Education Policy and Intergenerational Transfers in Equilibrium†

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THIS DRAFT: JANUARY 2013

Abstract
This paper compares partial and general 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. Altruistic parents make inter vivos transfers to their children. Labor supply during college, government grants and loans, as well as private loans, complement parental transfers as sources of funding for college education. We find that the current financial aid system in the U.S. improves welfare, and removing it would reduce GDP by two percentage points in the long-run. Any further relaxation of government-sponsored loan limits would have no salient effects. The short-run partial equilibrium effects of expanding tuition grants (especially their need-based component) are sizeable. However, long-run general equilibrium effects are 3-4 times smaller. Every additional dollar of government grants crowds out 20-30 cents of parental transfers.

JEL Classification: E24, I22, J23, J24.

Keywords: Education, Financial Aid, Inter vivos Transfers, Credit Constraints, Equilibrium.

†This paper was originally circulated under the title *Equilibrium Effects of Education Policies: A Quantitative Evaluation*. We received valuable feedback from numerous individuals and participants at conferences and seminars, especially at the University of Chicago 2007 conference on "Analytical Labor Economics", Cowles Foundation (Yale), Stanford University, the SED, and the INET Human Capital working group. We are grateful to Chris Tonetti for excellent research assistance at an early stage of this project and to Emily Nix for comments. Costas Meghir thanks the ESRC for funding under the Professorial Fellowship RES-051-27-0204 and the Cowles Foundation at Yale. Abbott and Gallipoli acknowledge financial support from the CLSRN and the SSHRC in Canada. We alone are responsible for all errors and interpretations.

1 Introduction

Investment in human capital is a key source of aggregate productivity growth and a powerful vehicle for social mobility. 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, the US Federal government spent roughly 150 billion dollars on loans and grants for college students in 2012 (source: Trends in Student Aid, College Board, 2012). Given the vast resources spent by these programs it is paramount to accurately quantify the effects of policies intended to advance college enrollment.

In this paper, we address this question by providing an empirical and quantitative analysis of the impact of financial aid policies on college attainment and the aggregate economy. Measuring how government-sponsored loans and tuition grants affect college enrollment decisions is extremely challenging because of the interplay between four crucial economic factors: (i) individual heterogeneity and uncertainty in the returns to college education, (ii) imperfections in financial markets, (iii) private sources of funding, and (iv) general equilibrium feedback effects.

As recognized by the micro-econometric literature, there is extensive heterogeneity in the return to education. Higher ability individuals have higher expected pecuniary returns from higher education and self-select into college.[1] There is also substantial heterogeneity in non-pecuniary (psychic) costs of college attendance. Modelling these psychic costs is necessary because pecuniary returns can only account for a part of the observed college attendance patterns by ability (see Cunha, Heckman, and Navarro, 2005; Heckman, Lochner, and Todd, 2006). This vast heterogeneity means that unless policies are precisely targeted towards specific groups most students are infra-marginal and largely unaffected by an intervention.

Labor economists have convincingly documented that earnings risk during working life is substantial and only partially insurable through borrowing, saving, labor supply adjustments, and family transfers (Blundell, Pistaferri, and Preston, 2008; Low, Meghir, and Pistaferri, 2010; Heathcote, Storesletten, and Violante, 2012; Gallipoli and Turner, 2011). As Levhari and Weiss (1974) originally emphasized, college education is a multi-period investment that

[1] 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).

requires an ex-ante commitment of resources and time, and hence uncertainty in its return is a key determinant of education decisions. Therefore students may be unwilling to finance college using loans when uncertainty about their future earnings and ability to repay is high. In this respect grants may be a better instrument to promote enrollment (e.g., Johnson, 2011).

At least since Becker (1964) it has been well understood that the amount of college education in an economy may not be optimal because young individuals own only small amounts of pledgeable assets and their future human capital cannot be used as collateral in imperfect financial markets. The key question is: how pervasive are credit constraints? Studies using the 1979 cohort of the National Longitudinal Survey of Youth (NLSY79) concluded that in the 1980s family income played a small role in college-attendance decisions, after controlling for child ability and several other family background characteristics (Cameron and Heckman, 1998; Keane and Wolpin, 2001; Carneiro and Heckman, 2002; Cameron and Taber, 2004). This result implies a stark policy recommendation: rather than easing credit constraints at the age of college enrollment decisions, government interventions should be directed to earlier stages of life in order to ameliorate college preparedness and reduce "psychic costs" of schooling (e.g., by improving the quality of the public school system). However, more recent studies based on the 1997 cohort of the NLSY (NLSY97) have reached a different conclusion. For example, Belley and Lochner (2007) find that parental financial resources matter much more for college attendance in the 2000s (they estimate roughly twice the effect observed in the 1980s). These new contributions reopened the debate on the role of financial aid for college students.

