ across skill quintiles. The matrix, reported in Table 4, implies a great deal of upward and downward mobility in the middle of the distribution, but less so at the top and the bottom, where the diagonal element is larger.

As explained above, due to data limitations we allow a child's non-cognitive skills to be influenced by parental education and by one's own cognitive skills, but not directly by parents' non-cognitive ability. Using NLSY79 data, we measure non-cognitive skills as the first principal component factor

Conditional Probabilities of Non-Cognitive Tercile 1					
	Child's Cognitive Quintile				
Mother's Edu	1	2	3	4	5
HSD	0.585	0.453	0.350	0.311	0.189
HSG	0.527	0.418	0.266	0.235	0.178
CLG	0.578	0.388	0.289	0.201	0.139

Conditional Probabilities of Non-Cognitive Tercile 2					
	Child's Cognitive Quintile				
Mother's Edu	1	2	3	4	5
HSD	0.297	0.367	0.339	0.316	0.347
HSG	0.362	0.330	0.386	0.333	0.318
CLG	0.283	0.343	0.353	0.356	0.337

Conditional Probabilities of Non-Cognitive Tercile 3					
	Child's Cognitive Quintile				
Mother's Edu	1	2	3	4	5
HSD	0.118	0.180	0.311	0.372	0.464
HSG	0.111	0.252	0.348	0.432	0.504
CLG	0.139	0.270	0.358	0.443	0.525

Notes: Each cell reports the conditional probability of the child being in the non-cognitive skill tercile corresponding to that table section. (NLSY79). Tercile 1 is the lowest, tercile 3 is the highest.

Table 5: Non-cognitive Ability Transitions

in the Rotter Scale and the Pearlin Mastery Scale scores. Table 5 reports conditional probabilities.

3.4 The Simulated Method of Moments Estimation

Table G.1 in the online appendix lists parameters that we set in advance. Given these, as well as the production function parameters, income processes and transition matrices for intergenerational transmission of cognitive and non-cognitive skills that we have just discussed, we estimate the remaining parameters using the simulated method of moments. In particular, this last step delivers parameters determining the psychic costs of education, the gender specific altruism load, and the paternalistic preference for education that we discuss in detail next.

These remaining parameters are estimated by minimizing an unweighted quadratic distance criterion between data moments and corresponding moments implied by the model. The model moments are produced by simulation, which often implies that the resulting criterion is not differentiable. We thus use the Nelder-Mead Simplex method, which is derivative free. In what follows we discuss results on psychic costs of education and intergenerational linkages in preferences. Table G.2 shows the remaining estimated parameters with corresponding standard errors, and Tables G.2 and G.3 show the moments matched in estimation.

3.5 Psychic Cost of Education

The parameters of the psychic costs of education are presented in Table 6. In interpreting these values note that all right hand side variables are standardized to have unit variance and mean zero.

On average, the implied baseline costs are 3.2% of discounted lifetime utility for high school students and 4.1% of discounted lifetime utility for college students.[29] However, there is substantial variation in psychic costs due to heterogeneity in cognitive skills, non-cognitive skills and idiosyncratic preferences shocks as reflected in the parameters $(\theta_{cog}, \theta_{non}, \kappa_{\epsilon})$.[30] Costs also change with gender: over the estimation period the college educated workforce still included a larger fraction of men, which explains the higher intercept estimated for women's college costs.

Non-cognitive skills appear to be essential in reducing the costs of high school attendance, whereas cognitive skills are less important at that stage. Idiosyncratic preference shocks are also an important component of high school costs. However, conditional on gender, they only explain 8% of the variance of psychic costs of high school and 17% of that for college. Thus most of the variance in psychic costs

[29] The cumulative average psychic cost of a college graduate is the sum of psychic costs experienced during both high school and college, and corresponds to roughly 7% of college students' lifetime utility.

[30] We also test whether skill-gender interactions significantly shift education attainment rates, and find no evidence of such shifts. More specifically, we estimate the relationship between education attainment, gender and skills, and then we test the significance of gender interactions with cognitive and non-cognitive skills.

Parameter		High School	College
ς_0^e	Constant	1.697	1.872
		(0.006)	(0.010)
ς_1^e	Female Dummy	-0.134	0.610
		(0.0150)	(0.006)
ς_2^e	$\log(\theta_{non})$	-0.605	-0.239
		(0.010)	(0.011)
ς_3^e	$\log(\theta_{cog})$	-0.233	-0.779
		(0.015)	(0.012)
ς_4^e	κ_ϵ	0.213	0.408
		(0.008)	(0.011)

Notes: Simulated Method of Moments estimates of psychic costs loadings. Estimates of asymptotic standard errors, which are corrected for simulation error, are in parentheses.

Table 6: Parameters of the Psychic Costs of Education

of schooling is explained by cognitive and non-cognitive skills, the former being more important for college and the latter for high school.

The overall consumption value of psychic costs is substantial, especially when abilities are low. Among students with median abilities and education preference shocks, college and high-school psychic costs added together are worth about \$135,000 on average, in year 2000 consumption terms. However, greater ability reduces these costs: a one standard deviation increase in cognitive skills reduced these costs by the equivalent of \$36,000; the corresponding reduction for a change in non-cognitive skills is \$30,000. Interestingly, for the very high skilled these costs can even be negative: for example, a student two standard deviations above the mean in cognitive and non-cognitive skills as well as education preferences would gain a utility equivalent to \$41,000 of consumption by completing both high school and college. The average psychic costs that we compute are comparable in magnitude to those reported in Cunha et al. (2005) and Heckman et al. (2006a).

3.6 Altruism, Paternalism and Inter vivos Transfers

Identification of altruism and paternalism is primarily driven by the size of inter vivos transfers and how these vary by gender. The NLSY97 provides information on family transfers received by young individuals. In particular, it asks respondents about any gifts in the form of cash (not including loans) from parents. Appendix E describes the sample we construct and the methodology we use to measure early inter vivos transfers, and it reports basic facts about parental gifts to young individuals, as recorded in the NLSY97. Since we model early inter vivos transfers as one-off gifts from parents to children occurring before college age, we restrict attention to the cumulative transfer between age 16 and 22. In our calculations we also include imputed rents for students living in their parents' house.[31]

In the data we observe male children receiving somewhat larger transfers than female children. The average transfer gifted to a male child is just above $33,000, while the average transfer gifted to a female child is around $29,000.

Paternalistic preference for college, as well as altruism, may motivate wealth transfers, as parents use conditional transfers to induce their children to attend college. To help identify this effect we use information about the relative college attainment rate of children from wealthy families relative to poorer families. In the NLSY97 the parents of respondents are asked to report their net worth. College attainment is strongly and positively correlated with reported net worth. For example, children whose parents are in the fourth quartile (top 25%) of the wealth distribution are 1.6 times as likely to become college graduates as those whose parents are in the third quartile. This is a moment we explicitly target, and successfully match, in estimation.

The resulting estimated altruism parameters are $\omega_{\hat{m}} = 0.29$ (s.e. $= 0.005$) for males and $\omega_{\hat{f}} = 0.25$ (s.e. $= 0.008$) for females, showing a small preference for boys, which translates to some gender differences in the counterfactuals we explore. The paternalism parameter is estimated to be $\xi = 0.201$ (s.e. $= 0.041$).

[31] As also emphasized by Johnson (2011), the co-residence component makes up a large fraction of the total inter vivos transfers.

Paternalism contributes a relatively small amount to parental utility and, on average, roughly 3% as much as altruism contributes to the utility of parents with college graduate children. This small number, however, conceals the fact that paternalism plays a crucial role in the college decisions of some children, in particular children from very affluent families. In simulations we observe that 4.8% of college graduates attend college because they receive college-conditional transfers that decisively alter their incentives. The average wealth of the parents of these students is slightly more than 10% larger than the corresponding figure for the average college student. At the same time, the return to education is somewhat lower for these students, as both their cognitive and non-cognitive abilities are on average 5% lower than the values in the broad population of college graduates. The fact that these students' abilities are only slightly lower indicates that they are initially 'marginal' with respect to the college choice, but the additional utility received by their parents causes college enrollment.

4 Assessing the Model's Behavior

We examine the behavior of the model along five dimensions. First, we analyze the implied cross-sectional age profiles for hours worked, earnings, consumption, and wealth. None of these moments is explicitly targeted in the parameterization (only those for wages are). Second, we study the determinants of parental transfers to children. Third, we measure the degree of intergenerational persistence of educational attainment and income in the model (also, not targeted). Fourth, we examine the role of parental wealth in determining educational achievement. Fifth, we reinforce the empirical plausibility of the model by simulating an artificial randomized experiment where a (treatment) group of high-school graduates receives a college tuition subsidy and a (control) group does not. This last simulation shows that the elasticity of college attainment with respect to tuition in our model is comparable to estimates from the empirical literature on schooling.

In Appendix J we show that the model provides reasonably good out-of-sample predictions on college attendance rates and wage premia when extrapolated to the year 2010. We also show that the

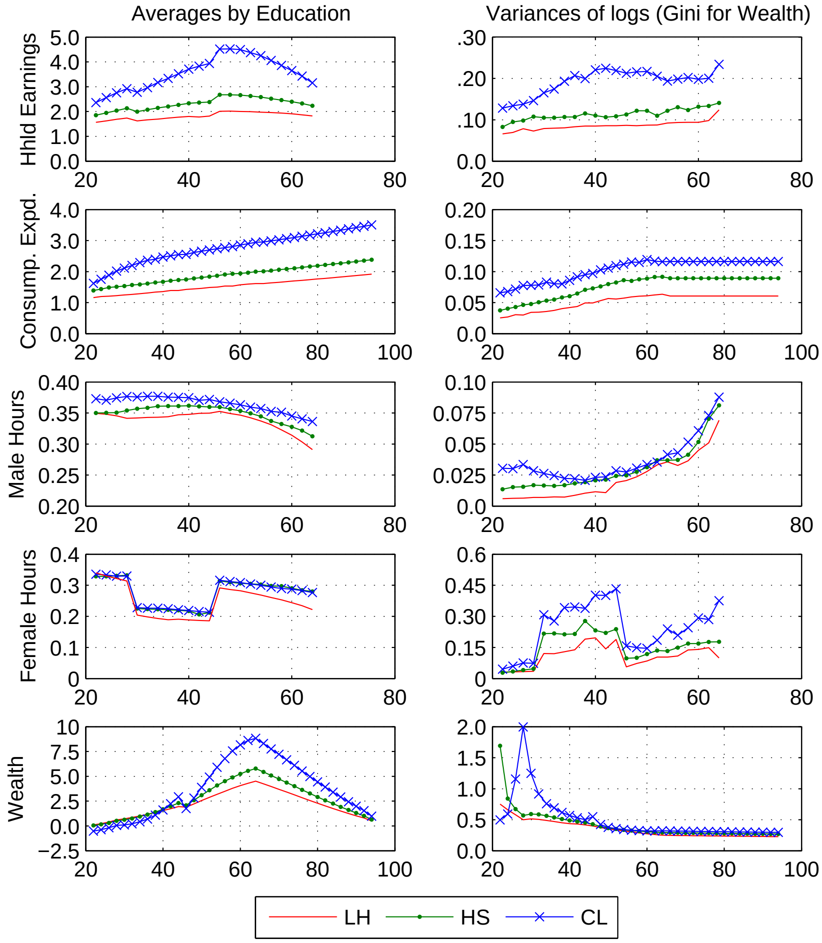

Figure 1: Statistics are presented by education. For family level variables (consumption and wealth) the education of the head (male) is used for classification. For wealth we use the absolute Gini coefficient as a measure of dispersion.

model generates substantial dispersion of educational attainment even after shutting down all cross-sectional variation in psychic costs. In other words the heterogeneity in returns and parental transfers play a crucial role in determining educational attainment (see Appendix J.2 for details).

4.1 Life-Cycle Profiles

Figure 1 plots averages and dispersion of log earnings, log consumption, and wealth over the life cycle, for our three education groups. It also reports log hours worked separately by gender.

Average hours worked increase in the level of education, which is a reflection of differences in the average return to work (the wage rate). For the same reason, hours drop faster for the less educated groups over the life cycle. Hours dispersion rises over the life cycle for all education groups, following the dispersion in labor productivity. Quantitatively, the rise in the variance of hours is in line with the data (see Figure 15 in Heathcote et al., 2010). Women's hours worked exhibit, as expected, changes due to the presence of children in the household.

The rise in average earnings over the life cycle is more pronounced for more educated households and the changes in the variance of log earnings between ages 25 and 60 (around 0.4 log points) are quantitatively consistent with empirical evidence (for an example, see Guvenen, 2009, Figure 4).[32]

A comparison between consumption and earnings paths (both their mean and dispersion) reveals that consumption smoothing through borrowing and saving is quite effective after the schooling phase. During working life the variance of log consumption grows between 0.03 and 0.05 log points, depending on education group. These changes compare to a rise twice as large in the variance of households' log earnings.[33]

Wealth accumulation features the typical hump-shaped pattern. In the model, the drop in household wealth at age 48 arises as a consequence of the inter vivos transfer to children. The drop is much larger for the highly educated families, whose children are the most likely to attend college. Young college students and college graduates decumulate their wealth and borrow to enroll in college and to smooth consumption in their first years of working life. Finally, note that wealth inequality declines gradually over the life cycle. The magnitude of this decline is very close to its empirical counterpart, as documented in Kaplan (2012) from SCF data.

4.2 Determination of Inter Vivos Transfers

Three forces shape parental decisions of how much to transfer to their children. The first purpose is narrowing the gap between parent's and child's lifetime utilities, and the extent to which parents want

[32]Households are categorized are based on the highest education within a household.

[33]During retirement, the combination of annuity markets and interest rate above the discount rate implies a linear upward sloping consumption pattern.

to close this gap depends on the degree of altruism ($\omega_{\hat{g}}$). This motive (intergenerational smoothing) is strongest for low ability and low earnings potential children, especially those with rich parents. Paternalism, as explained, pushes in this same direction. The second purpose is that of alleviating the financial constraints of children in the event they choose to go to college. This second motive (college education financing) is strongest for high ability children whose return to attending college is the highest.

The left panel of Figure 2 shows that in the model inter vivos transfers (IVTs) increase monotonically with parental wealth at the age of the transfer (age 48). For many poor families the marginal cost of transferring to the children is too high in terms of their own foregone consumption, and they make no transfer. The IVTs are zero or very low for a wide range of parental wealth levels.[34] Finally this plot also shows that, for given wealth, high-ability parents save more for the IVT, as they expect their children to be on average of a high ability type as well, therefore with large gains from college education.

However, for the reasons discussed above, IVTs are not monotonic in child's ability (right panel). For low levels of ability the intergenerational smoothing and paternalistic motive dominates and IVTs decline in child's ability (most sharply for high parental wealth). At the high end of child's ability, IVTs rise again as the college education financing motive dominates.

Parental IVTs determine the distribution of initial wealth in equilibrium. Meanwhile, the costs and returns to college education are jointly dictated by financial resources, and ability (directly, and through psychic costs). Therefore, it is important to ensure that the correlation among these two variables is consistent with data. Zagorsky (2007) uses the 2004 module of the NLSY79 to estimate a correlation between income (net worth) and AFQT test scores of 0.30 (0.16, respectively) in a sample of individuals aged 40 and 47. In our benchmark simulation, the correlation between income (wealth) and cognitive ability θ_{cog} for the same age range is 0.4 (0.07, respectively), hence empirically plausible.

[34]Indeed, in many cases parents would be better off with a negative transfer (i.e., receiving a transfer from their child) as they expect their child to earn more, eventually.

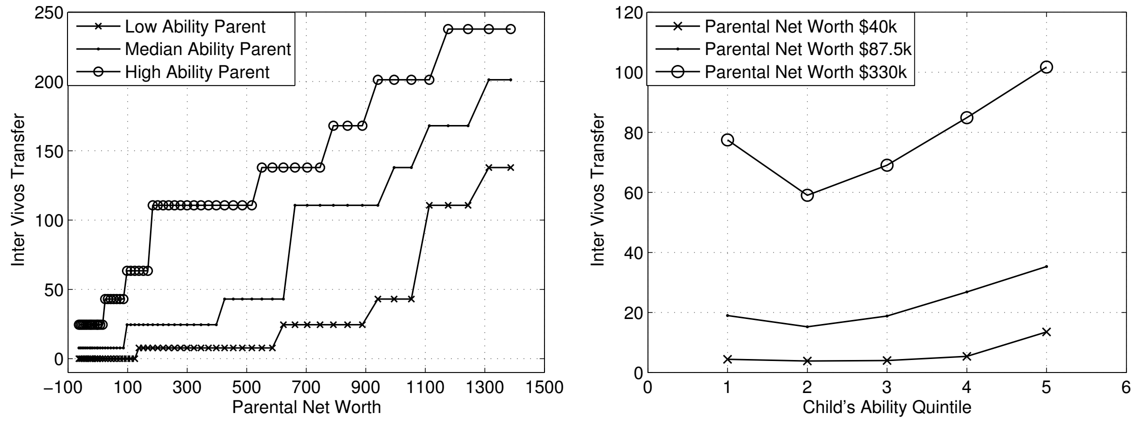

Figure 2: Parental transfers to children as a function of: children's ability and parental wealth (left panel); parental wealth and parent's ability (right panel).

4.3 Intergenerational Persistence of Education and Income

The model generates a realistic intergenerational correlation of college attainment. In the model 46.4% of those whose mother is a college graduate become college graduates themselves. Furthermore, 54.4% of those for whom both parents are college graduates become college graduates themselves. Although these statistics are not targeted in the estimation, we do well in replicating patterns observed in data. For example, in the NLSY79 47.2% of children whose mother is a college graduate also attain a college degree, while 55.3% of those for whom both parents are college graduates attain a college degree.

The model is able to replicate these high degrees of persistence in part because it includes non-cognitive traits and paternalism. Non-cognitive skills are important because parental education leads to improvements in these skills, which in turn reduces the psychic costs of college for children of educated parents. Paternalism increases the tendency for rich parents to 'send' their child to college, and hence it augments one's probability of attending college if parents are educated.

We also evaluate model performance in terms of intergenerational income persistence. Chetty et al. (2014) use IRS tax data to study the relationship between the mean child income rank and parents' income rank for cohorts of children born between 1971-1986, and estimate a linear regression slope between 0.25 and 0.35 for male children, depending on the birth year. We repeat this exercise on

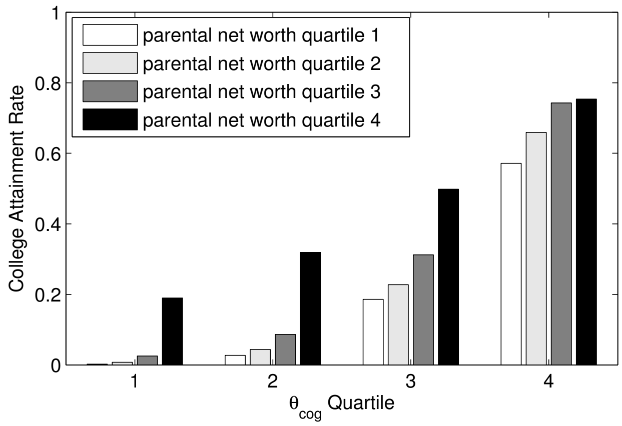

Figure 3: College attainment rate by cognitive ability and parental wealth: model simulations

our simulated data, with the same definition of pre-tax household income averaged over ages 31-46 for both children and parents, and find a slope of 0.315, thus in line with the empirical value.[35]

4.4 Parental Wealth and Educational Achievement

To examine the relative roles of family background and cognitive ability in the determination of education outcomes, we plot a bar graph that displays college graduation rates by ability quartile and parental net worth quartile in the model. Figure 3 shows a positive gradient in both dimensions, a feature that is very similar to the findings of Belley and Lochner (2007).