The extent to which credit constraints distort college attendance depends on the availability of other private sources of funding, such as parental transfers and in-school part-time work. Garriga and Keightley (2009) show that omitting the labor supply margin of college students may lead to large overestimates in the effects of tuition subsidies. Gale and Scholz (1994) show that inter vivos transfers (IVTs) for education are sizeable, thus they should be incorporated into models of education acquisition. Keane and Wolpin (2001) and Johnson (2011) estimate parental IVTs as a function of observable characteristics from the NLSY79. Brown, Scholz, and Seshadri (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.

Using this insight Winter (2012) argues that ignoring parental transfers may lead to wrong inference about the extent of credit constraints. We build on this body of evidence and account for some of its criticisms by developing a structural model where the parental transfer decision rule determines the distribution of initial wealth in equilibrium. A crucial implication of our framework is that more generous education policies may crowd out parental IVTs, and hence displace students' use of private financial resources to attend college.

The evaluation of large-scale financial aid policies, such as Stafford loans or Pell grants, targeted to the wider population rather than specific groups requires a general equilibrium model. Heckman, Lochner, and Taber (1998b,c) have led the way in advocating an approach to evaluation of education policies based on structural models that do not omit equilibrium feedbacks between aggregate quantities of labor of different education types and their relative prices. This approach has been also followed by Lee (2005), Lee and Wolpin (2006), Garriga and Keightley (2009), Bohacek and Kapicka (2012), Johnson and Keane (2013), and Krueger and Ludwig (2013).

Our framework of analysis combines these elements. We build a life-cycle, heterogeneous-agent model with incomplete markets of the type popularized by Huggett (1993) and Ríos-Rull (1995) and with inter-generational links in the tradition of Laitner (1992). Young individuals make education decisions based on productive ability (inherited from parents), psychic costs of schooling, and wealth. Imperfectly altruistic parents make inter vivos transfers that determine their children's initial wealth. Labor supply during college, government grants and loans, and private education loans, complement parental transfers as sources of funding for college education. During working life individuals make labor supply and consumption/saving decisions, and repay student loans. They face uninsurable random fluctuations in their labor productivity throughout the work stage of life. Labor inputs of different education levels are imperfect substitutes in the aggregate production function. Wages and the real interest rate clear input markets.

We obtain parameter estimates for our model by estimating key components such as the education specific stochastic wage processes and the aggregate production function by combining data from the PSID, the NLSY, the CPS and the macroeconomy. For some parameters where microeconometric estimation is not feasible or practical we use calibration to replicate key moments from the data. The US federal system of grants and loans is modelled in some detail in order to ensure that we capture the main sources of public funding for education allowing us to obtain a better estimate of the incidence of liquidity constraints and their impact. To lend additional credibility to our economic model we establish that simulated data are consistent with empirical data along a number of crucial dimensions that are not targeted in the parameterization. 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 (e.g. Guvenen, 2009; Heathcote, Storesletten, and Violante, 2012; Kaplan, 2011). The intergenerational correlation of income between parents and children is around 0.4, as documented by Solon (1999) for the US. Our modeling choices for federal financial aid imply marginal effects of parental wealth on college enrollment, controlling for child's ability, that are similar to those estimated by Belley and Lochner (2007) from the NLSY97. Moreover, when we use the model to simulate a 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, we estimate a treatment effect on college enrollment that is slightly larger than 3 percentage points. This estimate is consistent with the effects of quasi-randomized policy shifts surveyed by Kane (2003), and Deming and Dynarski (2009).