One striking feature of this plot is the much larger role played by parental wealth for low ability children compared to high ability ones. Most high ability children graduate from college regardless of parental wealth. However, among low ability children, those from the richest families attend college disproportionately more. Paternalism plays a key role in generating this pattern in the model: only wealthy parents can send children with low returns to college. Rich parents have a small marginal value of wealth and indulge in paternalistic utility (through conditional inter-vivos transfers), rather than saving those resources for own consumption.

[35]The more traditional intergenerational correlation measure in our simulated sample is 0.32. Jantti et al. (2006) estimate for the US is 0.36, and similar values are found by Solon (1999).

4.5 Tuition Elasticity of College Attainment

The simulated response of aggregate college attainment to a small change in tuition fees is also similar to responses measured in actual data. To measure this response in our model we perform a partial equilibrium simulation in which we reduce tuition fees by $1,000 per year just before a single cohort of children make their education decisions.[36] The aggregate graduation rate of this cohort increases by 3.5 percentage points (3.8 for men and 3.2 for women).

This response is broadly consistent with existing empirical evidence. Kane (2003) and Deming and Dynarski (1995) provide a synopsis of the empirical estimates from similar quasi-natural experiments in which a discrete change in aid policy affects one group of individuals but not others, and conclude that enrollment into college by high-school graduates benefitting from an additional tuition grant of $1,000 rises between 3 and 5 percentage points.[37] Other studies use cross-state variation in tuition costs to estimate that enrollment would rise by 4 to 6 percentage points per $1,000 reduction in tuition costs (Cameron and Heckman, 1998; Kane, 1994).

5 Policy Experiments

In this section we conduct two sets of policy experiments. The first is aimed at assessing the role of the *existing* federal financial aid system —loans and grants— while the second examines the effects of *marginal expansions* in financial aid.[38]

We are especially interested in the long-run general equilibrium (GE) effects of these policies. Long-run policy responses can be attributed to three major adjustments: (i) the response of the equi-

[36] In this experiment, the policy is announced to parents and children after the IVT. When we announce the subsidy before the IVT, and hence we allow for a limited behavioral response from parents in that period, the rise in attainment is just below 3 percentage points because the subsidy partially crowds out parental transfers.

[37] Among the policy changes surveyed in these studies, the closest to our simulated experiment are the Georgia Hope Scholarship program, the Social Security Student Benefit program, the Washington DC Tuition Assistance Grant program, the Cal Grant program, and other similar examples of discontinuities in fellowship eligibility at individual institutions.

[38] In all policy experiments we assume that college fees do not change and financial markets do not offer new or modified loan products.

librium distributions of education attainment and wealth accumulation, which affect factor prices; (ii) the endogenous response of alternative private sources of funding (student labor supply and, especially, parental transfers) that can mitigate the effect of policy changes; and (iii) budget balancing adjustments made by the fiscal authority, which will impact distortions in the economy.

We present our results in two steps. The first step (PE Short-run) computes changes in outcomes of interest for the first affected cohort, holding prices and fiscal variables constant. The policy announcement is made just before parents choose their inter vivos transfer, hence this experiment incorporates only the short-run behavioral response of parents (e.g. transfers) and children (e.g. labor supply in college) to the policy. We then consider an experiment in which GE adjustments take place and compute the long run steady-state with new market clearing prices and the new stationary distribution of individuals across education, wealth, and ability. Government expenditures G are held constant in this experiment, thus adjustments of marginal labor income tax rates are required to balance the government's budget. Note that it is not obvious whether expanding (cutting) federal aid programs will require a higher (lower) tax rate on labour. For example, broadening these programs can be self-financing through a wider tax base, particularly with imperfectly substitutable human capital aggregates (see Findeisen and Sachs (2015) for a discussion of these issues).

A key aspect of the results from our GE experiments is the analysis of welfare changes induced by the policy reform. We express these changes as a percentage of lifetime consumption for a newborn economic agent (an individual at age $j = 0$) behind the veil of ignorance with respect to her initial conditions (wealth and ability). To understand what drives the total welfare effect, we decompose it into three separate components: (i) a "level" effect on average consumption; (ii) an "uncertainty" effect due to changes in the volatility of individual consumption paths; and (iii) an "inequality" effect due to changes in the distribution of initial conditions. In Appendix H we provide a derivation of this welfare decomposition that builds on Benabou (2002).

5.1 Value of Existing Federal Aid Programs

In this section we explore how equilibrium outcomes would change in the model if federal aid programs were entirely removed from our benchmark representing the US economy. Key results are shown in Table 7. A variety of additional results are reported in Appendix I. Moreover, in Appendix J we assess the robustness of the grant and loan removal experiments under fixed interest rates, and for different values of the elasticity between human capital aggregates.

Removing Tuition Grants. Removing tuition grants induces a noticeable reduction in college attainment in the long-run. The loss of college students is partly mitigated by equilibrium price adjustments. As shown in the top panel (A) of Table 7, attainment in the short-run PE scenario would be 6.5 percentage points lower. In GE this scarcity effect puts upward pressure on the college premium which, in turn, induces a compensating rise in college graduation rates. The final long-run GE drop in college attainment is around 4 percentage points, still a sizable magnitude.

This drop in attainment comes about with significant alterations in the composition of the college student body. Skill quality is lower and family wealth becomes more important for college selection, as some able children from poorer families no longer find it feasible and/or optimal to attend college: college attainment in the lowest wealth tercile drops from 0.2 to 0.08.

Students are forced to gather additional resources through an increase in their labor supply while in college. The long-run increase of 4.5% in labor supply, together with the fact that students earn on average $10,000 a year through market work, means that almost 1/3 of the lost grants (average grant size is $1,500) is replaced by additional labor earnings.[39]

Parental transfers are marginally higher in PE, as families make up for the unexpected loss of government grants but become, on average, substantially lower in GE due to the lower lifetime wealth of parents in the counterfactual economy where output suffers a drop of almost 2 percent. It is only

[39] In our model we do not allow for potential disruptions to schooling effort associated with working while in college. See Garriga and Keightley (2015) for a model where time devoted to work competes with time needed to cumulate credits in college.

Panel A: Removal of Grants				
		Benchmark	P.E. Short-run	G.E. Long-run
College Graduation Rates	Men	0.294	0.242	0.271
	Women	0.282	0.201	0.222
	Men - top 1/3 of cognitive skills	0.695	0.590	0.556
	Women - top 1/3 of cognitive skills	0.577	0.411	0.414
	Total - top 1/3 of parental wealth	0.414	0.373	0.482
	Total - bottom 1/3 of parental wealth	0.205	0.132	0.082
Other Statistics	Crowding out of IVTs - Male	–	+$596	-$2,723
	Crowding out of IVTs - Female	–	+$253	-$3,157
	Student labor supply	–	+13.4%	+4.47%
	Aggregate output	–	–	-1.95%
	Welfare gain	–	–	-0.68%

Panel B: Removal of Student Loans				
		Benchmark	P.E. Short-run	G.E. Long-run
College Graduation Rates	Men	0.294	0.233	0.257
	Women	0.282	0.179	0.235
	Men - top 1/3 of cognitive skills	0.695	0.548	0.497
	Women - top 1/3 of cognitive skills	0.577	0.366	0.367
	Total - top 1/3 of parental wealth	0.414	0.363	0.576
	Total - bottom 1/3 of parental wealth	0.205	0.112	0.033
Other Statistics	Crowding out of IVTs - Male	–	+$2,837	+$3,740
	Crowding out of IVTs - Female	–	+$2,099	+$2,199
	Student labor supply	–	+38.3%	+5.84%
	Aggregate output	–	–	-2.95%
	Welfare gain	–	–	-0.65%

Table 7: Removal of Existing Federal Aid Programs from the Benchmark Economy

wealth-poor families that increase transfers to children in order to compensate for the loss of grants: Table I.3 shows that this crowding in ($3,100) offsets 1/4 of the loss in grants ($2,800 per year) for type $q = 1$ families whose children attend college both in the pre- and in the post-reform economy. Overall, many low-income students who counted on grants to reduce tuition fees now have to resort more extensively to loans: among college students, debt increases by 10%. However, students from wealthy backgrounds *increase* their college participation relative to the baseline: returns to education have risen and these students are in the best position to take advantage of this. The most evident consequence of this decline in quality and quantity of college students is in terms of productive efficiency of the economy: output falls by nearly 2 percent permanently.

One notable aspect of the results in panel (A) of Table 7 is the differential effect of the policy change on men and women: the drop in female college attainment is three times as large as for men. Gender-bias in altruism partly accounts for the differences between men and women, as it results in a larger GE drop in transfers for female children, and relatively less resources available for them to finance college education. We also observe that, while college attainment falls a lot more for women, the gender gap among college graduates widens further. This follows from the fact that our estimates of labor shares imply that $s^{m,CL} > s^{f,CL}$ in the production aggregator (4). Thus, even though the fall in quality-adjusted female college labor input is larger than for its male counterpart, the final impact on its marginal product is smaller.

The total ex-ante welfare loss in consumption equivalent units is sizable, almost -0.7%. The welfare losses due to a lower average level of consumption and more unequal initial conditions are equal to -0.8% and -0.7% respectively (see appendix Table I.2). As explained, in this economy average productivity suffers from lower schooling levels and worse sorting of children by ability. Inequality in initial conditions deteriorates for two reasons. One is that grants provide a substantial source of insurance "behind the veil of ignorance" against lower than average draws on parental characteristics. The second is the change in relative prices: the rise in the college premium redistributes against low-income low-ability individuals who do not enroll in college.

However, there is a surprisingly large offsetting welfare effect ($+0.8\%$) due to a reduction in average volatility of consumption in the population. This counteracting force arises because the wage processes of non-college workers (now more numerous) display considerably less uncertainty than those of college educated workers. This is particularly evident for the initial variance of the productivity shock, which is the most difficult component to insure because it affects young workers with low savings or in debt: as shown in Table 3, the dispersion of the initial productivity draws is much smaller for non-college workers.[40]

Removing Federal Loans. When federal loans are removed, college attainment drops by 8 percentage points in PE. This strong response suggests that, in spite of the large crowding-in of inter vivos transfers (which increase by $2,500 on average), in the short run many families are unable or unwilling to make up for the elimination of the loans available to college students, and so their children are no longer able to finance education.

In GE, the overall drop in the college graduation rate is somewhat muted because of the price adjustment, but also because of the substantial increase in families' saving: faced with the harmful removal of a large source of college financing, families devote more resources to saving for college despite being, on average, poorer in the new equilibrium (aggregate income falls by 3 percent). This is in sharp contrast to the response of families in the case of grants' removal, where transfers declined in the new equilibrium since students could still resort to more borrowing. The size of the federal loans program is such that those families who cannot count on private credit (type $q = 1, 2$) are compelled to save more to send their children to college. Table I.21 shows that inter vivos transfers in households whose children enroll in college increase by $11,000 for $q = 1$ families and by $19,000 for $q = 2$ families, vis-a-vis a reduction of $23,000 in borrowing capacity. This behavior represents a crowding in of 50 percent for the wealth-poor and over 80 percent for middle-class households.

There is, again, a significant worsening of selection on ability and on family wealth, which is

[40] Table 3 also shows that the persistence of the shocks is higher for college-graduates, making self-insurance harder.

even more substantial than that occurring after removing grants, suggesting that many highly skilled people rely on existing federal loans to finance college. The drop in college attainment of children in the bottom tercile of the wealth distribution —from 20 to 3 percent— is staggering. The total welfare loss from dismantling the federal loan program is of the same magnitude as the loss from removing all federal tuition grants but, interestingly, the offsetting uncertainty and inequality components of welfare are each twice as large (Table I.20).

Removing both Federal Grants and Loans. Removing the entire existing structure of financial aid results in qualitative patterns that are very similar to what we find after removing either grants or loans. However, cumulative effects are larger than simply adding the outcomes of the two separate experiments. College attainment in the long run drops by 5.5 percentage points and it becomes much less sensitive to ability and much more sensitive to parental wealth. College attendance in the top terciles of cognitive and non cognitive ability almost halves. Moreover, college attainment rates among the bottom two terciles of parental wealth —which averages 22.5 percent in the economy with federal aid— drops to 2.5 percent once the programs are scrapped. Table I.9 shows that those few wealth-poor families who send their children to college —the families with the smartest children who would gain very high returns from college— can do so only through a major saving effort that increases their transfer by nearly $25,000, or 75 percent of the combined value of the lost grants and credit availability.

Reinforcing patterns emerge through the intergenerational transmission of skills. First, when the fraction of college educated women declines, average non cognitive skills also fall. This effect, though, is modest: cumulative psychic costs of going to college rise on average by 1 percent. Second, when the average cognitive ability of women who go to college falls, so does the cognitive ability of their children. Thus, college educated families who have the financial means to afford to pay for college education, in the new equilibrium have children with lower returns to college.

Aggregate output falls by 4.5 percentage points. Ex-ante welfare drops by almost 2 percentage points. As we show in Appendix I, welfare is lower because of large losses in the average level of consumption (the level effect) and amplified differentials in initial conditions (the inequality effect). Notably, the average labor income tax increases by 1 percentage point: the same amount of expenditures G must be financed through a smaller tax base. Appendix tables I.7 through I.9 document these findings in detail.

5.2 Expansion of Loans Program: An Upper Bound

In this section, we argue that the value of marginal expansions of the current federal student loans program is rather small. In order to make this point, we compute the long-run equilibrium of an economy where the government does not offer any student loan but where, at the same time, there is no ad-hoc credit constraint with the exception of the "natural borrowing limit" implying that all liabilities —financed at the prevailing equilibrium rate r^{-}— must be extinguished upon retirement. With a slight abuse of language, we call this the "unconstrained" economy. The aim of this exercise is to compute an upper bound for the gains that the Federal student loan program can achieve, if expanded over and above its current configuration.[41]

Table 8 shows that, in the long-run equilibrium of the unconstrained economy, college attainment is just 1 percentage point higher. The sorting on ability improves significantly only for women from poor households who suffer from the combination of scarce family resources and adverse gender-bias in parental altruism. This is the only group for whom additional borrowing capacity appears to significantly change education decisions. Conditional on going to college, the financing mix of education changes: private debt replaces parental transfers and earnings from part-time work of college students, the latter crowding out being substantial.

In sum though, in this 'unconstrained economy' aggregate output and ex-ante welfare are only 1 and 0.4 percentage points higher, respectively, relative to the benchmark. This suggests that the

[41]To zoom in purely on loans, we maintain all other government interventions in the economy, including tuition subsidies, at their benchmark values.

"Unconstrained" Economy			
		Benchmark	G.E. Long-run
	Men	0.294	0.303
College	Women	0.282	0.292
Graduation	Men - top 1/3 of cognitive skills	0.695	0.708
Rates	Women - top 1/3 of cognitive skills	0.577	0.644
	Total - top 1/3 of parental wealth	0.414	0.362
	Total - bottom 1/3 of parental wealth	0.205	0.288
	Crowding out of IVTs - Male	–	-$3,932
Other	Crowding out of IVTs - Female	–	-$3,774
Statistics	Student labor supply	–	-33.7%
	Aggregate output	–	+1.16%
	Welfare gain	–	+0.42%

Table 8: Counterfactual Economy with Loose Private Credit Limits and without any Federal Student Loan Programs.

yield from marginal expansions of the federal loan program is, arguably, quite modest. More detailed results from this experiment are reported in Appendix I.

5.3 Expansion of Grants Program

Next, we turn our attention to how expansion of the existing federal grants program would affect equilibrium outcomes. We consider three possible ways to expand the current system of tuition subsidies. The first approach is to simply increase by $1,000 per year the amount by which every college graduate's education is subsidized. Of course, in GE any additional net costs from this expansion must be paid for; we choose to adjust labor income tax rates to this end.

Our second approach strengthens the progressiveness of the existing federal grants program by increasing grants proportionally. The result of this means-tested expansion is that poorer ($q = 1$) students benefit the most and richer ($q = 3$) students the least in absolute value. The proportional increase we implement is 52%, chosen so that the immediate (PE) cost to the government equals that of the general $1,000 per year expansion.

Finally, we implement an ability tested grant expansion, where increased funding is proportional to cognitive skills. Here grants are increased above their benchmark values according to a linear function of cognitive skills, of the form $1.55 \times \theta_{cog}$. This rule implies that the median ability child receives an extra $800 per year in grants, and that a student in the top decile of ability is entitled to an additional $700 in grants compared to a peer in the bottom decile. Once again, the short-run fiscal costs of this policy reform are the same as in the general grant expansion. Table 9 summarizes the results of these three experiments.

Qualitatively, all three experiments feature the same pattern: the college graduation rate increases in the long run. Sorting on ability rises and sorting on wealth falls. Overall, the larger and better stock of college graduates produces improvements in equilibrium output and welfare. Grants crowd-out inter vivos transfers and student labor supply. Transfers fall, on average, by 30 cents and student earnings by 40 cents, for each additional dollar of transfer. Both of these crowding-out effects on alternative sources of funding mitigate the effect of the policy.

A means-tested grant expansion generates larger gains in welfare (+0.4%) and output (+0.66%) than a general grant expansion. The greater benefits accrue because of better sorting into education by ability. The means-tested program is more successful than a general expansion because it is more effective in directing funding to financially constrained high-ability people. For the same reason, the ability-tested grant expansion is the least effective. Many high ability children have wealthy parents and are thus inframarginal with respect to the education decision, i.e. they would choose to graduate from college even in the absence of additional funding. Moreover, even those high ability children who don't come from rich families will have high potential returns and hence will be inframarginal as long as their family is not very poor. Detailed results for these experiments are reported in Appendix Tables I.16 to I.18.

Optimal Grant Size. We also explore the optimal size of means-tested grants, with labor income taxes adjusting to finance the optimal program. An expansion of 95% in the average size of tuition grants, i.e. nearly doubling the benchmark size (from $2,800 to $5,500 a year for poor families

Panel (A): General Tuition Grant Expansion ($1,000)

		Benchmark	P.E. Short-run	G.E. Long-run
College Graduation	Men	0.294	0.334	0.320
	Women	0.282	0.311	0.293
	Top 1/3 of cognitive skills	0.637	0.671	0.647
	Top 1/3 of parental wealth	0.414	0.437	0.401
	Bottom 1/3 of parental wealth	0.205	0.241	0.239
Other Statistics	Crowding out of IVTs	–	-$1,247	-$1,353
	Student labor supply	–	-6.05%	-3.22%
	Aggregate output	–	–	+0.46%
	Welfare gain	–	–	+0.32%

Panel (B): Means-tested Grant Expansion (52%)

		Benchmark	P.E. Short-run	G.E. Long-run
College Graduation	Men	0.294	0.332	0.325
	Women	0.282	0.314	0.297
	Top 1/3 of cognitive skills	0.637	0.654	0.659
	Top 1/3 of parental wealth	0.414	0.415	0.379
	Bottom 1/3 of parental wealth	0.205	0.253	0.283
Other Statistics	Crowding out of IVTs	–	-$183	-$791
	Student labor supply	–	-8.53%	-5.17%
	Aggregate output	–	–	+0.66%
	Welfare gain	–	–	+0.40%

Panel (C): Merit-based Grant Expansion ($1.55 \times \theta_{cog}$)

		Benchmark	P.E. Short-run	G.E. Long-run
College Graduation	Men	0.294	0.316	0.303
	Women	0.282	0.307	0.296
	Top 1/3 of cognitive skills	0.637	0.673	0.681
	Top 1/3 of parental wealth	0.414	0.419	0.399
	Bottom 1/3 of parental wealth	0.205	0.237	0.237
Other Statistics	Crowding out of IVTs	–	-$1,272	-$1,619
	Student labor supply	–	-7.53%	-3.90%
	Aggregate output	–	–	+0.57%
	Welfare gain	–	–	+0.31%

Table 9: Three Types of Expansions of the Federal Tuition Grant Program with the same Short-Run Budget Costs

Distribution of Welfare Changes			
	θ_{cog} tercile		
	1	2	3
$q = 1$	0.71%	2.91%	5.57%
$q = 2$	-5.22%	-5.43%	-2.19%
$q = 3$	-7.64%	-4.90%	-2.14%

Table 10: Distribution of Welfare Effects in the Optimal Means-tested Grant Expansion.

of type $q = 1$), while leaving unchanged the relative magnitude of subsidies awarded to students with different family resources, generates the greatest long-run gains in ex-ante welfare (+0.7 %) and output (+0.8 %). Larger and smaller grants are suboptimal.

Table 10 shows that this average welfare gain hides a great deal of heterogeneity across types. High-income, low-ability individuals lose almost the equivalent of 7.6% of lifetime consumption from the policy because they hardly benefit from grants, but taxes rise to finance the additional outlays and the college premium falls in equilibrium. Low-income, high-ability individuals are big-time winners. Within this group, girls obtain a welfare gain of nearly 8%, more than twice the gain for boys from the same family background. As a result of this policy, average ability of female college graduates increases by 15 percent.

6 Discussion

The design of education finance programs is an issue at the top of the policy and research agenda. How valuable are existing tuition grant and student loan programs? How large are the potential gains from expanding these programs further? And, does the impact of such interventions crucially depend on the time horizon over which they are evaluated? Our policy experiments offer new insights into all these questions.

Starting from the last question, we corroborate results by Heckman et al. (1998b,c), Lee (2005), and Lee and Wolpin (2006) and show that adjustments in relative wages, between gender and education groups, are the key reason why the consequences of policy might differ substantially in the long-run and in the short-run. This insight remains true even in a richer model, like ours, where vast heterogeneity in non-cognitive ability and associated psychic costs of schooling implies that many individuals are inframarginal in their college attendance decision. We find that, throughout all experiments, changes in college attainment in the long-run GE of the economy are roughly half the size compared to the short-run PE case where offsetting changes in the equilibrium distribution have not fully played out. As the previous literature suggests, price adjustments imply that aggregate effects are mitigated. However, we also find non trivial composition and selection effects of policies and we carefully quantify the associated welfare implications. In particular, we document how welfare changes are intimately related to sorting on ability and wealth.

Turning to the first two questions, we find that scrapping the federal aid system currently in place would significantly deteriorate productivity and welfare by reducing the aggregate stock of human capital through both the quantity margin (fewer college students) and the quality margin (fewer high-ability students from poor families). At the same time we show that, starting from the existing student loan and grant programs, further program expansions would yield small gains on average for the population at large. We do identify, though, sizable welfare gains from more generous loan limits and tuition subsidies for certain demographic groups: high-ability girls from low-income households reach almost double-digit welfare gains under some policy scenarios. Part of the reason is that our estimates suggest a certain degree of gender-bias in parental altruism against daughters who, as a result, receive smaller transfers and have a harder time affording a college education. This result is a clear indication that there are still individuals who are prevented from attending college because of liquidity constraints, potentially justifying additional targeted interventions.

Our welfare decomposition identifies three separate sources of welfare changes from policy reforms that increase college attainment and improve sorting by making attendance depend more on skills and less on parental wealth: (i) improvements in aggregate output due to a higher stock of human capital; (ii) reduced inequality in initial conditions due to a redistribution of income occurring through a shrinking relative price of college-educated labor; (iii) increased volatility of consumption due to a compositional change of the labor force towards college graduates who, according to our estimates, face higher income uncertainty. This third component can, surprisingly, offset up to one half of the sum of welfare effects from the first two sources mitigating the total ex-ante welfare gains.

Finally, throughout our study we have highlighted two key margins of adjustment that are not typically considered in the traditional policy evaluation literature. The first channel is the adjustment of funding by parents, which is a sizable source of support for college. The second channel is students' labor supply. Both margins respond to policy interventions. We find that an additional dollar in grants provided by the government crowds out, on average, 30 cents of private parental transfers in the long-run equilibrium. There is, however, substantial heterogeneity in crowding-out effects. More generous grants displace transfers in different proportions depending on family resources, with the transfers made by wealthy families being generally crowded out the most. This finding implies that means-tested grant expansions are more effective because they crowd out parental transfers to a lesser extent than expansions of aid across the board. Also student labor supply is sensitive to policy. Across experiments, an extra dollar in grants crowds out another 40 cents in labor earnings by students in college. Accounting for the existing patchwork of policies, adjustments in these alternative means of privately funding education replace/displace around 70 cents of every dollar subtracted/added to federal grants. This result suggests that policy evaluations that omit these joint adjustment margins might be misleading.

7 Conclusions

The capacity of people to optimally invest in education is crucial for economic prosperity and social mobility, and is an important determinant of the income distribution (see Becker and Tomes, 1979; Loury, 1981). In the presence of insurance and credit market imperfections that prevent those individuals with the highest returns to education from investing in schooling, education policies can improve allocations and welfare.

In this paper, we have offered a quantitative assessment of the role played by the existing system of financial aid to college. We did so in a general-equilibrium life-cycle model of the US economy that features: (i) intergenerational linkages through altruism and paternalism, and intergenerational transmission of abilities that is affected by parental education and is, hence, endogenous; (ii) non-pecuniary psychic costs of education that depend on cognitive and non-cognitive abilities; (iii) various means of financing the pecuniary cost of education —over and above what is offered by the government— such as parental transfers, private borrowing, and labor supply in college; (iv) idiosyncratic uninsurable earnings risk that makes education an investment with uncertain outcome; (v) imperfect substitution between gender and education groups in production, which leads to redistributive implications of education policies through relative prices.

Our bottom line is that the current configuration of federal loans and grant programs has substantial value in terms of both output and welfare, whereas further expansions of these programs can only marginally improve aggregate outcomes. An important caveat, though, is that for certain demographic groups —in particular, high-ability girls from poor families—- gains from targeted interventions can be sizable.

Our model is rich and realistic in many dimensions. At the same time, its computational complexity forced us to abstract from a number of additional aspects that might influence policy evaluation.

We modeled the endogeneity of the distribution of abilities by assuming that a child's ability depends on parental education in a mechanical way. A parallel line of research (e.g., Caucutt and Lochner, 2012; Cunha and Heckman, 2007; Cunha et al., 2010; Heckman and Mosso, 2014) stresses the importance of complementarities between college-age policies and interventions that release parental constraints in the critical phase of early skill accumulation. Explicitly modelling sequential human capital investments at different stages of a child's life would flesh out the extent to which early interventions may improve the effectiveness of tertiary education policies.

Another interesting generalization would account for heterogeneity in college types (e.g. Fu, 2014) allowing for the endogenous determination of returns based on demand and supply of different college types, thereby recognizing that more able and richer students are, in equilibrium, matched with better colleges. This complementarity may strengthen the role of financial aid policies that improve sorting.

Recent work (see Ionescu and Simpson, 2016; Lochner and Monje-Naranjo, 2011) has emphasized the expansion of private provision of student credit. Nesting endogenous borrowing constraints within an equilibrium framework, similar to the one developed in this paper, would allow for explicit co-determination of all credit and skill prices. Such a model, while significantly more complex, could answer interesting questions about how the price of borrowing in private markets would endogenously respond to education policy reforms.

In all our counterfactual policy experiments we kept the configuration of all other fiscal policies unchanged. As emphasized by Krueger and Ludwig (2016), there is a certain degree of substitutability between progressive taxation and education subsidies: both policies induce some redistribution, the former through fiscal instruments, the latter through relative prices of different types of labor. An implication of this observation to bear in mind when interpreting our findings is therefore that they are *conditional* on the prevailing degree of progressivity of the tax/transfer system, but major tax reforms could significantly affect the landscape of effective education policies.

Finally, in one of our experiments we computed the allocations of a counterfactual economy without any credit constraint that would impede education investments, and we assessed the scope for additional gains from expanding federal student loans. We find that such gains are arguably small. An alternative, but much more challenging, approach to quantify the maximum gains from education policies, relative to the status quo, would be to directly compute the constrained-efficient allocations chosen by a planner facing the same market structure as the individuals in the decentralized equilibrium.

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ONLINE APPENDIX

A Value Functions and Competitive Equilibrium

A.1 Working Households

The value function for a married couple in periods before and after making transfers to their children is given by

$$\begin{aligned} W_j(a_j, z_j^f, z_j^m, \boldsymbol{\theta}^f, \boldsymbol{\theta}^m, e^f, e^m) &= \max_{c_j^m, c_j^f, \ell_j^m, \ell_j^f, a_{j+1}} \Big\{ u_j\left(c_j^m, c_j^f, \ell_j^f, \ell_j^m\right) \\ & \quad + \beta \mathbb{E}_{z^f, z^m}[W_{j+1}(a_{j+1}, z_{j+1}^f, z_{j+1}^m, \boldsymbol{\theta}^f, \boldsymbol{\theta}^m, e^f, e^m)] \Big\} \\ & \quad s.t. \\ (1+\tau_c)c_j + a_{j+1} &= + \sum_{g \in \{f,m\}} (1-\tau_w)\, w^{g,e} \varepsilon_j^{g,e}\left(\boldsymbol{\theta}^g, z_j^g\right)\left(1-\ell_j^g\right) \\ & \quad + \psi + [1 + r(1-\tau_k)]\, a_j \\ c_j &= [(c_j^m)^{\tilde{\rho}} + (c_j^f)^{\tilde{\rho}}]^{\frac{1}{\tilde{\rho}}} \\ a_{j+1} &\geq -\underline{a}^e, \quad c_j \geq 0, \quad \ell_j^g \in [0,1] \\ z_{j+1}^g &\sim \Gamma_z^{g,e^g}\left(z_{j+1}^g \mid z_j^g\right). \end{aligned} \tag{A1}$$

The main differences between this decision problem and that in equation (7) are that (i) two sources of labor supply are available to the family, and (ii) the economies of scale in consumption are present. With a slight abuse of notation we have used r for both the interest rate on saving and the one on borrowing ($r^- = r + \iota$ in the main text).

A.2 Inter Vivos Transfers

In section 2.3 we describe the decision problem of a household in the period when parents choose transfers to their children. Formally, in the period of the inter vivos transfer, parents solve the following problem:

$$
\begin{aligned}
W_j(a_j, z_j^f, z_j^m, \boldsymbol{\theta}^f, \boldsymbol{\theta}^m, e^f, e^m; \hat{g}, \hat{\theta}, \hat{\kappa}_\epsilon) \quad &= \quad \max_{c_j^m, c_j^f, \ell_j^m, \ell_j^f, \hat{a}_0, \hat{a}^{CL}, a_{j+1}} \Big\{ u_j(c_j^m, c_j^f, \ell_j^m, \ell_j^f) \\
& \quad + \beta \mathbb{E}_{z^f, z^m} \Big[W_{j+1}(a_{j+1}, z_{j+1}^f, z_{j+1}^m, \boldsymbol{\theta}^f, \boldsymbol{\theta}^m, e^f, e^m) \Big] \\
& \quad + 2\omega_{\hat{g}} V_0^*(\hat{\mathbf{a}}, \hat{g}, \hat{\boldsymbol{\theta}}, \hat{q}, \hat{\kappa}_\epsilon) + 2\xi \cdot \mathbf{1}_{\{\hat{e}=CL\}} \Big\} \\
& \quad s.t. \\
(1+\tau_c)c_j + a_{j+1} + 2\hat{a} + 2\frac{\hat{a}^{CL}}{1+r} \quad &= \quad + \sum_{g \in \{f,m\}} (1-\tau_w)\, w^{g,e} \varepsilon_j^{g,e} \left(\boldsymbol{\theta}^g, z_j^g \right) \left(1 - \ell_j^g \right) \\
& \quad + \psi + [1 + r(1-\tau_k)]\, a_j \\
c_j \quad &= \quad [(c_j^m)^{\tilde{\rho}} + (c_j^f)^{\tilde{\rho}}]^{\frac{1}{\tilde{\rho}}} \\
a_{j+1} \geq -\underline{a}, \quad \hat{a}_0 \quad &\geq 0, \quad \hat{a}^{CL} \geq 0, \quad c_j \geq 0, \quad \ell_j^g \in [0,1] \\
z_{j+1}^g \quad &\sim \quad \Gamma_z^{g,e^g} \left(z_{j+1}^g \mid z_j^g \right) \\
\hat{\theta}_{cog} \quad &\sim \quad \Gamma_{\theta_{cog}} \left(\hat{\theta}_{cog} | \theta_{cog}^f \right), \quad \hat{\theta}_{non} \sim \Gamma_{\theta_{non}} \left(\hat{\theta}_{non} | \hat{\theta}_{cog}, e^f \right) \\
\hat{q} \quad &= \quad \begin{cases} 1 & \text{if } a_j \leq a^* \text{ and } \max\left\{ w^{m,e}\varepsilon_j^{m,e}, w^{f,e}\varepsilon_j^{f,e} \right\} \leq w^* \\ 2 & \text{if } a_j \leq a^* \text{ and } \max\left\{ w^{m,e}\varepsilon_j^{m,e}, w^{f,e}\varepsilon_j^{f,e} \right\} > w^* \\ 2 & \text{if } a^* < a_j \leq a^{**} \\ 3 & \text{if } a_j > a^{**} \end{cases}
\end{aligned} \tag{A2}
$$

where w^* is the wage rate such that one would earn the model equivalent of \$85,000 if they worked 35% of their time endowment. This then stipulates that the higher earning parent would earn less than \$85,000 if they work fulltime (35% of their time endowment) in order for $q = 1$ to occur.

A.3 Retired Households

From period j^{RET} onwards couples enter the retirement stage, in which they solve the following problem:

$$
\begin{aligned}
W_j^R(a_j, e^f, e^m) &= \max_{c_j^m, c_j^f, a_{j+1}} \left\{ u\left(c_j^m, c_j^f, 1, 1\right) + \beta \zeta_{j+1} W_{j+1}^R(a_{j+1}, e^f, e^m) \right\} \qquad \text{(A3)} \\
& \quad s.t. \\
(1+\tau_c) c_j + a_{j+1} &= p(e^f) + p(e^m) + \psi + \zeta_{j+1}^{-1}[1 + r(1-\tau_k)] a_j \\
c_j &= [(c_j^m)^{\tilde{\rho}} + (c_j^f)^{\tilde{\rho}}]^{\frac{1}{\tilde{\rho}}} \\
a_{j+1} &\geq 0, \quad c_j \geq 0.
\end{aligned}
$$

Pension income $p(e^g)$ is dependent on education, as outlined above. The inflation of assets by ζ_{j+1}^{-1} reflects the perfect annuity markets assumption.

A.4 Stationary Recursive Competitive Equilibrium

It is useful to introduce some additional notation to simplify the definition of an equilibrium. Let $\mathbf{s}_j^g \in S_j^g$ denote the age-specific state vector of an unmarried individual of gender g in the recursive representation of the agents' problems in Section 2.2 of the paper. For an unmarried individual we also define $\mathbf{s}_j^{g,e} \in S_j^{g,e}$ to be the state vector conditional on the gender and education level (the current school cycle for students). For married couples we instead define the state-vector of the whole family, including shared assets as well as gender-specific productivity shocks, abilities and education attainments. We define such extended state vector as $\tilde{\mathbf{s}}_j \in \tilde{S}_j$. Just like we did for single individuals, we also define a state vector conditional on the gender and education of a spouse as $\tilde{\mathbf{s}}_j^{g,e} \in \tilde{S}_j^{g,e}$. For married individuals one needs to distinguish between the education of the partners, and we do so by referring to the gender specific education level e^g. Finally, we define the vector of measures over Borel sigma-algebras defined over those state spaces as $\boldsymbol{\mu} = \left\{\mu_j^g, \mu_j^{g,e}, \tilde{\mu}_j, \tilde{\mu}_j^{g,e}\right\}$.

A *stationary recursive competitive equilibrium* for this economy is a collection of: (i) decision rules of unmarried individuals for education $\left\{d^{HS}\left(\mathbf{s}_0^g\right), d^{CL}\left(\mathbf{s}_1^g\right)\right\}$, consumption, leisure, wealth holdings, and student debt $\left\{c_j\left(\mathbf{s}_j^g\right), \ell_j\left(\mathbf{s}_j^g\right), a_{j+1}\left(\mathbf{s}_j^g\right), b_{j+1}\left(\mathbf{s}_j^{g,CL}\right)\right\}$, decision rules of married households $\left\{c_j^m\left(\tilde{\mathbf{s}}_j\right), c_j^f\left(\tilde{\mathbf{s}}_j\right), \ell_j^m\left(\tilde{\mathbf{s}}_j\right), \ell_j^f\left(\tilde{\mathbf{s}}_j\right), a_{j+1}\left(\tilde{\mathbf{s}}_j\right)\right\}$, inter vivos transfers $\left\{\hat{a}_0\left(\tilde{\mathbf{s}}_{j^{TR}}\right), \hat{a}^{CL}\left(\tilde{\mathbf{s}}_{j^{TR}}\right)\right\}$; (ii) value functions $\left\{V_j\left(\mathbf{s}_j^g\right), V_j^e\left(\mathbf{s}_j^g\right), W_j\left(\tilde{\mathbf{s}}_j\right), W_j^R\left(\tilde{\mathbf{s}}_j\right)\right\}$; (iii) aggregate capital and labor inputs $\left\{K, H^{f,LH}, H^{f,HS}, H^{f,CL}, H^{m,LH}, H^{m,HS}, H^{m,CL}\right\}$; (iv) prices $\left\{r, w^{f,LH}, w^{f,HS}, w^{f,CL}, w^{m,LH}, w^{m,HS}, w^{m,CL}\right\}$;

(v) labor income tax $\{\tau_w\}$; (vi) a vector of measures $\boldsymbol{\mu}$, such that:

1. The decision rules of singles and couples solve their respective household problems, and $\left\{V_j\left(\mathbf{s}_j^g\right), V_j^e\left(\mathbf{s}_j^g\right), W$ are the associated value functions.