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. These experiments yield five main results. First, existing federal grant programs improve welfare and, by promoting skill acquisition through college education, add about 1.5% to aggregate output. Second, the expansion of tuition subsidies induces nontrivial crowding out in both parental IVTs and in the labor supply of college students. We estimate that a $1,000 reduction in tuition fees lowers annual hours worked by college students by 4%. Further, we estimate that every additional dollar of government grants crowds out 20-30 cents of parental IVTs on average. There is considerable variation in crowding out. One important difference is that richer parents' transfers are crowded out considerably more than poorer parents' transfers. This introduces a regressive element to increases in grants. Third, expansions of the grant program may have sizeable effects on enrollment in the short run, but long-run general equilibrium effects are 3-4 times smaller. Besides the attenuating role played by the crowding out of parental IVTs and student's labor supply, the central force at work is the relative price response. As college enrollment rises in response to more generous grants, the relative price of college educated labor falls and offsets the direct partial equilibrium impact of the policy on the quantity of college graduates. We verify that the equilibrium adjustment of the interest rate and the tax rate has only minor consequences. Fourth, government-sponsored loans are an especially valuable source of college financing for high-ability children whose parents cannot afford to fund the entire cost of college. These children recognize the high return from college education for their ability type, and are willing to borrow, heavily at times, to acquire a tertiary degree. As a result, the current government-sponsored loan program is welfare improving, and we find that removing it would reduce aggregate output by 1.5 percentage points. Indeed, we estimate that the combined system of federal aid to college students (grants and loans) is worth 2.5 percent of GDP. Fifth, it is more effective to condition aid on family means than student ability. This result follows from the fact that, given the existing institutional and credit environment, most high ability individuals would choose to attend college regardless of the additional transfers, meaning that ability-testing targets many individuals who are inframarginal to the education choice.

Our calculations suggest that borrowing limits for college students are already quite generous: expanding them would have negligible consequences on enrollment, output and welfare in the long run. However, we also find that parental wealth is a significant determinant of college attendance, as is the case in the NLSY97 data (Belley and Lochner, 2007). We reconcile these findings by noting that estimated psychic costs of college attendance decrease in family wealth. Therefore, relaxing credit limits for able children of poor households does not augment college enrollment much because these high-school students have large disutility of further education.[2] We interpret this correlation as capturing the fact that the quality of local public schools is highly linked to the neighborhood housing price and wealth level of its residents (as in, e.g., Fernandez and Rogerson, 1998). This interpretation is not inconsistent with the relevance of earlier credit constraints, as discussed in Restuccia and Urrutia (2004) and Caucutt and Lochner (2012), or with the substantial amount of heterogeneity in students' preferences for college documented by Fu (2012) who shows that a large fraction of students,

[2] Johnson (2011) also finds small effects of relaxing borrowing constraints in spite of estimating his model on the NLSY97. The reason is that students in his model are very reluctant to take up education loans in the first place due to the uncertainty about dropping out of college and future earnings risk. Lochner and Monje-Naranjo (2011) point out that one problem with this result is that students actually borrow much more in the data than in the model. Our findings are not subject to this critique since in calibrating the model we match numerous statistics on student access to credit, including their average cumulative loans at graduation.

mainly low-ability ones, may prefer the outside option over any college option.

The remainder of the paper is organized as follows. Section 2 outlines the model economy and defines equilibrium. Section 3 describes the model's parameterization. Section 4 further validates the model by assessing its behavior along several key dimensions not explicitly targeted in the calibration. Section 5 presents all the policy experiments. Section 6 provides a general discussion of the main findings and some context. Section 7 concludes. The Appendix contains additional details on the parametrization and on the results of the policy experiments.

2 Model

2.1 Brief overview

We specify an overlapping generations general equilibrium model. Individuals start by making sequential education decisions: whether to attend and complete high school and, following that, whether to attend and complete college. When education is complete, they choose their work hours until retirement. Idiosyncratic uninsurable labor market risk makes individual earnings, and hence the return to education, stochastic. Throughout their life individuals choose their consumption expenditures. They can borrow only up to a limit, and save through a non state-contingent asset. The life cycle has a maximum length, but individuals may die earlier. There is no aggregate risk.

The alternative to education is either work or leisure: these define the opportunity cost of education. In addition to this opportunity cost, individuals face tuition costs and psychic costs of education that depend both on their ability and family background. While in college students can support themselves by choosing to work, running down savings, and obtaining grants and government or private loans; access to these external sources of funding depends on parental wealth.