2. The representative firm optimally chooses factors of productions, and input prices equate their marginal products,

$$r+\delta = F_K\left(K,\mathcal{H}\right) \tag{A4}$$

$$w^{g,e} = F_{H^{g,e}}\left(K,\mathcal{H}\right), \text{ for } e \in \{LH, HS, CL\}, \text{ and } g \in \{f,m\}.$$

3. The labor market for each gender and education level clears

$$H^{g,e} = \sum_{j=j^e+1}^{j^{CL}} \int_{S_j^{g,e}} \varepsilon^{g,e}\left[1-\ell\left(g,e,\mathbf{s}_j^{g,e}\right)\right] d\mu_j^{g,e} + \sum_{j=j^{CL}+1}^{j^{RET}-1} \int_{\tilde{S}_j^{g,e}} \varepsilon^{g,e}\left[1-\ell^g\left(g,e^g,\tilde{\mathbf{s}}_j^{g,e}\right)\right] d\tilde{\mu}_j^{g,e} +$$
$$\mathbb{I}_{\{e=HS\}} \cdot \sum_{j=j^{HS}+1}^{j^{CL}} \int_{S_j^{g,HS}} \varepsilon^{g,HS}\left[1-\bar{t}-\ell\left(g,HS,\mathbf{s}_j^{g,HS}\right)\right] d\mu_j^{g,HS}$$

where the first term in the sum is the effective labour supply of singles and the second term is the effective labour supply of married. The third term in the sum only enters the calculation of HS human capital stocks, and accounts for the effective labor supply of college students who supply HS-equivalent labour until they graduate college.

4. The asset market clears

$$K = \sum_{j=0}^{j^{CL}} \sum_{g\in\{f,m\}} \int_{S_j^g} a_j\left(\mathbf{s}_j^g\right) d\mu_j^g + \sum_{j=j^{CL}+1}^{J} \int_{\tilde{S}_j} a_j\left(\tilde{\mathbf{s}}_j\right) d\tilde{\mu}_j.$$

The aggregate net worth of all households (married and singles) equals the capital stock.

5. The goods market clears

$$\sum_{j=0}^{j^{CL}} \sum_{g\in\{f,m\}} \int_{S_j^g} c_j\left(\mathbf{s}_j^g\right) d\mu_j^g + \sum_{j=j^{CL}+1}^{J} \sum_{g\in\{f,m\}} \int_{\tilde{S}_j} c_j\left(\tilde{\mathbf{s}}_j\right) d\tilde{\mu}_j + \delta K + G + \Phi + \Upsilon = F\left(K,\mathcal{H}\right)$$

where c is the CES aggregator of the spouses' consumption, and Φ is the aggregate amount of private expenditures in educational services by college students

$$\Phi = \sum_{j=j^{HS}+1}^{j^{CL}} \sum_{g\in\{f,m\}} \phi \int_{S_j^{g,CL}} d\mu_j^{g,CL}$$

and Υ is the value of the services provided by the financial intermediation sector, which consists of the aggregation of all intermediation costs on private student loans and on credit extended to the working age population.

6. The government budget constraint holds

$$G + \sum_{j=j^{WK}+1}^{J} \int_{\tilde{S}_j} (p(e^f) + p(e^m))d\tilde{\mu}_j + \psi + E = \tau_c \sum_{j=1}^{j^{CL}} \sum_{g\in\{f,m\}} \int_{S_j^g} c_j\left(\mathbf{s}_j^g\right) d\mu_j^g + \\ + \tau_c \sum_{j=j^{CL}+1}^{J} \int_{\tilde{S}_j^g} c_j\left(\tilde{\mathbf{s}}_j\right) d\tilde{\mu}_j + \tau_w \sum_e w^e H^e + \tau_k r K.$$

In the LHS of the government budget, E are net government expenditures in financial aid:

$$\begin{aligned} E &= \sum_{j=j^{HS}+1}^{j^{CL}} \sum_{g\in\{f,m\}} \int_{S_j^{g,CL}} \left[\mathfrak{g}\left(q,\theta\right) - \Delta b_j\left(s_j\right)\right] d\mu_j^{g,CL} + \left(\iota + \iota^u\right) \sum_{j=j^{HS}+1}^{j^{CL}} \sum_{g\in\{f,m\}} \int_{S_j^{g,CL}} b_j d\mu_j^{g,CL} \\ &- r^u \sum_{j=j^{HS}+1}^{j^{CL}} \sum_{g\in\{f,m\}} \int_{S_j^{g,CL}} \left[\mathbb{I}_{\{q=1, b_j<-\underline{b}^s\}} \cdot (b_j + \underline{b}^s) + \mathbb{I}_{\{q=2\}} \cdot b_j\right] d\mu_j^{g,CL} \\ &- \sum_{g\in\{f,m\}} \int_{\tilde{S}_{j^{CL}+1}^{g,CL}} \mathbb{I}_{\{q<3,\tilde{a}<0\}} \tilde{a}_{j^{CL}+1} d\mu_{j^{CL}+1}^{g,CL}. \end{aligned}$$

Government outlays (first row) are determined by grants $\mathfrak{g}$, plus the total amount of loans extended to college students, equal to the sum of the Δb_j increments each period, plus the intermediation cost incurred on these loans. Revenues (second and third rows) are determined by: (i) interest on unsubsidized loans during college and, (ii) debt repayments after graduation. As summarized in equation (15), $\tilde{a}_{j^{CL}+1}$ is net assets based on $a_{j^{CL}+1}$, $b_{j^{CL}+1}$ and q. For those with student debt $\tilde{a}_{j^{CL}+1}$ is the present value of all payments made on student loans, depending on the amount borrowed and applicable interest rates. Student debt is refinanced into a single bond whose face value is $\tilde{a}_{j^{CL}+1}$ and equals the present value of future student debt liabilities. Therefore, repayments of student loans are the sum of all negative $\tilde{a}_{j^{CL}+1}$ by college graduates who draw government loans (i.e. those with $q < 3$).

7. Individual and aggregate behaviors are consistent: the vector of measures $\boldsymbol{\mu}$ is the fixed point of $\boldsymbol{\mu}(S) = Q(S, \boldsymbol{\mu})$ where (i) $Q(S, \cdot)$ is a transition function generated by the individual decision rules, the exogenous laws of motion $\left\{\varGamma_{\theta_{cog}}, \varGamma_{\theta_{non}}, \varGamma_{z}^{g,e}\right\}$, exogenous matching probabilities, the institutional rules determining federal aid eligibility q, and the survival rates $\left\{\zeta_j\right\}$; (ii) and S is the generic subset of the Borel-sigma algebra defined over the state space.

A.5 Computation of Equilibrium

This section describes the solution method for our long-run GE economy. The usual nested fixed point approach is extended in order to accommodate the novel features of our model. That is, the essence of our approach is to guess a set of prices and taxes, compute decision rules (given prices and taxes) to simulate the economy, and finally verify whether those are the stationary equilibrium prices and taxes. To accommodate endogenous inter vivos transfers we must also begin with guesses of the decision rules of age zero agents and the initial distribution of wealth.

Specifically, we execute the following steps:

1. Make an initial guess for the wage vector, $\tilde{\mathbf{w}}$, and the real interest rate, $\tilde{r}$. Also make an initial guess for the age zero consumption decision rule, $\tilde{c}_0$, and the initial distribution of wealth $\tilde{\mathbf{a}}_0$. In the policy experiments, an initial guess for the labor tax rate is also required.

2. Solve the household dynamic programming problem described in main text at the prices $\tilde{\mathbf{w}}$ and $\tilde{r}$. This is a finite horizon problem easily solved by backward induction using Euler equation methods. At the age inter vivos transfers are given, the intergenerational Euler equation requires the optimal consumption decision of the age 0 child. The guess $\tilde{c}_0$ is used here. The solution yields optimal decision rules for education, take-up of student loans, consumption, leisure, private saving/borrowing, and inter vivos transfers. We solve the age-specific problems at 96 asset grid points. We make the problem feasible by solving with *Fortran MPI* using one processing core per asset grid point.

3. Simulate the life-cycles of 38,400 men and 38,400 women (400 per processing core) who start with initial wealths given by $\tilde{\mathbf{a}}_0$. Each of the simulated agents is exogenously matched with another agent with opposite gender in the sample who represents her/his spouse and, at the age

of the IVT, to two new agents who represent their children. The education levels of the spouses in these matches are generated by the $Q^{g,e}$ functions described in the main text. Similarly, the abilities of parents and children in these matches are consistent with the intergenerational transition matrices for cognitive and non-cognitive ability. Importantly, these matches are fixed across iterations so that the inter vivos transfer given by the parent in the match converges to the initial wealth of the child in the match.

4. This step consists of four sub-steps:

   (i) Aggregate the decisions of the simulated agents to check market clearing conditions and update prices appropriately.

   (ii) Compare simulated inter vivos transfers to $\tilde{\mathbf{a}}_0$ and update appropriately.

   (iii) Compare the age zero consumption rule to $\tilde{c}_0$ and update appropriately.

   (iv) If computing a policy experiment, update the labor tax rate appropriately in case the government budget constraint is not satisfied.

5. If updates were required in any of sub-steps (i)-(iii) of step (4) (i-iv for an experiment), return to step (2) and proceed with the updated guesses. Otherwise, exit because a fixed point of the algorithm has been achieved.

Once the fixed point has been attained, simulated data from the economy can be used to compute the various moments of interest.

B Aggregate Technology Parameters

For the estimation of the aggregate technology parameters we use data from the Current Population Survey (CPS) for 1968-2001 (see Heckman et al., 1998a). The sample includes the adult universe (i.e., the population of marriageable age, with all individuals aged 15 and over unless they have missing or zero earnings, or missing educational attainment information)[42]. We compute total wage bills in billions of dollars for the three education groups, as well as for their subsets by gender. Dividing the relevant wage bill by the (normalized) marginal product of human capital estimated from PSID data (see discussion in Appendix C below), we obtain point estimates of total efficiency-weighted labor

[42] Since earnings data are top-coded in the CPS, we extrapolate the average of the top-coded values by using a tail approximation based on a Pareto distribution. Polivka (2000) provides evidence that this method closely approximates the average of the top-coded tails by validating the fitted data through undisclosed and confidential non top-coded data available only at the BLS.

supply (human capital aggregates) by education, gender and year. Because of the well documented relative demand shifts over the period considered, we let share parameters vary over time. For example $s_t^e = \exp(s_0^e + g^e t)$, where t denotes calendar year and g^e captures the growth rate in each human capital share of type e. Shares are normalized to sum to one at every t.

We proceed sequentially. First, we estimate the parameters governing gender aggregation within education groups. Then, we use these estimates to derive education-specific stocks and estimate the parameters governing education aggregation.

Gender-specific parameters. For each given education group, we use variation in the gender-specific wage bills ($\varpi_t^{f,e}$) over time to estimate the elasticity between labor input from different genders. Taking first-order conditions, and the $\log$ of both sides, we arrive at:

$$\log\left(\frac{\varpi_t^{f,e}}{\varpi_t^{m,e}}\right) = \log\left(\frac{s_t^{f,e}}{s_t^{m,e}}\right) + \chi\log\left(\frac{H_t^{f,e}}{H_t^{m,e}}\right), \tag{B1}$$

an equation that holds for all education groups e. Recall that $\chi \in (-\infty, 1]$.

Under the null hypothesis that the elasticity parameter χ does not vary across education groups, we have three independent equations which can be jointly estimated and, then, used to test the iso-elasticity assumption. We estimate a specification based on time differences of the equation (B1) above. This specification identifies the elasticity from changes over time in the ratios of wage bills and of human capital stocks of each education-gender group.

We control for endogeneity of these human capital stocks by using various sets of instruments. First, we use instruments based on different sets of lags of human capital aggregates. Next, we verify robustness of the results using, either as a replacement or in addition, instruments corresponding to the stock of men and women with a given education in a given year. The total number of people with a given education level, whether working or not, is a slow moving stock and therefore independent of the autocorrelated component in the right hand side variables. The estimation procedure is based on a stacking method which allows one to test for differences in the elasticity of substitution across different types of labor (like in a Chow test). The results are reported in Table B.1. Panel (A) reports point estimates of the substitutability parameter, panel (B) reports different tests of the iso-elasticity hypothesis, which cannot be rejected.

The estimated 'education-conditional' elasticity of substitution between gender-specific aggregates ranges between 1.2 and 1.9. In numerical simulations, the gender weights for different education groups are set to the values estimated for the year 1999. Female shares are, respectively, $s^{f,LH} = 0.34$, $s^{f,HS} = 0.40$ and $s^{f,CL} = 0.38$.

Education-specific parameters. After aggregating gender-specific stocks of human capital using equation (4), a similar procedure can be applied to estimate the elasticity of substitution between the three education-specific human capital aggregates. From aggregator (3) and the equilibrium condition in the labor market, we derive expressions for the wage bills ϖ_t^e. For education groups HS and CL, for example, we write,

$$\log\left(\frac{\varpi_t^{CL}}{\varpi_t^{HS}}\right) = \log\left(\frac{s_t^{CL}}{s_t^{HS}}\right) + \rho\log\left(\frac{H_t^{CL}}{H_t^{HS}}\right) \tag{B2}$$

We estimate the elasticity of substitution among labor inputs using the empirical counterparts of pair-wise ratios like the one in equation $(B2)$. Also in this case we estimate a specification based on first-differences of equation $(B2)$. We control for possible endogeneity of human capital inputs in the production function through an IV approach. We experiment with different sets of instruments. First, we use lagged regressors (lags up to 5 periods back are included in the first step, depending on the specification). Alternatively, and as a robustness check, we also instrument using the total number of people in each education group in a given year, including those people not working. This latter instrument, being a stock, is independent of the serial correlation properties of the technology shock.

Table B.2 reports results for the estimation of the ρ elasticity parameters. Panel (A) reports results obtained by using, as instruments, lags of human capital or education 'headcounts' or both. Panel (B) reports tests of the null hypothesis of iso-elasticity for the different specifications (more specifications and tests are available from the authors. Results are fairly robust.) Overall, all specifications give rather similar results and we are unable to reject the null hypothesis that the aggregate technology is iso-elastic at the 5% level of significance. The restricted model with a unique ρ improves the efficiency of the estimator, which is particularly valuable since we are using a relatively short time series (approximately 30 observations).

The estimated value for ρ ranges between 0.68 and 0.98. In the simulations we use $\rho = 0.7$. This corresponds to an elasticity of substitution of 3.3, which is within the range of our estimates and consistent with values discussed in the literature. The estimated values for the education weights used in the simulations are $s^{LH} = 0.16$, $s^{HS} = 0.38$, $s^{CL} = 0.46$, which are those for the year 1999.

	Panel (A): Estimation				
	Specification				
	(1)	(2)	(3)	(4)	(5)
First stage IV	Up to 3 lags	Up to 4 lags	Edu.stock (L)	Edu.stock (G)	4 Lags,Edu.stock (L+G)
Number of obs.	75	72	84	84	72
	Coefficient	Coefficient	Coefficient	Coefficient	
	(S.E.)	(S.E.)	(S.E.)	(S.E.)	(S.E.)
$\chi^{f,m\|LH}$	.06	.14	-.10	.44	.19
	(.12)	(.10)	(.39)	(.18)	(.08)
$\chi^{f,m\|HS}$	.62	.51	.23	.56	.50
	(.27)	(.21)	(.46)	(.40)	(.18)
$\chi^{f,m\|CG}$	.39	.73	.55	.58	.51
	(.47)	(.35)	(.45)	(.68)	(.23)
$\chi^{f,m\|LH,HS,CG}$	.17	.25	.19	.47	.26
	(.11)	(.09)	(.23)	(.16)	(.07)

	Panel (B): Hypothesis Testing				
	Specification				
	(1)	(2)	(3)	(4)	(5)
First stage IV	Up to 3 lags	Up to 4 lags	Edu.stock (L)	Edu.stock (G)	4 Lags,Edu.stock (L+G)
Null Hypothesis	F-stat.	F-stat.	F-stat.	F-stat.	F-stat.
$\chi^{f,m\|LH} = \chi^{f,m\|HS}$	$F_{(1,69)} = 3.58$	$F_{(1,66)} = 2.48$	$F_{(1,78)} = .31$	$F_{(1,78)} = .07$	$F_{(1,66)} = 1.88$
	$Pr. > F = .06$	$Pr. > F = .12$	$Pr. > F = .58$	$Pr. > F = .80$	$Pr. > F = .18$
$\chi^{f,m\|HS} = \chi^{f,m\|CG}$	$F_{(1,69)} = 0.18$	$F_{(1,66)} = 0.27$	$F_{(1,78)} = .23$	$F_{(1,78)} = .00$	$F_{(1,66)} = .02$
	$Pr. > F = .67$	$Pr. > F = .61$	$Pr. > F = .63$	$Pr. > F = .97$	$Pr. > F = .90$
$\chi^{f,m\|LH} = \chi^{f,m\|CG}$	$F_{(1,69)} = 0.46$	$F_{(1,66)} = 2.50$	$F_{(1,78)} = 1.17$	$F_{(1,78)} = .04$	$F_{(1,66)} = 1.63$
	$Pr. > F = .50$	$Pr. > F = .12$	$Pr. > F = .28$	$Pr. > F = .85$	$Pr. > F = .21$
$\chi^{f,m\|LH} = \chi^{f,m\|HS} = \chi^{f,m\|CG}$	$F_{(1,69)} = 1.91$	$F_{(2,66)} = 2.23$	$F_{(2,78)} = .59$	$F_{(2,78)} = .05$	$F_{(2,66)} = 1.57$
	$Pr. > F = .16$	$Pr. > F = .12$	$Pr. > F = .56$	$Pr. > F = .95$	$Pr. > F = .22$

Table B.1: Panel (A): Estimates of χ for various specifications. χ^{e_1,e_2} denotes the parameter determining the elasticity of substitution between genders g_1 and g_2 estimated with the corresponding wage-bill ratio equation. $\chi^{f,m|CL,HS,LH}$ denotes the estimate from the restricted (iso-elastic) model. Labels (L) and (G) indicate whether the stock of people with given education enters in Level or Growth rate in the estimated equation. (B): Tests for equality of elasticities of substitution among labor inputs. P-values are reported below the F-statistic.

Panel (A): Estimation

	Specification				
	(1)	(2)	(3)	(4)	(5)
First stage IV	Up to 3 lags	Up to 4 lags	Edu.stock(L)	Edu.stock(G)	3 Lags,Edu.stock(L+G)
Number of obs.	78	75	84	84	78
	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)
$\rho^{HS,LH}$	.40	.70	4.69	2.10	.73
	(.72)	(.37)	(13.27)	(1.72)	(.29)
$\rho^{CL,HS}$	.26	.58	.33	.27	.51
	(1.05)	(1.02)	(2.60)	(1.17)	(.46)
$\rho^{CL,LH}$	1.93	1.59	1.04	1.04	.99
	(1.17)	(.88)	(1.40)	(.64)	(.27)
$\rho^{CL,HS,LH}$	.68	.81	.91	0.98	.75
	(.31)	(.24)	(.33)	(.34)	(.13)

Panel (B): Hypothesis Testing

	Specification				
	(1)	(2)	(3)	(4)	(5)
First stage IV	Up to 3 lags	Up to 4 lags	Edu.stock (L)	Edu.stock (G)	3 Lags,Edu.stock (L+G)
Null Hypothesis	F-stat.	F-stat.	F-stat.	F-stat.	F-stat.
$\rho^{HS,LH} = \rho^{CL,HS}$	$F_{(1,72)} = .01$	$F_{(1,69)} = .01$	$F_{(1,78)} = .10$	$F_{(1,78)} = .78$	$F_{(1,72)} = .16$
	$Pr. > F = .92$	$Pr. > F = .91$	$Pr. > F = .75$	$Pr. > F = .38$	$Pr. > F = .69$
$\rho^{CL,HS} = \rho^{CL,LH}$	$F_{(1,72)} = 1.12$	$F_{(1,69)} = .57$	$F_{(1,78)} = .06$	$F_{(1,78)} = .34$	$F_{(1,72)} = .78$
	$Pr. > F = .29$	$Pr. > F = .45$	$Pr. > F = .81$	$Pr. > F = .56$	$Pr. > F = .38$
$\rho^{HS,LH} = \rho^{CL,LH}$	$F_{(1,72)} = 1.25$	$F_{(1,69)} = .88$	$F_{(1,78)} = .07$	$F_{(1,78)} = .33$	$F_{(1,72)} = .41$
	$Pr. > F = .27$	$Pr. > F = .35$	$Pr. > F = .79$	$Pr. > F = .57$	$Pr. > F = .52$
$\rho^{CL,LH} = \rho^{CL,HS} = \rho^{HS,LH}$	$F_{(2,72)} = .73$	$F_{(2,69)} = .47$	$F_{(2,78)} = .07$	$F_{(2,78)} = .40$	$F_{(2,72)} = .46$
	$Pr. > F = .49$	$Pr. > F = .63$	$Pr. > F = .93$	$Pr. > F = .67$	$Pr. > F = .64$

Table B.2: Panel (A): Estimates of ρ for various specifications. ρ^{e_1,e_2} denotes the parameter determining the elasticity of substitution between groups e_1 and e_2 estimated with the corresponding wage-bill ratio equation. $\rho^{CL,HS,LH}$ denotes the estimate from the restricted (iso-elastic) model. Labels (L) and (G) indicate whether the education stock enters in Level or Growth rate in the estimated equation. (B): Tests for equality of elasticities of substitution among labor inputs. P-values are reported below the F-statistic.

C Individual Productivity Dynamics

Wage-age profiles from the PSID: The Panel Study of Income Dynamics (PSID) is a longitudinal survey of the US population. We use data for the waves from 1968 to 2011 (referring to calendar years 1967 to 2010). Since 1997 the PSID has become biannual. We follow closely the sampling criteria of Meghir and Pistaferri (2006) but consider both heads and spouses in the SRC sample, which was originally nationally representative, so we use no sample weights in the calculations. By selecting both heads and spouses we are able to separately estimate all relevant parameters separately for men and women.[43] After excluding the SEO sample, and observations with no reported gender or marital status, our sample of heads and spouses includes 5,044 individuals (2,350 men and 2,694 women). We keep only people with 8 or more (possibly non continuous) individual-year observations, and we eliminate individuals with outliers in earnings growth, defined as changes in log-earnings larger than 4 or less than -2, which reduces the sample to 3,748 individuals (1,684 men and 2,064 women).

The wage variable we use for our calculations is the hourly earnings (total labor income divided by total hours worked) for the head of the household expressed in 1992 dollars by deflating nominal wages through the CPI-U for all urban consumers.[44] Information on the highest grade completed is used to allocate individuals to three education groups: high school drop-outs, high school graduates, and college graduates.

Quadratic age polynomials are separately estimated for men and women, by education group. We only use observations between ages 22 and 65. We don't use self-employment observations and include dummies for year and state. For women we also control for marital status and we use a Heckman-selection estimator to correct for observation bias in employment: more specifically, we construct Inverse Mills ratios by estimating a participation equation which exploits variation in unearned family income, net of transfers, to identify transitions into and out of market employment.[45] In Table C.1 we present the point estimates for different education groups.

Price of labor inputs from PSID: Once we filter out age effects from hourly wages for all education/gender groups, we construct first-differences in logs. This also filters out ability, since it enters linearly in the log-wage equation. Performing this estimation in first differences is essential because the average ability by education and gender group is not constant over time due to composition

[43]In the PSID the head of the household is generally a male whenever there is a cohabiting male/female couple. However if the husband or boyfriend is incapacitated and unable to fulfill the functions of Head, then the FU will have a female Head. We identify 642 such cases in which the married head of household is a female.

[44]The earnings variable includes the labor part of both farm and business income, wages, bonuses, overtime, commissions, professional practice and others.

[45]The unearned income instruments appear to do a good job of identifying selection into employment, being highly significant in all first stage regressions. The Inverse Mills ratios all have the expected sign (results available from the authors).

	Dependent variable: Log hourly wages, men		
	Less than HS	**HS Graduate**	**College Graduate**
Age	.040936	.0673272	.1197059
	(.0045)	(.0016467)	(.0023598)
Age^2	-.000397	-.0006699	-.0011914
	(.0000514)	(.0000197)	(.0000285)
	Dependent variable: Log hourly wages, women		
	Less than HS	**HS Graduate**	**College Graduate**
Age	.0295213	.033165	.0794265
	(.0055355)	(.0019255)	(.0027072)
Age^2	-.0002874	-.0003267	-.000845
	(.0000633)	(.0000232)	(.0000332)

Table C.1: Estimated age polynomials' coefficients (PSID). S.E. in parenthesis.

changes within the group. Therefore, we can easily estimate through time dummies the time series of price growth in each education/gender group, i.e., the term $\Delta \log w_t^{g,e}$. Given a normalization one can recover spot prices year by year.[46]

Wage-ability gradient from NLSY: Ability is approximated by the AFQT89. We use the NLSY79 to estimate the effect of ability on wages. To overcome the problem that the NLSY provides observations only for workers between age 14 and 45, we use wage data from the PSID 1968-2011 to estimate age polynomials for different education groups. After the age profiles have been used to filter out age effects from the log wage observations in the NLSY79 –and assuming, as in the model, that any residual unobserved error term is uncorrelated with θ_{cog}– we can identify the loading factors by running simple regressions. For each education group $e \in \{LH, HS, CL\}$ an OLS regression of log individual wages on time dummies and on log AFQT89 scores (as a proxy for θ_{cog}) was fit in order to recover $\lambda^{g,e}$ (see equation C1). We use specifications with time dummies to control for time variation in market wages, but estimates are almost identical to those obtained without time dummies. We also include dummies to control for marital status and number of children.[47] For hourly wages, we use the wage variable corresponding to the hourly rate of pay on the current or most recent job

[46] We use a normalization based on the relative hourly wages observed in our PSID sample in 1989. First we compute average wages by education group for 1989, and next we correct for ability composition using information from the NLSY79 (AFQT test scores distribution together with their education-specific gradient on wages). We choose 1989 because people from the NLSY79 are between age 23 and 31, which means most of them are already working. Additional details on the normalization and the ability adjustment are available upon request.

[47] To check robustness we run specifications based on wages which are not purged of the estimated PSID age-effects: again, results based on these measures are similar to those obtained for the age-free wages reported below.

(the so-called CPS job), available only from 1979 to 1994. We start with the 11,878 individuals for which we have AFQT89 scores. We drop individuals for which we cannot observe the highest grade completed, which brings the sample to 11,844 individuals. Next, we drop observations for which the wage is missing, ending up with 11,222 individuals. We drop those observations with annual work hours missing or larger than 5,840: this reduces the sample to 11,207 individuals. Dropping individuals who report (at least once) hourly wages above $400 or below $1 further reduces the sample to 10,625. We also eliminate individuals who report log wage increases larger than 4 or smaller than -2, which leaves 10,433 workers in the sample. When we split this sample in 3 education groups, we get a HS drop-outs' sample of 1,550 individuals, a HS graduates' sample of 6,940 individuals and a college graduates' sample of 1,943 individuals. [48] Table 2 reports estimates of the ability gradient by education group, and for the pooled sample. All standard errors are corrected for individual clustering. The NLSY contains two additional measures of wages: (i) a variable corresponding to the hourly rate of pay in the first reported job, available only from 1979 to 2002; (ii) a hourly wage rate obtained dividing total earnings by total hours worked in the previous calendar year. The latter variable can be constructed for each wave between 1979 and 2002. The earnings' measure includes wages, salary, commissions or tips from all jobs, before deductions for taxes. The ability gradient estimated from our preferred wage measure is close to the estimated ability gradients estimated using these two alternative definitions of hourly wages. Differences are statistically insignificant and confirm the robustness of the estimated reduced-form ability gradients.

Estimation of error component model for wage residuals: The final step is estimating the parameters of the persistent-transitory shocks model for wage residuals. Wage residuals are obtained from NLSY data purging from individual log wages time dummies, the age component and the ability component, calculated as explained above.

For estimation, we use a Minimum Distance Estimator originally developed by Rothenberg (1971); Chamberlain (1984). In a nutshell, as moments we use the covariances of wage residuals at various lags for different age groups. Table 3 reports the estimates of these parameters obtained for the 15-year period between 1979 and 1993.[49]

The idiosyncratic labor productivity process $\varepsilon_j^{g,e}\left(\theta_{cog}, z_j^g\right)$ for individual i is specified as:

$$\varepsilon_{ij}^{g,e} = \lambda^{g,e} \log \theta_{cog,i} + A^{g,e}(j_{it}) + z_{ijt}^{g,e}, \tag{C1}$$

[48]We use all workers including NLSY79 over-samples in our estimation to maximize the number of observations: a dummy is introduced to control for possible hourly wage differences of workers from the over-samples. Over-sample dummies are mostly not significant. Even when significant they are very small.

[49]More details are available from the authors upon request.

where $A^{g,e}$ is a quadratic age-polynomial, and

$$z_{ijt}^{g,e} = \varrho^{g,e} z_{i,j-1,t-1}^{g,e} + \eta_{ijt}^{g,e}, \qquad \eta_{ijt}^{g,e} \overset{iid}{\sim} N\left(0, \sigma_{\eta t}^{g,e}\right). \tag{C2}$$

Finally, we let the initial draw $z_{i0t}^{g,e} \sim N\left(0, \sigma_{z_0}^{g,e}\right)$. The loading on skills $\lambda^{g,e}$, the persistence of idiosyncratic productivity $\varrho^{g,e}$, and the variance of idiosyncratic productivity innovations $\sigma_{\eta t}^{g,e}$ all vary by gender and education attainment.

Note that by using an observable variable as a proxy for permanent heterogeneity, we avoid selection bias in the estimation of the process for $u_{ijt}^{g,e}$. Moreover, if one estimates wage equations from individual panel data sets, as we do, selection bias attributable to persistent shocks becomes less severe. The issue of selection bias ensuing from persistent shocks is related to the so-called "incidental parameters problem" discussed in Heckman (1981). The severity of the incidental parameters problem becomes smaller as the number of panel observation for each given individual in a sample increases.

D Abilities Distribution and Transmission

Cognitive skills: In our model, cognitive ability θ_{cog} represents a set of permanent characteristics that affect lifetime earnings as well as educational attainment. For the purpose of approximating the distribution of cognitive ability over the population we use data from the 'Children of the NLSY79' survey, which provides test scores of cognitive skills for both mothers and children. We link these scores to build pairs of mother and child test-score measurements and estimate an ability transition matrix.

The 'Children of the NLSY79' survey began in 1986 and has occurred biennially since then. This survey provides detailed information on the development of children born to NLSY79 women. A battery of cognitive, socio-emotional, and physiological assessments are administered to these children at various ages and scores recorded.

There are 11,340 children born to the total 4,890 female respondents of the NLSY79 who are mothers of at least one child. We link the children's file to the main data file using the individual identifier for mothers. Each child has test scores taken in different years. However, many child/year combinations do not have any test score observations. The child test scores reported are the PIAT Math, the PIAT reading comprehension, the PIAT Reading Recognition, and the PPVT score. We use the latest PIAT Math test scores to rank children's ability: in particular, we use standardized scores of the PIAT Math test, which are derived on an age-specific basis from the child's raw score and are comparable across ages. The Peabody Individual Achievement Test (PIAT) is a wide-ranging measure of academic achievement which is well known and used in applied research. For details of the way the PIAT is computed and "normed" by age, see Chapter 2 (page 89 and up) of the "NLSY79 Child and Young Adult Users Guide". In general, the PIAT Math is a highly reliable and valid assessment. As described in the "NLSY Child Handbook:1986-1990" and "The NLSY Children 1992", it correlates closely with other cognitive measures, and it is both predicted by and predicts scores on a variety of the other assessments.

This leaves us with 3,389 mothers and 7,589 mother-child pairs. We restrict our attention only to mothers who are part of the cross-sectional (nationally representative) sample of the NLSY79, which further reduces our mother-child pairs to 4,455 and the total number of mothers to 2,087.

The fact that children took the PIAT test at different ages should have no relevance because we use standard scores which control for the age of the test-subject. In a robustness check we also computed ability transition matrices using a smaller sample including only mother-child pairs for which the child was at least 13 years of age at the time of the test and results were virtually the same.

To measure ability of mothers, we use AFQT scores. During the summer and fall of 1980, NLSY79 respondents participated in an effort of the U.S. Departments of Defense and Military Services to update the norms of the Armed Services Vocational Aptitude Battery (ASVAB). A total of 11,914 civilian and military NLSY79 respondents completed this battery of tests.[50] A composite score derived from selected sections of the battery can be used to construct an approximate and unofficial Armed Forces Qualifications Test score (AFQT) for each youth. The AFQT is a general measure of trainability and a primary criterion of enlistment eligibility for the Armed Forces. Two methods of calculating AFQT scores, developed by the U.S. Department of Defense, have been used by CHRR to create two percentile scores, an AFQT80 and an AFQT89, for each respondent. We use the latter score in our analysis, because it is also the ability measure used in the estimation of the wage equations (see below).

Test-scores are used to assign mothers and children to quintiles, according to their relative ranking in the sample. After splitting mothers and children into these quintiles, we compute the conditional probabilities of transiting from a given mother's quintile to her child's quintile. The estimated ability transition matrix across quintiles is reported in Table 4. For each maternal quintile we report the conditional probability of ending up in that quintile. The matrix implies a great deal of upward and downward mobility in the middle of the distribution, but less so at the top and the bottom, where the

[50]The ASVAB consists of 10 tests that measure knowledge and skill in the following areas: (1) general science; (2) arithmetic reasoning; (3) word knowledge; (4) paragraph comprehension; (5) numerical operations; (6) coding speed; (7) auto and shop information; (8) mathematics knowledge; (9) mechanical comprehension; and (10) electronics information.

diagonal element is larger.

Intergenerational transmission of non-cognitive skills: To parameterize the process by which non-cognitive skills are transmitted we use data from the main NLSY79 sample. Due to data limitations we assume that a child's non-cognitive skills are influenced by parental education, but not directly by parents' non-cognitive skills. Because the NLSY79 contains good measures of a person's cognitive and non-cognitive skills, as well as parental education, this is a feasible approach to measuring non-cognitive persistence.

We employ two measures of non-cognitive skills: the Rotter Scale score and the Pearlin Mastery Scale score. To combine these measures we compute their first principal component factor, which results in a standardized indicator of non-cognitive skills. The parameterization also requires cognitive skills, for which we use the same five bins of AFQT89 scores used in the transmission on cognitive skills, and maternal education, which we attain be classifying maternal education as LH, HS or CL. We have 5,220 complete observations for these three variables. For the simulations we need to know the probability that a child is in a particular non-cognitive skill tercile, conditional on having a given level of cognitive skills and maternal education. Table 5 reports conditional probabilities: the first matrix shows the conditional probabilities of being in non-cognitive bin 1, the second matrix shows the conditional probabilities of being in non-cognitive bin 2, etc. For example, a person whose mother is a high-school dropout and who has the lowest level of cognitive skills has probabilities 0.585, 0.297 and 0.118 of being in non-cognitive skill bins 1, 2, and 3, respectively.

E Inter-vivos Transfers

Our source of information on inter-vivos transfers (i.e., gifts from parents to their children) is the NLSY97. We mostly use measures from the 'Income' subsection of the survey, complemented with information from the College Experience section.[51]

Transfers measured in the Income section refer to *all* income transferred from parents or guardians to youth that are neither loans nor regular allowance. This information is elicited through a series of questions, which also assess whether the individual lives with both, one or none of their parents. Our measure of inter-vivos transfers uses the inter vivos transfer variable from youth who live with both parents, when it is available. When the youth reports not living with both parents we sum

[51] The College Experience section has information about parental transfers earmarked for financial aid while attending a post-secondary academic institution. These transfers are not fully consistent with the information in the 'Income' section, contain many skips and, most importantly, they do not cover all transfers. For this reason we only use limited information from this section and make sure to include it so as to minimize reports' error.

the inter-vivos transfers from both living mother/mother figure and father/father figure.[52] If any of these values are missing (e.g. mother's transfer) then we include only the non-missing value (in this example, father's transfer). Observations which have missing values for all three possibilities to report inter-vivos transfers are dropped from the sample: there are 370 individuals with no usable record of transfers, and they are excluded from the sample.[53]

For youth living at home we also compute the implicit transfer corresponding to the value of rent, which is based on the estimated average rent paid by independent youth of the same age.

We use waves from 1997 to 2003.[54] This gives us an initial sample of 12,686 youths who were between age 12 and 16 in 1997. Only respondents that are part of the cross-sectional (representative) sample are kept, which leaves 6,748 individuals. We compute the cumulative transfers received between ages 16 and 22. When we drop observations for youth below age 16 in 1997, and 13 cases of obvious mis-reporting, we obtain a final sample of 6,346 youth and a total number of observations equal to 21,136. In this final sample, approximately 75% of youth report living in households with at least one (biological or adoptive) parent as guardian.[55] In the final sample from the Income section, one third of observations (32.4%) report positive cash transfers elicited from the relevant survey questions, meaning 67.6% reported not receiving any such transfers. However, when imputed rent is included, 75.1% of observations have positive transfers. The value of imputed rent varies from age to age with a minimum of $4,966 per year for kids aged 16 and a maximum of $6,615 for 22 year old youth.

In the College Experience section questions about financial help from parents are asked for each term in College and refer to transfers specifically provided for school.[56] The sampling restrictions are the same as the ones used for the Income section. Parental aid variables are categorized by year for each respondent, and then summed up to generate an average variable for each year between 1997 and 2003. Given the way questions were designed and asked, the transfers recorded in the College section should be a subset of the transfers recorded in the Income section. However in a large number of cases, especially for students enrolled in 4-year Colleges, the transfer measures in the College section are larger than those in the Income section. Following some correspondence with the BLS,

[52] Those individuals who do not live with a mother/mother figure or a father/father figure, and whose biological mother and father are not alive, are not asked questions on transfers.

[53] Further investigation reveals that these individuals also exhibit missing values for various other variables, and information about them appears incomplete.