Importantly, savings originate from parental transfers that are assumed to occur just before the first education decision is made. Preferences are altruistically linked so that the parent values the child's utility at some rate equal to, or below, her own. Because of altruism, the optimal size of a parental transfer depends on the marginal value of wealth of their child. This, in turn, depends on the child's ability (which the parent knows at that point) and, as a result, on the level of education that the child is expected to achieve given any level of transfers. Ability itself is assumed exogenous, but correlated to that of their parents through an estimated intergenerational transition matrix.

The economy includes a production sector with an aggregate production function whose inputs are physical capital and three different types of human capital, corresponding to the three levels of education (statutory, high school and college). The human capital inputs are the efficiency units supplied at the going prices and depend on the number of individuals working, their education, their ability, and their stochastic individual productivity. Since the various types of human capital are imperfect substitutes (based on our estimates and others before us) the returns to education are endogenous and will depend on the relative supplies of each type. All prices, including the return to physical capital, are determined by market clearing.

The government sector consumes, runs a social security system, raises taxes on income and consumption, and funds college education either by direct subsidies or by offering loans at a subsidized rate to lower income individuals and at a market rate to those from middle income families whose parental guarantees are not sufficient to obtain loans from the private sector. In addition, there is a rudimentary private banking sector that intermediates loans at an exogenously given rate.

2.2 Demographics and the life cycle

Demographics: The economy is populated by $J+1$ overlapping generations. Let $j = 0, \ldots, J$ denote age. The probability of surviving from age $j-1$ to age j is denoted by ζ_j. We let $\zeta_j = 1$ as long as the individual is in school or at work $\left(j \leq j^{WK}\right)$, but $\zeta_j < 1$ during retirement, from $j = j^{WK}+1$ to J. Conditional on reaching age J, death is certain at the end of the period ($\zeta_{J+1} = 0$). We set the size of the newborn cohort so that total population is normalized to 1.

Life cycle: The life cycle of an individual has three distinct stages. In the first stage, the individual goes to school and acquires education. There are three levels of educational attainment: Less than High-School, High-School degree and College degree, which are denoted by $e \in \{LH, HS, CL\}$, respectively. Let j^e denote the last period of the school cycle e, with the convention that $j^{LH} = -1$ is the last period of compulsory high-school education. Until that age individuals are dependent "children". Starting from the following period ($j = 0$) individuals begin making independent decisions.

At age $j = 0$ individuals immediately choose whether to drop out of high school or continue. This decision, denoted $d^{HS} \in \{0, 1\}$, entails commitment to enroll in school until age j^{HS}. At age $j^{HS} + 1$ the agent decides whether to enroll in college, a choice which we denote by $d^{CL} \in \{0, 1\}$. This decision requires full commitment to completing college at age j^{CL} because drop-outs are not modeled.[3] During schooling, students choose their level of consumption/saving. 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. High school students do not work and their leisure is exogenously fixed at $\bar{l}$.

Agents begin the work stage of their lives at age 0, $j^{HS} + 1$ or $j^{CL} + 1$ depending on their education decision. During this stage, which lasts until mandatory retirement age j^{WK}, agents choose labor supply and consumption/saving. Retirement starts at age $j^{WK} + 1$. During retirement, individuals do not work ($l = 1$), receive a pension from the government, and allocate consumption/saving over their remaining lifetime of uncertain length.

2.3 Preferences and intergenerational links

Preferences: The period utility of workers and retirees $u(c_j, l_j)$ is strictly increasing and strictly concave in consumption $c \geq 0$ and leisure $l \in [0, 1]$, continuously differentiable, and satisfies Inada conditions. Utility in school has an additional separable component, $\kappa^e(\theta, q)$, $e \in \{HS, CL\}$, which is a function of fixed individual innate "ability" $\theta \in [\theta_{\min}, \theta_{\max}]$ and parental wealth group $q \in \{1, 2, 3\}$ (explained below). The function $\kappa^e(\theta, q)$ reflects psychic costs of schooling in terms of effort, preparedness, or taste for education (see, e.g., Heckman, Lochner, and Todd, 2006).

Intergenerational links: Individuals are partially altruistic towards their offspring. Their child's expected lifetime utility enters their own value function with weight $\omega \in [0, 1]$. This one-sided altruism manifests itself as a monetary transfer once in the lifetime. At age j^{TR}

[3] To avoid further complexity, we abstract from modelling the college drop-out decision. The model could be easily extended by introducing a "disutility shock" of attending college, i.e., a stochastic component of the psychic cost (κ^{CL}, see below), realized after the college attendance decision, whose distribution could depend on individual characteristics.