[54] Data for 2004 are dropped as there are no comparable inter-vivos amounts available after that year.

[55] In principle, observations should be weighted when tabulating population characteristics. However, as suggested by the BLS, the use of weights is inappropriate in samples generated after dropping observations reporting item non-responses. Nonetheless we also experiment using the BLS custom weighting engine to construct specific weights for our sample, with results changing only marginally. In what follows we use only results from the un-weighted sample.

[56] After one term has been reported, the respondent is asked if the information for the next term has changed from the previous term, and if it has not, the information is not recollected.

	Women		Men	
	Not in College	In College	Not in College	In College
Less than HS	3,021	N/A	3,658	N/A
HS Graduate	3,229	N/A	3,820	N/A
College Graduate	5,499	7,506	5,433	8,203
Average	4,157		4,737	

Table E.1: Yearly inter-vivos transfers by gender and educational attainments, and by current college enrollment status of the child. Amounts are expressed in year 2000 dollars and include allowances.

we concluded that transfer measures from the College section are generally less reliable than those in the Income section. However, it is also possible that respondents included parental payments of tuition fees in the College section transfer (for instance, if the parents paid tuition fees directly and respondents chose not to report such amounts in the Income section).

To calculate inter-vivos transfers, we chose to use both sources of data. More specifically, we use completed schooling by survey year 2009 to classify individuals within three groups: (1) those who have completed a 4-year college degree, and those who are currently enrolled in, or have completed, a graduate degree; (2) those who have completed a high school degree, but are not in group (1); (3) those who have not completed a high school degree.

Table E.1 summarizes the *average* yearly transfer received by girls and boys with different education achievement (as of survey year 2009); in the case of College graduates we distinguish between transfers received while in College and transfers received in other years. For the years of College attendance we approximate the total inter-vivos transfer as the maximum between transfers recorded in the Income section and transfers recorded in the College Experience section.[57]

Using the gender-specific average transfers in Table E.1 we compute the total amount received by youth with less than a College degree over a 7 year period by simply multiplying estimated yearly transfers and allowances by seven (note that all amounts are expressed in year 2000 dollars). In the case of College graduates we compute the total transfer received over 7 years by summing up the average amount received while in College multiplied by four (which is the College duration in the model) and the amount received while out of College multiplied by three.

[57] An alternative way to approximate transfers during College years is to sum the measures from the two sections, rather than taking the higher one. This results in very similar average yearly transfers.

	Institutional Grants		Private Grants		Average Amount
Income	share receiving	Amount	share receiving	Amount	
<$30k	0.36	$4,077	0.12	$2,061	$1,715
$30k-80k	0.34	$5,474	0.16	$2,281	$2,234
>$80k	0.28	$5,383	0.14	$2,338	$1,855

Table F.1: Summary of institutional and private grants data used for the computation of the net tuition fees (NCES)

Looking separately at transfers by gender of the child, this procedure results in a total transfer of $29,096 for women and $33,164 for men. These figures are used to target transfers-by-gender in the benchmark economy. Transfers reported in Table E.1 include allowances.

F Cost of College Attendance, Grants, and Loans

To calculate the price of college attendance and the extent of government aid to higher education financing through grants we focus on the sample of full-time full year (FTFY) students enrolled in public and private not-for-profit 4-year post-secondary institutions. This group of students is the closest counterpart to students in the model. All our statistics refer to the year 2000 and nominal amounts are in 2000 dollars. According to the "Student Financing of Undergraduate Education: 1999-2000" (SFUE, thereafter), a report published by the National Center for Education Statistics (NCES), 65% of these students were enrolled in public colleges and 35% were enrolled in private not-for-profit colleges (Table 1.10).

Cost of college: The cost of college attendance has three components: (i) tuition and fees, (ii) non-tuition expenses that would only be incurred by a college-student, and (iii) institutional and private grants which reduce the cost to families. The publication "Trends in College Pricing, 2000" published by the College Board, reports that average tuition and fees in public institutions in 2000-2001 were $3,510 in public institutions and $16,332 in private ones. We add non-tuition expenses, which includes books and other supplies, amounting to $704 and $730, respectively, in the two types of colleges. We also add an additional $500 to account for any commuting or room and board expenses that would not be incurred by a worker. Average tuition and non-tuition expenses (before grants) amount to $9,210. According to the SFUE, average tuition and fees did not differ by income level of the family in public institutions. In private institutions (where only 1/4 of students are enrolled), average fees were only roughly 20% lower for families whose income was between $20,000-40,000 compared to fees faced

	Federal Grants		State Grants		Average Amount
Income	% receiving	Amount	% receiving	Amount	
<$30k	0.72	$2,753	0.38	$826	$2,820
$30k-80k	0.14	$1,579	0.21	$455	$668
<$80k	0.01	$1,605	0.07	$133	$143

Table F.2: Summary of federal and state grants by family income level (US Department of Education)

by families whose income exceeded $100,000 (Table 2.2-B).

Institutional and private grants are effectively a way to reduce the cost of attendance. Roughly half of these grants are based on pure merit and half are based on need. This fact, together with the negative empirical correlation between family need and students' merit, explains why both the fraction of students receiving grants and their amount is not strongly correlated with family income, as reported in Table F.1 which is based on the SFUE, Table 1.2-G.

To arrive at our estimate of average net tuition ($6,710) we subtract average private and institutional grants from average tuition expenses.

Federal and state grants: Based on the "Guide to U.S. Department of Education Programs" (GDEP thereafter) published by the US Department of Education, we identify three main federal grant programs. The *Federal Pell Grant Program* is the largest single source of grants to undergraduates. It provides need-based grants to individuals to access post-secondary education. It is especially targeted to the lowest-income students. In 2000 it provided $7.3 billion to 3.8 million students, with a maximum grant of $3,125. The *Federal Supplemental Education Opportunity Grant* has a more modest endowment (approximately 15 times smaller). These are grants which supplement the amount received through Pell up to a maximum of $2,100. *Smart Grants* are awarded to needy student who are enrolled in certain technical fields and maintain a cumulative GPA of at least 3.0 in the first year – and so they're partly merit based. The program is approximately as big as the Supplemental Opportunity grant program. State funding is very diverse, but most of the funds available are concentrated in 10 "high-aid" states. Only a very small fraction of state grant awards are merit-based (less that 18%). The fraction of students receiving federal and state grants and their average amount by family income levels (from Table 1.2-G of the SFUE) is summarized in Table F.2.

We use the average amount for these three income levels, and the joint distribution of income and wealth in the model, to calibrate the dependence of the transfers function $\mathfrak{g}(q, \boldsymbol{\theta})$ on assets (through the state variable q). In the baseline experiment, we do not allow $\mathfrak{g}$ to depend on $\boldsymbol{\theta}$. However in one of our policy experiments we consider the introduction of merit-based grants.

Federal loans: While grants are administered by both federal government and states, loans are almost entirely administered by the federal government (less than 1% of the total loan volume is state-based). The largest federal loan program in the US is the *Federal Family Education Loan Program*. The total volume of loans available in 2000 through this program was around $40 billion, extended to around 10 million students. The program includes two main types of loans to students, *Subsidized* and *Unsubsidized Stafford Loans*. A third form of loan offered by the *Federal Family Education Loan Program* are *Parent PLUS loans.* These are loans made to the parents on behalf of a child to help pay for tuition by covering up to the cost of attendance less other aid. Eligibility for the PLUS Loan depends on a credit check and interest rates are similar to those in the private sector. Since this type of loan is equivalent to parents borrowing and then making a transfer to their child, we do not model them explicitly (Johnson, 2010, makes the same modelling choice). The other major source of financial aid for undergraduates, beyond the *Federal Family Education Loan Program,* is the *William D. Ford Federal Direct Loan Program*. This is, in essence, an alternative source of funding for Stafford loans whose total size is roughly half of that available through the *Federal Family Education Loan Program*. Finally, the *Federal Perkins Loan Program* provides low-interest loans to help needy students to finance undergraduate education whose conditions are similar to those of the subsidized Stafford loans. Its total funding is small though, roughly 3% of Stafford loans. Because of their nature, we aggregate these loans with subsidized Stafford loans in our calculations. In light of this discussion, in calibrating the features of the Federal loan program, we focus on (subsidized and unsubsidized) Stafford loans only.

Subsidized Stafford Loans are loans to students who meet a financial needs test (based on family income and assets), with the interest paid by the government on behalf of borrowers while the student is in school. Interest payments after school are subsidized. In 2000, the total cumulative borrowing limit for subsidized loans over the four years of college was $17,125.

Unsubsidized Stafford Loans are loans available to students who either do not meet a financial needs test or do qualify, but need to supplement their subsidized loans. The interest on the unsubsidized Stafford loan cumulates when in school, it is added to the principal, and the student starts repaying her debt after graduation. In 2000, the cumulative unsubsidized Stafford loans limit over the four years of college was $23,000. For those students who do qualify for subsidized loans, $23,000 is the total limit of their Stafford loan (i.e. subsidized plus unsubsidized loans). Therefore we fix the total cumulative (subsidized and unsubsidized) Stafford debt limit $\underline{b}^s + \underline{b}^u$ to $23,000. Repayment plans for Stafford loans typically impose fixed monthly amount for a loan term of up to 10 years. But extended repayment periods can be obtained.

According to the SFUE, among graduating seniors in the year 2000, 62.1% of students had (subsidized or unsubsidized) federal loans (Table 1.3-A). Furthermore, 84.1% of federal loans were at least partly subsidized, implying that 52.5% of students would have subsidized loans (Table 1.6-A).

Private loans: The report "Private Loans and Choice in Financing Higher Education" published by the Institute for Higher Education Policy (2003) contains useful information on private borrowing with the purpose of funding post-secondary education. Available estimates suggest that private loans at that time composed only 12 percent of the total volume of Federal loans (page 9). For many student borrowers, a poor credit rating often is the largest barrier to obtaining a private loan. Less than 1% of private loan products were credit-blind, or available without a credit check (page 15). However, for those who qualify, interest rates on private loans are often more advantageous of those on Stafford Loans (Figure 2.2). In 2000, 8.3% of graduating seniors received private (non-federal) loans (Student Financing of Undergraduate Education: 1999-2000, NCES, Table 1.4A).

Conversion of student loans into private bonds: In the model, we assume that student loans can be converted to private bonds at graduation. However, because higher interest rates apply to student loans, the principal is inflated up the point that the converted debt equals the net present value of student loans liabilities. Because of the fixed payment nature off student loans we can simply apply annuity formulas to derive the inflation factor

$$\text{factor} = \frac{r^u}{1-(1+r^u)^{-10}} \times \frac{1-(1+r^-)^{-10}}{r^-},$$

where a 10 period repayment (20 years) has been assumed. Thus, the equivalent private debt will be the outstanding student loan principal multiplied by the 'factor'. That is, $\tilde{a}_3 = \text{factor} \times \tilde{b}_3$ for federal loans. A similar formula with r^p in place of r^u applies for private student loans.

G Parameter Values

The tables in this appendix list all parameter values for the baseline specification of the model.

Parameter	Value	Description
γ	2.0	Determines intertemporal elasticity of substitution (0.5)
ν_j^m	5.5	Determines avg Frisch elast. of labour supply for men and non-mother women (0.33)
ν_{30-45}^f	5.7	Determines avg Frisch elast. of labour supply for mothers (0.67)
ζ_j	varies	Mortality rates for retired hh based on US Life Tables 2000.
$\underline{a}^{CL}$	1.36	Limits borrowing of CL households to $75,000
$\underline{a}^{HS}$	0.45	Limits borrowing of HS households to $25,000
$\underline{a}^{LH}$	0.27	Limits borrowing of LH households to $15,000
$\underline{b}^s$	0.312	Limits subsidized loans to $17,250 for $q = 1$ students
$\underline{b}$	0.416	Limits total student loans to $23,000 for $q = 1$ and $q = 2$ students.
$\underline{a}^p$	0.416	Limits private loans to $23,000 for $q = 3$ students
$\bar{t}$	0.30	Requires students to study for 30% of time endowment
ι^u	0.053	Interest premium on Stafford loans (0.026 annually)
$\phi(q)$	0.070, 0.109, 0.118	Tuition fees for $q = 1, 2, 3$ students
α	0.35	Capital share of GDP
δ	0.07	Depreciation rate of capital
τ_w	0.27	Labor income tax rate
τ_c	0.05	Consumption tax rate
τ_k	0.40	Capital income tax rate

Table G.1: Externally Set Parameters. Sources listed in the main text. Other externally set parameters whose estimation is discussed in Appendices B,C, and D are: production function, income processes, and transition matrices for cognitive and non-cognitive skills

Parameter	Description	Value	(s.e.)
β	Time discount factor	0.944	(0.006)
ϑ_j^g	Male and non-mother female leisure preference	0.240	(0.004)
ϑ_{30-45}^f	Female with children leisure preference	0.505	(0.005)
ω^m	Altruism towards sons	0.289	(0.008)
ω^f	Altruism towards daughters	0.250	(0.005)
ξ	Paternalistic utility from a child's college going	0.201	(0.041)
a^*	Wealth upper limit for subsidized loans (group q=1)	2.07	(0.202)
a^{**}	Wealth lower limit for private student loans (group q=3)	2.68	(0.499)
ι^p	Interest premium for private student loans	0.048	(0.006)
ι	Basic borrowing wedge that applies to all debt	0.097	(0.010)
ψ	Redistributive transfer	0.44	(0.008)

Moment Matched	Target Value	Model Value
Capital-output ratio	2.0	2.1
Average male labour supply	0.350	0.349
Average labour supply of mothers	0.210	0.211
Average IVT to female child	$29,096	$29,044
Average IVT to male child	$33,164	$33,012
Ratio of college grad. rate in fourth (top) quartile of parental wealth to grad. rate in third quartile	1.63	1.56
HS Fraction of Female Population (cross-section)	0.584	0.584
HS Fraction of Male Population (cross-section)	0.567	0.567
CL Fraction of Female Population (cross-section)	0.282	0.282
CL Fraction of Male Population (cross-section)	0.294	0.294
Fraction of students with subsidized loans	0.525	0.516
Fraction of students with any gov't loans	0.621	0.633
Fraction of students with private loans	0.083	0.086
Fraction of workers with negative net worth	0.077	0.071
Var(log post-tax income)/Var(log pre-tax income)	0.61	0.61

Table G.2: Top Panel: Parameters Estimated by Method of Moments. Bottom Panel: Equal Number of Moments Matched.

		High School Drop-Out Rates (Data)				
		Cognitive quintile				
		1	2	3	4	5
Non-	1	0.535	0.162	0.110	0.008	0.00
Cognitive	2	0.376	0.083	0.038	0.012	0.00
tercile	3	0.198	0.096	0.055	0.005	0.00

		College Graduation Rates (Data)				
		Cognitive quintile				
		1	2	3	4	5
Non-	1	0.022	0.077	0.153	0.303	0.677
Cognitive	2	0.034	0.086	0.212	0.379	0.764
tercile	3	0.034	0.162	0.255	0.473	0.772

Table G.3: Attainment Rates - NLSY97 Data

		High School Drop-Out Rates (Simulated)				
		Cognitive quintile				
		1	2	3	4	5
Non-	1	0.533	0.162	0.079	0.069	0.001
Cognitive	2	0.367	0.094	0.065	0.052	0.000
tercile	3	0.255	0.067	0.034	0.016	0.000

		College Graduation Rates (Simulated)				
		Cognitive quintile				
		1	2	3	4	5
Non-	1	0.087	0.114	0.166	0.298	0.648
Cognitive	2	0.094	0.125	0.177	0.334	0.725
tercile	3	0.106	0.142	0.193	0.399	0.806

Table G.4: Attainment Rates - Model Simulations

H Welfare Decomposition

Let $\mathbf{s}_0 \equiv (g, \hat{\mathbf{a}}, \boldsymbol{\theta}, q, \kappa_\epsilon) \in S_0$ be the vector of initial individual states at age $j = 0$ and μ_0 its stationary equilibrium distribution. Let $V^*(\mathbf{c}, \mathbf{l}; \mathbf{s}_0)$ be expected lifetime utility of an individual with initial states $\mathbf{s}_0$ upon becoming adult, i.e. at the time of its first decision, the HS dropout decision at age $j = 0$. This value, defined in equation (6), takes into account all uncertainty in future adult life with respect to marital matching and income shocks (recall that survival risk is perfectly insured through annuities). The arguments $(\mathbf{c}, \mathbf{l})$ are meant to capture that this value is inclusive of all future utility coming from the random sequences of individual consumption and leisure, consumption and leisure of the spouse after marriage, and consumption and leisure of the offsprings at the time of the inter vivos transfer (because of altruism). Finally, let A and B denote the pre-reform and post-reform economies, respectively.

The total welfare gain from the policy reform (ω_{tot}), expressed as a leisure-compensated consumption equivalent variation, is

$$\int_{S_0} V^*\left(\mathbf{c}^B, \mathbf{l}^B; \mathbf{s}_0\right) d\mu_0^B = \int_{S_0} V^*\left((1+\omega_{tot})\,\mathbf{c}^A, \mathbf{l}^A; \mathbf{s}_0\right) d\mu_0^A. \tag{H1}$$

As discussed by Benabou (2002), this total welfare change of the policy reform, conceptually, can be broken down into three components: (i) a *level* effect of the reform on the level of average consumption, (ii) an *uncertainty* effect on the volatility of the agents' consumption paths that affects welfare because of risk aversion and incomplete markets, and (iii) an *inequality* effect on the equilibrium distribution of initial conditions μ_0. As shown in Floden (2001), if the utility function is homothetic in its arguments, this decomposition is additive. Our utility function does not satisfy this property though, and thus we have to define one of the three components residually.

We start from the computation of the level effect and denote by $V^*\left(C^A, L^A\right)$ the value function V^* in the pre-reform economy A, where each realization of these sequences is replaced by the average consumption and average leisure in the population. Then, the leisure-compensated consumption level differential effect ω_{lev} between the two economies pre and post reform (A, B) can be defined as:

$$V^*\left(C^B, L^B\right) = V^*\left((1+\omega_{lev})\,C^A, L^A\right). \tag{H2}$$

Note that in these values there is no heterogeneity left, meaning that V^* with arguments (C, L) is the same independently of initial conditions, and there is no uncertainty left because the consumption and leisure sequences are constant forever and for everyone (individuals, their spouses, and their offsprings). We label ω_{lev}, the level effect of the policy reform.