(during the work stage) each individual (now a parent) has the opportunity to choose a non-negative amount of resources to transfer to their child. The parental transfer fully determines the child's initial asset level a_0. For tractability we do not model multiple transfers or endogenous timing of transfers. Our focus is on transfers made during the late teens and college years, which can be captured reasonably well as a one-off lump sum.

Individuals are also linked by the intergenerational transmission of ability. A parent with ability θ has a probability of having a child with ability less than or equal to $\hat{\theta}$ determined by the conditional c.d.f. $\Gamma_\theta\left(\hat{\theta}, \theta\right)$. Parents know the function Γ_θ, but only at age j^{TR} (just before the inter vivos transfer) the ability of the child is fully revealed to both.

A final intergenerational linkage arises from the dependence of a child's education financing opportunities (through loans and grants) on parental wealth. This is discussed in more detail below.

2.4 Individual labor productivity

Individual labor efficiency ε_j^e for an individual of education e at age j is the sum of three components in logs,

$$\log \varepsilon_j^e = \lambda^e \log \theta + \xi_j^e + z_j^e \tag{1}$$

where λ^e is an education-specific loading factor on (log-) ability, ξ_j^e is an education-specific age profile for productivity, and z_j^e is a stochastic component drawn from the education-specific c.d.f. $\Gamma_z^e(z_{j+1}, z_j)$ describing the conditional cumulative probability of a realization less than or equal to z_{j+1} at age $j+1$ when the idiosyncratic stochastic component at age j was z_j. Let Γ_0^e denote the initial distribution of productivity upon entry in the labor market with educational level e. Finally, we assume that the labor services of a college student are equivalent to those of the average high-school graduate of the same age and ability θ.[4]

2.5 Commodities, technology, and markets

Commodities: There are two kinds of commodities in the economy: (i) the final good, which can be used for private/public consumption, investment, education services, and intermediation services provided by the banking sector; and (ii) efficiency units of the three types of

[4]For simplicity we abstract from the fact that part time work may be paid less.

labor. They are all exchanged in competitive markets. We let the price of the final good act as the numeraire.

Production technology: The final good is produced by a representative firm which operates a constant returns to scale (CRS) technology

$$F\left(K, \mathcal{H}\left(H_{LH}, H_{HS}, H_{CL}\right)\right)$$

employing physical capital K, which depreciates at rate $\delta \in (0,1)$, and the three types of human capital bundled in the aggregator $\mathcal{H}$, also displaying CRS. Each human capital stock H_e is the sum of individual hours worked times efficiency units of labor, ε_j^e, over all working-age individuals within each education group. Recall that the stock H_{HS} is also augmented by the effective labor supply of the college students. We denote by w^e the equilibrium price of an effective hour of labor of type e.

Education sector: The education sector offers a range of college degrees. Each degree has the same pecuniary return, but different non-pecuniary attributes, and hence different operating costs ϕ per year of college, per student.[5] Since the sector is competitive, ϕ is also the price of attending a year of college faced by the student, i.e. the tuition fees (before grants and loans). We summarize this heterogeneity through the distribution $\Phi\left(\bar{\phi}, \sigma_\phi\right)$. High school education is financed by the government, and is included in government expenditures G.

Financial assets and markets: There are three financial assets, all risk-free, traded in competitive markets: (i) a claim on physical capital used as a vehicle for saving, with equilibrium interest rate r; (ii) one-period government bonds carrying the same interest rate r by no-arbitrage; and (iii) a one-period private loan contract exchanged among households through the banking system. Households with positive savings receive from banks an equilibrium interest rate which must equal r (again, by no-arbitrage). Banks lend the funds to other households with borrowing needs at the rate $r^p = r + \iota$, where the wedge between the two interest rates is the cost of overseeing the loans ($\iota > 0$ per unit of consumption intermediated).

Individuals face a private debt limit that varies with phases of the life-cycle. Retirees and high-school students cannot borrow. In the work-stage, agents can borrow in private markets

[5] Relevant non-pecuniary attributes explaining differences in tuition fees are prestige, location, characteristics of student body, infrastructures, etc. Actual differences in tuition fees clearly also reflect differentials in the quality of the degree. The model could be extended to incorporate this additional dimension of heterogeneity, but to avoid further complexity we have abstracted from college quality.

up to a limit $\underline{a}$. A subset of college students –those whose parental net worth is above a given threshold a^{**}— can borrow privately up to $\underline{a}^p$, at the equilibrium interest rate rate r^p. We think of these students as having either an excellent credit score, or as being safe borrowers from the banks' viewpoint because of their parental wealth.[6]

Finally, there are perfect annuity markets insuring retired households' survival risk.

2.6 Education and fiscal policies

The government offers grants and loans to help students who are considering college education.[7] We model the financial aid program to reproduce the key features of the US system which we describe in Appendix F. The government assesses parental wealth at the age of the inter vivos transfer j^{TR} to determine eligibility status q of the child for financial aid.

Education loans: If parental wealth $a_{j^{TR}}$ is below the threshold a^*, then $q = 1$ and children qualify for subsidized government loans up to a limit $\underline{b}^s$. Interest on subsidized loans is forgiven during college, and cumulates at rate r^s during working life. Students of type $q = 1$ who have reached the borrowing limit for subsidized loans can access additional unsubsidized loans up to $\underline{b}^u$. Unsubsidized loans cumulate interest at rate r^u both during and after college.

If parental wealth $a_{j^{TR}}$ is between a^* and a^{**}, then $q = 2$ and children qualify only for unsubsidized loans up to the cumulative limit $\underline{b}^s + \underline{b}^u$. Recall that if parental wealth is above a^{**}, students can also borrow privately at the rate r^p. Because $r^u \geq r^p$, these students will use government loans only if they need to borrow beyond the private borrowing limit $\underline{a}^p$. For this third group of students, $q = 3$.

All government loans are subject to a fixed repayment scheme: for n periods after the start of employment, the individual repays an amount π every period until exhaustion of all the principal plus interest.[8] Therefore, the last period of repayment in the individual life cycle is

[6]Actual interest rates on private educations loans depend on the credit score because of default risk. See Ionescu and Simpson (2012). As a result, poor families with low credit scores face high borrowing rates on private education loans. Implicitly, we are assuming that these rates are so high that these families choose not to use the private market to finance education of their kids. We choose a^{**} to replicate the fraction of households who borrow privately.

[7]Some states make large transfers to local colleges. Since we focus on federal policies, we exclude these transfers from the model's government budget constraint. These transfers also explain part of the variation in out-of-pocket fees for students, which we model explicitly.

[8]The fixed repayment schedule is another reason why an individual with type $q = 3$ who can borrow privately (and hence with a flexible repayment schedule) will prefer to do that before tapping into federal loans.

$j^{CL} + n < j^{TR}$.[9] In summary, the key exogenous policy parameters of the education loan program are $\{n, a^*, r^s, r^u, \underline{b}^s, \underline{b}^u\}$.

If at the end of college the individual has an amount $b_{j^{CL}} < 0$ of education debt, π is determined by the actuarial formula

$$\pi = \begin{cases} -\frac{r^s}{1-(1+r^s)^{-n}} b_{j^{CL}} & \text{if } q = 1 \text{ and } -\underline{b}^s \leq b_{j^{CL}} < 0 \\ \frac{r^s}{1-(1+r^s)^{-n}} \underline{b}^s - \frac{r^u}{1-(1+r^u)^{-n}} \left(b_{j^{CL}} + \underline{b}^s\right) & \text{if } q = 1 \text{ and } b_{j^{CL}} < -\underline{b}^s \\ -\frac{r^u}{1-(1+r^u)^{-n}} b_{j^{CL}} & \text{if } q \in \{2,3\} \text{ and } b_{j^{CL}} < 0 \end{cases} \tag{2}$$

which shows that, given the policy parameter triplet (r^s, r^u, n), there is a one-to-one mapping between the pair $\left(b_{j^{CL}}, q\right)$ and π.

Education grants: Grants are awarded by the government through the formula $g(q, \theta)$ where the dependence on (q, θ) makes grants a function of both parental wealth and students' ability. Hence, we allow grants to be both need-based and merit-based.

Fiscal policies: The government levies proportional taxes at rate τ_c on consumption, τ_w on labor earnings, and τ_k on capital income and pays a lump-sum transfer ψ which makes the system progressive.[10] Tax revenues are used to finance non-valued government consumption G, transfers, education policies, a social security system that pays pension benefits p^e to all workers of type e, and interest to service debt rD, where D is the stock of outstanding government bonds.[11]

2.7 The individual problem in recursive form

It is convenient to describe the individual problem backward, from retirement to schooling.