Next, we compute certainty equivalent consumption for each type s_0, i.e., we replace the random sequence $\mathbf{c}$ with a constant vector $\bar{c}$ for each s_0 such that:

$$V^*\left(\bar{c}\left(\mathbf{s}_0\right), \mathbf{l}; \mathbf{s}_0\right) = V^*\left(\mathbf{c}, \mathbf{l}; \mathbf{s}_0\right). \tag{H3}$$

This certainty equivalent calculation compensates for consumption uncertainty in individual income and income of the spouse, through risk in marital matching.[58] Next, we calculate the average certainty equivalent consumption in the population in economy $j \in \{A, B\}$:

$$\bar{C}^j = \int_{S_0} \bar{c}\left(\mathbf{s}_0\right) d\mu_0^j$$

And we compute the average welfare cost of uncertainty in our economy as:

$$V^*\left(\bar{C}^j, L^j\right) = V^*\left(\left(1 - p_{unc}\right) C^j, L^j\right).$$

We do it for both economies $j \in \{A, B\}$, and calculate the welfare gain from reduced uncertainty, or the uncertainty effect, of the policy reform as:

$$\omega_{unc} = \frac{1 - p_{unc}^B}{1 - p_{unc}^A} - 1. \tag{H4}$$

In order to obtain an additive decomposition, we then define *residually* the welfare gain from reduced inequality as:

$$\tilde{\omega}_{ine} = \frac{1 + \omega_{tot}}{\left(1 + \omega_{lev}\right)\left(1 + \omega_{unc}\right)} - 1.$$

We also performed an independent check that this residual component is close to its exact counterpart ω_{ine} as follows. Define the cost of inequality in initial conditions in economy j as:

$$\int_{S_0} V^*\left(\bar{c}\left(\mathbf{s}_0\right), L^j; \mathbf{s}_0\right) d\mu_0^j = V^*\left(\left(1 - p_{ine}^j\right) \bar{C}^j, L^j\right). \tag{H5}$$

[58] We follow Floden (2001) and, in the left hand side of $(H3)$ we do not allow individuals to re-optimize their leisure in the counterfactual where we replace their random sequence of consumption with the certainty equivalent value. We have verified that our calculations are robust to this choice.

Note that here we are using the certainty equivalent in the left-hand side of $(H5)$ and therefore the concavity of V^* captures only the reduction in value due to dispersion in $\mathbf{s}_0$ not to uncertainty in the consumption sequences. We do this calculation in both the pre and post reform economy, and define the exact welfare gain of reduced inequality as:

$$\omega_{ine} = \frac{1 - p_{ine}^B}{1 - p_{ine}^A} - 1. \tag{H6}$$

I Policy Experiments

This Appendix reports additional outcomes of all the policy experiments on government financial aid to college students described in Section 5 in the main text.

Removal of Tuition Grants - Panel A (Enrollment)

Group	Benchmark	P.E. Short-run	G.E. Long-run
Male	0.294	0.242	0.271
Female	0.282	0.201	0.222
θ_{cog} tercile 1	0.060	0.054	0.089
θ_{cog} tercile 2	0.169	0.120	0.167
θ_{cog} tercile 3	0.637	0.502	0.485
θ_{non} tercile 1	0.170	0.138	0.159
θ_{non} tercile 2	0.276	0.215	0.243
θ_{non} tercile 3	0.419	0.322	0.339
$q = 1$	0.232	0.142	0.122
$q = 2$	0.410	0.382	0.398
$q = 3$	0.445	0.437	0.590
Inter Vivos Tr. tercile 1	0.147	0.091	0.056
Inter Vivos Tr. tercile 2	0.165	0.116	0.062
Inter Vivos Tr. tercile 3	0.554	0.468	0.623
Parent's Net Worth ter. 1	0.205	0.132	0.082
Parent's Net Worth ter. 2	0.246	0.171	0.176
Parent's Net Worth ter. 3	0.414	0.373	0.482
Parent's Income tercile 1	0.141	0.089	0.057
Parent's Income tercile 2	0.186	0.129	0.096
Parent's Income tercile 3	0.538	0.457	0.588
Mother's Education LH	0.097	0.072	0.092
Mother's Education HS	0.252	0.190	0.217
Mother's Education CL	0.464	0.380	0.444
Father's Education LH	0.167	0.129	0.119
Father's Education HS	0.238	0.178	0.190
Father's Education CL	0.439	0.358	0.429

Table I.1: Response of college enrollment to the elimination of federal tuition grants.

Removal of Tuition Grants - Panel B (Aggregates)

	Benchmark	P.E. Short-run	G.E. Long-run
Parental Net Worth Gini	0.567	0.567	0.573
Gender log-Wage Gap	0.319	0.333	0.313
Labor Income Tax Rate	0.2700	0.2700	0.273
%Δ GDP	–	–	-1.95%
Welfare CEV (ω_{tot})	–	–	-0.68%
Welfare CEV (ω_{lev})	–	–	-0.83%
Welfare CEV (ω_{unc})	–	–	+0.82%
Welfare CEV (ω_{ine})	–	–	-0.66%
High School Graduation Rate	0.864	0.864	0.854
Δ% Avg Student Labor	–	+13.4%	+4.47%
Male CL Price Premium*	0.240	0.240	0.334
Female CL Price Premium*	0.247	0.247	0.274
Δ% Male CL Lifetime Earnings**	–	–	+4.89%
Δ% Female CL Lifetime Earnings**	–	–	+3.41%
Δ% Male HS Lifetime Earnings**	–	–	-2.85%
Δ% Female HS Lifetime Earnings**	–	–	-2.57%
IVT to Parental Wealth Ratio - Men	0.328	0.326	0.329
IVT to Parental Wealth Ratio - Women	0.304	0.300	0.293

*The ‘college price premium’ is the log-difference in the price per unit of human capital supplied Relative to HS workers.

** Discounted lifetime earnings of an individual with median characteristics and a spouse with median characteristics.

Table I.2: Response of aggregate variables to the elimination of federal tuition grants.

Removal of Tuition Grants - Panel C (Crowding In/Out)

	P.E. Short-run		G.E. Long-run	
	$ - change	% - change	$ - change	% - change
Average	+409	+0.57%	-2,871	-3.83%
Male	+596	+0.77%	-2,723	-3.33%
Female	+253	+0.37%	-3,157	-4.42%
$q = 1$	+1,622	+5.90%	+3,109	+12.1%
$q = 2$	+990	+1.17%	-3,355	-3.90%
$q = 3$	+188	+0.17%	-9,790	-7.46%

This table reports change in average inter vivos transfers received by individuals who finish college in both the benchmark and experiment.

Table I.3: Crowding in/out of inter vivos transfers in response to the elimination of federal tuition grants.

Removal of Student Loans - Panel A (Enrollment)

Group	Benchmark	P.E. Short-run	G.E. Long-run
Male	0.294	0.233	0.257
Female	0.282	0.179	0.235
θ_{cog} tercile 1	0.060	0.053	0.136
θ_{cog} tercile 2	0.169	0.112	0.215
θ_{cog} tercile 3	0.637	0.454	0.433
θ_{non} tercile 1	0.170	0.126	0.198
θ_{non} tercile 2	0.276	0.196	0.257
θ_{non} tercile 3	0.419	0.296	0.330
$q = 1$	0.232	0.132	0.115
$q = 2$	0.410	0.323	0.321
$q = 3$	0.445	0.445	0.637
Inter Vivos Tr. tercile 1	0.147	0.079	0.017
Inter Vivos Tr. tercile 2	0.165	0.102	0.020
Inter Vivos Tr. tercile 3	0.554	0.438	0.747
Parent's Net Worth ter. 1	0.205	0.112	0.033
Parent's Net Worth ter. 2	0.246	0.143	0.175
Parent's Net Worth ter. 3	0.414	0.363	0.576
Parent's Income tercile 1	0.141	0.077	0.020
Parent's Income tercile 2	0.186	0.114	0.074
Parent's Income tercile 3	0.538	0.427	0.690
Mother's Education LH	0.097	0.067	0.105
Mother's Education HS	0.252	0.174	0.251
Mother's Education CL	0.464	0.346	0.355
Father's Education LH	0.167	0.120	0.119
Father's Education HS	0.238	0.165	0.194
Father's Education CL	0.439	0.323	0.531

Table I.4: Response of college enrollment to the elimination of federal student loans

Removal of Student Loans - Panel B (Aggregates)

	Benchmark	P.E. Short-run	G.E. Long-run
Parental Net Worth Gini	0.567	0.567	0.575
Gender log-Wage Gap	0.319	0.334	0.295
Labor Income Tax Rate	0.2700	0.2700	0.2769
$\%\Delta$ GDP	–	–	-2.95%
Welfare CEV (ω_{tot})	–	–	-0.65%
Welfare CEV (ω_{lev})	–	–	-1.17%
Welfare CEV (ω_{unc})	–	–	+1.75%
Welfare CEV (ω_{ine})	–	–	-1.20%
High School Graduation Rate	0.864	0.864	0.856
$\Delta\%$ Avg Student Labor	–	+38.3%	+5.84%
Male CL Price Premium*	0.240	0.240	0.322
Female CL Price Premium*	0.247	0.247	0.309
$\Delta\%$ Male CL Lifetime Earnings**	–	–	+9.29%
$\Delta\%$ Female CL Lifetime Earnings**	–	–	+5.71%
$\Delta\%$ Male HS Lifetime Earnings**	–	–	-5.65%
$\Delta\%$ Female HS Lifetime Earnings**	–	–	-4.30%
IVT to Parental Wealth Ratio - Men	0.328	0.294	0.326
IVT to Parental Wealth Ratio - Women	0.304	0.271	0.308

*The 'college price premium' is the difference in the price per unit of human capital supplied relative to HS workers.

** The discounted earnings of an individual with median characteristics and a spouse with median characteristics.

Table I.5: Response of aggregate variables to the elimination of federal student loans.

Removal of Student Loans - Panel C (Crowding In/Out)

	P.E. Short-run		G.E. Long-run	
	$ - change	% - change	$ - change	% - change
Average	+2,519	+1.32%	+2,803	+3.37%
Male	+2,837	+1.84%	+3,740	+4.17%
Female	+2,099	+0.86%	+2,199	+2.84%
$q = 1$	+4,142	+14.8%	+19,140	+33.8%
$q = 2$	+6,870	+7.65%	+10,748	+12.1%
$q = 3$	+0	+0.00%	-10,450	-8.38%

This table reports change in average inter vivos transfers received by individuals who finish college in both the benchmark and experiment.

Table I.6: Crowding in/out of inter vivos transfers in response to the elimination of federal student loans.

Removal of Grants and Loans - Panel A (Enrollment)

Group	Benchmark	P.E. Short-run	G.E. Long-run
Male	0.294	0.186	0.237
Female	0.282	0.148	0.226
θ_{cog} tercile 1	0.060	0.051	0.120
θ_{cog} tercile 2	0.169	0.102	0.215
θ_{cog} tercile 3	0.637	0.347	0.360
θ_{non} tercile 1	0.170	0.106	0.179
θ_{non} tercile 2	0.276	0.159	0.230
θ_{non} tercile 3	0.419	0.235	0.286
$q = 1$	0.232	0.074	0.026
$q = 2$	0.410	0.318	0.148
$q = 3$	0.445	0.439	0.689
Inter Vivos Tr. tercile 1	0.147	0.031	0.001
Inter Vivos Tr. tercile 2	0.165	0.049	0.004
Inter Vivos Tr. tercile 3	0.554	0.421	0.690
Parent's Net Worth ter. 1	0.205	0.049	0.006
Parent's Net Worth ter. 2	0.246	0.098	0.052
Parent's Net Worth ter. 3	0.414	0.353	0.636
Parent's Income tercile 1	0.141	0.031	0.005
Parent's Income tercile 2	0.186	0.055	0.042
Parent's Income tercile 3	0.538	0.413	0.648
Mother's Education LH	0.097	0.050	0.088
Mother's Education HS	0.252	0.131	0.219
Mother's Education CL	0.464	0.303	0.357
Father's Education LH	0.167	0.079	0.103
Father's Education HS	0.238	0.116	0.179
Father's Education CL	0.439	0.303	0.443

Table I.7: Response of college enrollment to the elimination of federal grants and federal student loans

Removal of Grants and Loans - Panel B (Aggregates)

	Benchmark	P.E. Short-run	G.E. - Long-run
Parental Net Worth Gini	0.567	0.567	0.580
Gender log-Wage Gap	0.319	0.334	0.318
Labor Income Tax Rate	0.2700	0.2700	0.2799
$\%\Delta$ GDP	–	–	-4.43%
Welfare CEV (ω_{tot})	–	–	-1.85%
Welfare CEV (ω_{lev})	–	–	-2.72%
Welfare CEV (ω_{unc})	–	–	+2.68%
Welfare CEV (ω_{ine})	–	–	-1.73%
High School Graduation Rate	0.864	0.864	0.855
$\Delta\%$ Avg Student Labor	–	+38.3%	+3.99%
Male CL Price Premium*	0.240	0.240	0.408
Female CL Price Premium*	0.247	0.247	0.491
$\Delta\%$ Male CL Lifetime Earnings**	–	–	+7.81%
$\Delta\%$ Female CL Lifetime Earnings**	–	–	+7.04%
$\Delta\%$ Male HS Lifetime Earnings**	–	–	-5.84%
$\Delta\%$ Female HS Lifetime Earnings**	–	–	-5.41%
IVT to Parental Wealth Ratio - Men	0.328	0.293	0.318
IVT to Parental Wealth Ratio - Women	0.304	0.269	0.290

*The ‘college price premium’ is the difference in the price per unit of human capital supplied relative to HS workers.

** The discounted earnings of an individual with median characteristics and a spouse with median characteristics.

Table I.8: Response of aggregate variables to the elimination of federal grants and federal student loans.

Removal of Grants and Loans - Panel C (Crowding In/Out)

	P.E. Short-run		G.E. Long-run	
	$ - change	% - change	$ - change	% - change
Average	+794	+1.32%	+1,770	+1.97%
Male	+1,149	+1.14%	+2,521	+2.72%
Female	+484	+0.58%	+797	+0.91%
$q = 1$	+4,394	+11.7%	+24,624	+58.5%
$q = 2$	+1,235	+1.40%	+2,913	+3.34%
$q = 3$	+128	+0.10%	-12,495	-10.1%

This table reports change in average inter vivos transfers received by individuals who finish college in both the benchmark and experiment.

Table I.9: Crowding in/out of inter vivos transfers in response to the elimination of all federal grants and federal student loans.

$1,000 General Grant Expansion - Panel A (Enrollment)

Group	Benchmark	P.E. Short-run	G.E. Long-run
Male	0.294	0.334	0.320
Female	0.282	0.311	0.293
θ_{cog} tercile 1	0.060	0.080	0.081
θ_{cog} tercile 2	0.169	0.216	0.191
θ_{cog} tercile 3	0.637	0.671	0.647
θ_{non} tercile 1	0.170	0.200	0.177
θ_{non} tercile 2	0.276	0.309	0.301
θ_{non} tercile 3	0.419	0.458	0.442
$q = 1$	0.232	0.272	0.268
$q = 2$	0.410	0.432	0.398
$q = 3$	0.445	0.462	0.407
Inter Vivos Tr. tercile 1	0.147	0.179	0.189
Inter Vivos Tr. tercile 2	0.165	0.216	0.206
Inter Vivos Tr. tercile 3	0.554	0.572	0.524
Parent's Net Worth ter. 1	0.205	0.241	0.239
Parent's Net Worth ter. 2	0.246	0.289	0.279
Parent's Net Worth ter. 3	0.414	0.437	0.401
Parent's Income tercile 1	0.141	0.167	0.179
Parent's Income tercile 2	0.186	0.231	0.220
Parent's Income tercile 3	0.538	0.569	0.519
Mother's Education LH	0.097	0.123	0.122
Mother's Education HS	0.252	0.292	0.274
Mother's Education CL	0.464	0.491	0.430
Father's Education LH	0.167	0.200	0.202
Father's Education HS	0.238	0.275	0.261
Father's Education CL	0.439	0.468	0.458

Table I.10: Response of college enrollment to a $1,000 per year increase in federal grants ($4,000 total)

$1,000 General Grant Expansion - Panel B (Aggregates)

	Benchmark	P.E. Short-run	G.E. Long-run
Parental Net Worth Gini	0.567	0.567	0.577
Gender log-Wage Gap	0.319	0.313	0.297
Labor Income Tax Rate	0.2700	0.2700	0.2704
$\%\Delta$ GDP	–	–	+0.46%
Welfare CEV (ω_{tot})	–	–	+0.32%
Welfare CEV (ω_{lev})	–	–	+0.18%
Welfare CEV (ω_{unc})	–	–	+0.02%
Welfare CEV (ω_{ine})	–	–	+0.12%
High School Graduation Rate	0.864	0.864	0.868
$\Delta\%$ Avg Student Labor	–	-6.05%	-3.22%
Male CL Price Premium*	0.240	0.240	0.220
Female CL Price Premium*	0.247	0.247	0.218
$\Delta\%$ Male CL Lifetime Earnings**	–	–	-0.78%
$\Delta\%$ Female CL Lifetime Earnings**	–	–	-1.17%
$\Delta\%$ Male HS Lifetime Earnings**	–	–	+0.24%
$\Delta\%$ Female HS Lifetime Earnings**	–	–	+1.40%
IVT to Parental Wealth Ratio - Men	0.328	0.326	0.320
IVT to Parental Wealth Ratio - Women	0.304	0.309	0.301

*The 'college price premium' is the difference in the price per unit of human capital supplied relative to HS workers.

** The discounted earnings of an individual with median characteristics and a spouse with median characteristics.

Table I.11: Response of aggregate variables to a $1,000 per year increase in federal grants ($4,000 total).

$1,000 General Grant Expansion - Panel C (Crowding In/Out)

	P.E. Short-run		G.E. Long-run	
	$ - change	% - change	$ - change	% - change
Average	-1,247	-1.65%	-1,353	-2.27%
Male	-1,554	-1.91%	-1,377	-2.22%
Female	-865	-1.22%	-1,330	-2.34%
$q = 1$	-750	-4.23%	-1,034	-4.42%
$q = 2$	-1,210	-3.13%	-1,592	-2.56%
$q = 3$	-3,410	-2.72%	-2,081	-1.63%

This table reports change in average inter vivos transfers received by individuals who finish college in both the benchmark and experiment.

Table I.12: Crowding in/out of inter vivos transfer in response to a $1,000 per year increase in federal grants ($4,000 total).

Means Tested Grant Expansion - Panel A (Enrollment)

Experiment Characteristics	Benchmark	P.E. Short-run	G.E. Long-run
Male	0.294	0.332	0.325
Female	0.282	0.314	0.297
θ_{cog} tercile 1	0.060	0.073	0.081
θ_{cog} tercile 2	0.169	0.211	0.194
θ_{cog} tercile 3	0.637	0.674	0.659
θ_{non} tercile 1	0.170	0.193	0.179
θ_{non} tercile 2	0.276	0.308	0.296
θ_{non} tercile 3	0.419	0.467	0.459
$q = 1$	0.232	0.279	0.293
$q = 2$	0.410	0.407	0.345
$q = 3$	0.445	0.449	0.368
Inter Vivos Tr. tercile 1	0.147	0.192	0.215
Inter Vivos Tr. tercile 2	0.165	0.214	0.232
Inter Vivos Tr. tercile 3	0.554	0.562	0.487
Parent's Net Worth ter. 1	0.205	0.253	0.283
Parent's Net Worth ter. 2	0.246	0.290	0.272
Parent's Net Worth ter. 3	0.414	0.415	0.379
Parent's Income tercile 1	0.141	0.181	0.205
Parent's Income tercile 2	0.186	0.237	0.240
Parent's Income tercile 3	0.538	0.552	0.489
Mother's Education LH	0.097	0.126	0.136
Mother's Education HS	0.252	0.289	0.279
Mother's Education CL	0.464	0.493	0.436
Father's Education LH	0.167	0.209	0.211
Father's Education HS	0.238	0.274	0.271
Father's Education CL	0.439	0.464	0.449

Table I.13: Response of college enrollment to a proportional 52% increase in federal grants (equal fiscal cost in PE as a $1,000 per year expansion).

Means Tested Grant Expansion - Panel B (Aggregates)

	Benchmark	P.E. Short-run	G.E. Lomg-run
Parental Net Worth Gini	0.567	0.567	0.575
Gender log-Wage Gap	0.319	0.312	0.306
Labor Income Tax Rate	0.2700	0.2700	0.2701
$\%\Delta$ GDP	–	–	+0.66%
Welfare CEV (ω_{tot})	–	–	+0.40%
Welfare CEV (ω_{lev})	–	–	+0.59%
Welfare CEV (ω_{unc})	–	–	-0.22%
Welfare CEV (ω_{ine})	–	–	+0.03%
High School Graduation Rate	0.864	0.864	0.868
$\Delta\%$ Avg Student Labor	–	-8.53%	-5.17%
Male CL Price Premium*	0.240	0.240	0.215
Female CL Price Premium*	0.247	0.247	0.212
$\Delta\%$ Male CL Lifetime Earnings**	–	–	-1.56%
$\Delta\%$ Female CL Lifetime Earnings**	–	–	-1.94%
$\Delta\%$ Male HS Lifetime Earnings**	–	–	+0.65%
$\Delta\%$ Female HS Lifetime Earnings**	–	–	+0.71%
IVT to Parental Wealth Ratio - Men	0.328	0.327	0.322
IVT to Parental Wealth Ratio - Women	0.304	0.304	0.301

*The ‘college price premium’ is the difference in the price per unit of human capital supplied relative to HS workers.
** The discounted earnings of an individual with median characteristics and a spouse with median characteristics.

Table I.14: Response to aggregate variables to a proportional 52% increase in federal grants (equal fiscal cost in PE as a $1,000 per year expansion).

Means Tested Grant Expansion - Panel C (Crowding In/Out)

		P.E. Short-run		G.E. Long-run	
		$ - change	% - change	$ - change	% - change
Crowding Out	Average	-183	-0.31%	-791	-1.36%
	Male	-160	-0.19%	-607	-1.09%
	Female	-197	-0.38%	-970	-1.60%
	$q = 1$	-704	-2.81%	-1545	-6.64%
	$q = 2$	-108	-0.13%	-261	-0.28%
	$q = 3$	-36	-0.03%	+1576	+1.20%

This table reports change in average inter vivos transfers received by individuals who finish college in both the benchmark and experiment.

Table I.15: Crowding in/out of inter vivos transfers in response to a 52% increase in federal grants (equal fiscal cost in PE as a $1,000 per year expansion).

Ability Tested Grant Expansion - Panel A (Enrollment)

Experiment Characteristics	Benchmark	P.E. Short-run	G.E. Long-run
Male	0.294	0.316	0.303
Female	0.282	0.307	0.296
θ_{cog} tercile 1	0.060	0.066	0.052
θ_{cog} tercile 2	0.169	0.194	0.166
θ_{cog} tercile 3	0.637	0.673	0.681
θ_{non} tercile 1	0.170	0.189	0.177
θ_{non} tercile 2	0.276	0.297	0.290
θ_{non} tercile 3	0.419	0.449	0.432
$q = 1$	0.232	0.262	0.250
$q = 2$	0.410	0.428	0.397
$q = 3$	0.445	0.441	0.433
Inter Vivos Tr. tercile 1	0.147	0.175	0.177
Inter Vivos Tr. tercile 2	0.165	0.206	0.210
Inter Vivos Tr. tercile 3	0.554	0.553	0.512
Parent's Net Worth ter. 1	0.205	0.237	0.241
Parent's Net Worth ter. 2	0.246	0.278	0.251
Parent's Net Worth ter. 3	0.414	0.419	0.406
Parent's Income tercile 1	0.141	0.165	0.169
Parent's Income tercile 2	0.186	0.225	0.220
Parent's Income tercile 3	0.538	0.544	0.510
Mother's Education LH	0.097	0.115	0.115
Mother's Education HS	0.252	0.279	0.260
Mother's Education CL	0.464	0.481	0.459
Father's Education LH	0.167	0.195	0.195
Father's Education HS	0.238	0.265	0.256
Father's Education CL	0.439	0.452	0.425

Table I.16: Response of college enrollment to an increase in federal grants that is proportional to ability $1.55 \times \theta_{cog}$ (equal fiscal cost in PE as a $1,000 per year expansion).

Ability Tested Grant Expansion - Panel B (Aggregates)

	Benchmark	P.E. Short-run	G.E. Long-run
Parental Net Worth Gini	0.567	0.567	0.568
Gender log-Wage Gap	0.319	0.313	0.315
Labor Income Tax Rate	0.2700	0.2700	0.2703
$\%\Delta$ GDP	–	–	+0.57%
Welfare CEV (ω_{tot})	–	–	+0.31%
Welfare CEV (ω_{lev})	–	–	+0.50%
Welfare CEV (ω_{unc})	–	–	-0.00%
Welfare CEV (ω_{ine})	–	–	-0.19%
High School Graduation Rate	0.864	0.864	0.868
$\Delta\%$ Avg Student Labor	–	-7.53%	-3.90%
Male CL price Premium*	0.240	0.240	0.227
Female CL price Premium*	0.247	0.247	0.211
$\Delta\%$ Male CL Lifetime Earnings**	–	–	-0.24%
$\Delta\%$ Female CL Lifetime Earnings**	–	–	-1.08%
$\Delta\%$ Male HS Lifetime Earnings**	–	–	+0.70%
$\Delta\%$ Female HS Lifetime Earnings**	–	–	+1.15%
IVT to Parental Wealth Ratio - Men	0.328	0.327	0.322
IVT to Parental Wealth Ratio - Women	0.304	0.305	0.300

*The 'college price premium' is the difference in the price per unit of human capital supplied relative to HS workers.

** The discounted earnings of an individual with median characteristics and a spouse with median characteristics.

Table I.17: Response of aggregate variables to an increase in federal grants that is proportional to ability $1.55 \times \theta_{cog}$ (equal fiscal cost in PE as a $1,000 per year expansion).

Ability Tested Grant Expansion - Panel C (Crowding In/Out)

	P.E. Short-run		G.E. Long-run	
	$ - change	% - change	$ - change	% - change
Average	-1,272	-2.10%	-1,619	-2.64%
Male	-1,476	-2.39%	-1,976	-3.32%
Female	-1,068	-1.74%	-1,253	-1.99%
$q = 1$	-726	-2.91%	+412	+1.71%
$q = 2$	-2,651	-3.19%	-3,380	-4.63%
$q = 3$	-1,738	-1.38%	-3,630	-2.89%

*This table reports change in average inter vivos transfers received by individuals who finish college in both the benchmark and experiment.

Table I.18: Response of inter vivos transfers to an increase in federal grants that is proportional to ability $1.55 \times \theta_{cog}$ (equal fiscal cost in PE as a $1,000 per year expansion).

“Unconstrained” Economy - Panel A (Enrollment)

Group	Benchmark	P.E. Short-run	G.E. Long-run
Male	0.294	–	0.303
Female	0.282	–	0.292
θ_{cog} tercile 1	0.060	–	0.035
θ_{cog} tercile 2	0.169	–	0.171
θ_{cog} tercile 3	0.637	–	0.686
θ_{non} tercile 1	0.170	–	0.172
θ_{non} tercile 2	0.276	–	0.285
θ_{non} tercile 3	0.419	–	0.435
$q = 1$	0.232	–	0.276
$q = 2$	0.410	–	0.302
$q = 3$	0.445	–	0.367
Inter Vivos Tr. tercile 1	0.147	–	0.222
Inter Vivos Tr. tercile 2	0.165	–	0.252
Inter Vivos Tr. tercile 3	0.554	–	0.418
Parent’s Net Worth ter. 1	0.205	–	0.288
Parent’s Net Worth ter. 2	0.246	–	0.247
Parent’s Net Worth ter. 3	0.414	–	0.362
Parent’s Income tercile 1	0.141	–	0.216
Parent’s Income tercile 2	0.186	–	0.248
Parent’s Income tercile 3	0.538	–	0.429
Mother’s Education LH	0.097	–	0.142
Mother’s Education HS	0.252	–	0.272
Mother’s Education CL	0.464	–	0.412
Father’s Education LH	0.167	–	0.198
Father’s Education HS	0.238	–	0.259
Father’s Education CL	0.439	–	0.419

Table I.19: Response of college enrollment to the elimination borrowing constraints for college and married working age households.

“Unconstrained” Economy - Panel B (Aggregates)

	Benchmark	P.E. Short-run	G.E. Long-run
Parental Net Worth Gini	0.567	–	0.572
Gender log-Wage Gap	0.319	–	0.295
Labor Income Tax Rate	0.2700	–	0.318
$\%\Delta$ GDP	–	–	+1.16%
Welfare CEV (ω_{tot})	–	–	+0.41%
Welfare CEV (ω_{lev})	–	–	+0.31%
Welfare CEV (ω_{unc})	–	–	+0.55%
Welfare CEV (ω_{ine})	–	–	-0.44%
High School Graduation Rate	0.864	–	0.863
$\Delta\%$ Avg Student Labor	–	–	-33.7%
Male CL Price Premium*	0.240	–	0.254
Female CL Price Premium*	0.247	–	0.191
$\Delta\%$ Male CL Lifetime Earnings**	–	–	+1.89%
$\Delta\%$ Female CL Lifetime Earnings**	–	–	+1.02%
$\Delta\%$ Male HS Lifetime Earnings**	–	–	-0.72%
$\Delta\%$ Female HS Lifetime Earnings**	–	–	+0.09%
IVT to Parental Wealth Ratio - Men	0.328	–	0.313
IVT to Parental Wealth Ratio - Women	0.304	–	0.279

*The ‘college price premium’ is the difference in the price per unit of human capital supplied relative to HS workers.

** The discounted earnings of an individual with median characteristics and a spouse with median characteristics.

Table I.20: Response of aggregate variables to the elimination borrowing constraints for college and married working age households.

“Unconstrained” Economy - Panel C (Crowding In/Out)

	P.E. Short-run		G.E. Long-run	
	$ - change	% - change	$ - change	% - change
Average	–	–	-$3,856	-6.64%
Male	–	–	-$3,932	-6.94%
Female	–	–	-$3,774	-6.32%
$q = 1$	–	–	-$709	-3.53%
$q = 2$	–	–	-$6,539	-7.87%
$q = 3$	–	–	-$9,486	-7.56%

This table reports change in average inter vivos transfers received by individuals who finish college in both the benchmark and experiment.

Table I.21: Crowding in/out of inter vivos transfers in response to the elimination borrowing constraints for college and married working age households.

Simulation with Year 2010 Parameters

	Model		Data	
	Year 2000	Year 2010	Year 2000	Year 2010
Male College Attainment	0.29	0.32	0.29	0.34
Female College Attainment	0.28	0.36	0.28	0.34
College Wage Premium	0.58	0.63	0.58	0.65*
Gender Earnings Gap**	0.73	0.75	0.74	0.77

* Due to lack of comparable estimates for 2010, the College-HS premium is based on estimates by Autor et al. (2008) for 2005. An alternative estimate by Autor (2014), based on a different education grouping, suggests a college-HS premium of about 0.66 log points in 2010.

** The gender gap is measured as in Goldin (2014). It corresponds to the ratio of median earnings of full-time women to full-time men. We set 0.3 of the time endowment as the full-time threshold.

Table J.1: Predicted and actual college attainment and skill/gender premia in 2010.

J Sensitivity Analysis

J.1 Extrapolating the Model: 2000 vs 2010

To assess the 'out of sample' performance of the model, we have extrapolated its equilibrium implications to a different time period. In particular, we have set the following parameters to those prevailing in the year 2010: (i) share parameters of different human capital in production; (ii) tuition costs and value of other education expenditures; (iii) credit limits for both subsidized and unsubsidized college loans.[59] Then, keeping all other parameters unchanged, we have computed a new equilibrium allocation to verify how well the model would approximate observed enrollment rates and education/gender premia in 2010. Results, presented in Table J.1, suggest that the model does a very reasonable job in approximating equilibrium outcomes ten years out of sample.

[59]Based on information from the National Centre for Education Statistics, the specific changes are: (i) adjustment of the production technology shares to $s^{LH} = .15$, $s^{HS} = .36$, $s^{CL} = .49$, $s^{m,LH} = .65$, $s^{m,HS} = .59$, $s^{m,CL} = .59$; (ii) tuition growth of roughly $\$1,100$ per year between 2000 and 2010 (in year 2000 dollars); (iii) debt limits' expansion to $\$19,000$ for subsidized and $\$31,000$ for unsubsidized/private loans (expressed in year 2010 dollars, equivalent to 15,447 and 25,203 in year 2000 dollars).

Sensitivity of Enrollment to Psychic Costs Variation

College Attainment Rates - Benchmark Psychic Cost Variation

		Cognitive quintile				
		1	2	3	4	5
Non-	1	0.087	0.114	0.166	0.298	0.648
Cognitive	2	0.094	0.125	0.177	0.334	0.725
tercile	3	0.106	0.142	0.193	0.399	0.806

College Attainment Rates - No Psychic Cost Variation

		Cognitive quintile				
		1	2	3	4	5
Non-	1	0.125	0.168	0.248	0.355	0.512
Cognitive	2	0.140	0.190	0.262	0.391	0.525
tercile	3	0.155	0.201	0.266	0.400	0.530

Table J.2: College Attainment Rates with/out Psychic Costs

J.2 Eliminating Cross-Sectional Variation in Psychic Costs

We have also performed a sensitivity analysis on the role of psychic costs of education for enrollment choices. In particular, we have checked how important psychic costs are for explaining variation in education decisions. To this purpose we have set the loadings in the college psychic cost equation (5) to zero (only keeping the estimated constants), and we have solved for the implied equilibrium allocation. This exercise shows that much of the dispersion in education attainment persists even after shutting down cross sectional variation in psychic costs. While psychic costs are obviously important to get a more realistic enrollment pattern, it appears that model variation in schooling is not exclusively due to the estimated psychic costs.

To better interpret the results displayed in table J.2, we also fit simple linear probability models for college attainment to the simulated data, in which cognitive and non-cognitive skills were regressors. The effect of a one-standard deviation increase in cognitive skills on college attainment rates is 40% smaller when psychic cost variation is eliminated, thus 60% of co-variation between schooling attainment and cognitive skills is explained by other model elements, such as the fact that returns to college rise with cognitive ability.

For co-variation between non-cognitive skills and college attainment, obviously the psychic costs are the only direct link and thus will be very important. It is somewhat surprising that, in fact, 23% of the association between non-cognitive skills and college attainment turns out to be driven by model elements aside from psychic costs (based on the same simulated data regression described above).

Sensitivity to Closed Economy Assumption

Removal of Tuition Grants	Closed Economy	Small Open Economy
Δ% GDP	-1.95%	-1.82%
Δ college attainment rate	-0.052	-0.022
Δ% avg ability college grads	-3.35%	-5.04%
Avg Crowding out of IVTs*	-3.83%	+3.27%
Removal of Student Loans	**Closed Capital Markets**	**Open Capital Markets**
Δ% GDP	-2.95%	-2.20%
Δ% college attainment	-0.042	-0.035
Δ% avg ability college grads	-9.88%	-10.8%
Avg Crowding out of IVTs*	+3.37%	+14.2%

*average % change in IVTs to chidren who go to college in both the benchmark and experiment.

Table J.3: This table illustrates the sensitivity of our main results to the assumption that interest rates are exogenously set (as in a small open economy).

This association is driven by the relationship between parental education and non-cognitive skills in the intergenerational transmission channel: average parental education (and hence income/wealth) is greater among children in higher non-cognitive skill groups.

J.3 Sensitivity of Policy Outcomes to Closed Economy Assumption

One possible concern about our results may relate to the endogenous determination of interest rates. The general equilibrium adjustments might be different if the price of credit was exogenously given. To check the robustness of our results we therefore consider a ‘small open economy’ alternative: the annual interest rate is exogenously set at 4.2%. We compute the outcomes of the grant and loan removal policies in this alternative equilibrium where only human capital prices, and tax rates, adjust. The results, reported in Table J.3, show that aggregate effects are qualitatively similar but somewhat reduced. For example, when government student loans are removed, GDP falls by 2.2% in the long-run, rather than by 2.95% as we find for a closed economy. The mechanics of this GDP reduction are slightly different. Within an open economy, drops in college enrollment are less severe while changes in ability composition of college graduates are more severe. Thus, the stock of college educated human capital falls by comparable amounts, but for rather different reasons. Differences in the crowding out of parental transfers offer an insight into why this happens: in the open economy parents boost their transfers to college-going kids by much more when government aid is removed,

Sensitivity to Elasticity of Substitution Between H^e Aggregates in Production

		Elasticity $(1/(1-\rho))$.	
Removal of Tuition Grants	2.5	3.3	5.0
$\Delta\%$ GDP	-1.98%	-1.95%	-1.94%
Δ college attainment rate	-0.073	-0.052	-0.028
$\Delta\%$ avg ability college grads	-3.38%	-3.35%	-3.18%
Avg Crowding out of IVTs*	-4.21%	-3.83%	-1.24%
		Elasticity $(1/(1-\rho))$.	
Removal of Student Loans	2.5	3.3	5.0
$\Delta\%$ GDP	-3.18%	-2.95%	-2.72%
$\Delta\%$ college attainment	-0.048	-0.042	-0.028
$\Delta\%$ avg ability college grads	-11.8%	-9.88%	-7.21%
Avg Crowding out of IVTs*	+2.68%	+3.37%	+6.58%

*Average % change in IVTs to chidren who go to college in both the benchmark and experiment.

Table J.4: This table illustrates the sensitivity of our main results to variation in the estimated value of ρ. In the benchmark economy we have an elasticity of 3.3, corresponding to $\rho = 0.7$.

which is an indication that selection into college due to parental wealth has become more important. In such open economy scenario the interest rate cannot fall, whereas in the closed economy case it falls by nearly 20 basis points. Any significant downward adjustment in the returns to assets implies a fall in the incomes of wealth rich families who provide relatively larger inter vivos transfers to their children.[60]

When returns to holding wealth do not adjust downward, low ability children from relatively richer families displace high ability children from poorer families to a larger extent than would occur in a closed economy.

J.4 Sensitivity of Policy Outcomes to ρ

When examining the effects of education policies, it is interesting to gauge how sensitive equilibrium outcomes are to alternative values of the production parameter ρ, which dictates the elasticity of substitution between H^e aggregates. In Table J.4 we report results for a sensitivity analysis in which we consider different values of ρ and we compare education policy outcomes to those obtained under

[60]The inter vivos crowding in/out statistics refer to the selected sample who go to college in both benchmark and experiment. Unconditional changes in IVTs are smaller.

the benchmark parametrization (that is, $\rho = .7$). As expected, changes in college attainment rates are larger when the elasticity of substitution is lower. Moreover, even when considering a fairly high elasticity (equal to five), one can still detect sizable GE effects on GDP, ability composition and inter vivos transfers.