[9] Enforceability of government students loans is very high: student loans cannot be expunged by bankruptcy, and wage garnishments and tax offsets can be used as repayments. In light of these features we assume they are fully enforceable. The assumption that n is such that the individual must finish its repayment before the inter vivos transfer is made for tractability. This restriction is not binding when the model is calibrated to US data on typical repayment periods of this type of debt contracts, which is typically 20 years.

[10] The tax τ_k is levied only on positive capital income. We use τ_k throughout with the convention that if $a < 0$ (and therefore $r = r^p$) then $\tau_k = 0$.

[11] Since government debt needs no intermediation through the financial sector to be exchanged, the government can borrow at the cheaper rate r relative to the households' borrowing rate $r^p = r + \iota$. Alternative assumptions have no significant bearing on the results.

Retirement stage: From age $j^{WK}+1$ to age J, the individual solves:

$$\begin{aligned}
\Omega_j\left(e,a_j\right) &= \max_{c_j,a_{j+1}} u\left(c_j,1\right)+\beta\zeta_{j+1}\Omega_{j+1}\left(e,a_{j+1}\right) \\
& s.t. \\
\left(1+\tau_c\right)c_j+a_{j+1} &= p^e+\psi+\left(\zeta_{j+1}\right)^{-1}\left[1+r\left(1-\tau_k\right)\right]a_j \\
a_{j+1} &\geq 0, \quad c_j\geq 0
\end{aligned} \tag{3}$$

where p^e is a social security benefit conditional on the education level (the reason why e remains a state variable of this problem besides wealth a_j). The term ζ_{j+1} in the budget constraint reflects the perfect annuity markets assumption. The retired agent does not work $(l_j=1)$ and cannot borrow.

Work stage after the inter vivos transfer: From age $j^{TR}+1$ until retirement, the working individual solves:

$$\begin{aligned}
W_j\left(e,a_j,\theta,z_j\right) &= \max_{c_j,l_j,a_{j+1}} u\left(c_j,l_j\right)+\beta\mathbb{E}_z W_{j+1}\left(e,a_{j+1},\theta,z_{j+1}\right) \\
& s.t. \\
\left(1+\tau_c\right)c_j+a_{j+1} &= \left(1-\tau_w\right)w^e\varepsilon_j^e\left(\theta,z_j\right)\left(1-l_j\right)+\psi+\left[1+r\left(1-\tau_k\right)\right]a_j \\
a_{j+1} &\geq -\underline{a}, \quad c_j\geq 0, \quad l_j\in[0,1] \\
z_{j+1} &\sim \Gamma_z^e\left(z_{j+1}\mid z_j\right)
\end{aligned} \tag{4}$$

The individual state variables in this problem are education level e, asset holdings a_j, ability θ, and the productivity shock z_j. The variable w^e is the price of an effective hour ε_j^e of labor of type e. Workers can borrow up to an exogenously set debt limit $\underline{a}$ from private markets. In the last period of work before retirement $\left(j=j^{WK}\right)$ the continuation value is replaced by $\zeta_{j^{WK}+1}\Omega_{j^{WK}+1}\left(e,a_{j^{WK}+1}\right)$.

Work stage in the period of the inter vivos transfer: At age j^{TR}, the individual problem reads:

$$\begin{aligned}
W_j\left(e, a_j, \theta, z_j, \hat{\theta}\right) &= \max_{c_j, l_j, \hat{a}_0, a_{j+1}} u\left(c_j, l_j\right) + \beta\left[\mathbb{E}_z W_{j+1}\left(e, a_{j+1}, \theta, z_{j+1}\right) + \omega \mathbb{E}_{\hat{z}_0} V^*\left(\hat{a}_0, \hat{\theta}, \hat{z}_0, q\right)\right] \\
& s.t. \\
\left(1+\tau_c\right) c_j + a_{j+1} + \hat{a}_0 &= \left(1-\tau_w\right) w^e \varepsilon_j^e\left(\theta, z_j\right)\left(1-l_j\right) + \psi + \left[1 + r\left(1-\tau_k\right)\right] a_j \qquad (5) \\
a_{j+1} &\geq -\underline{a}, \quad \hat{a}_0 \geq 0, \quad c_j \geq 0, \quad l_j \in [0,1] \\
z_{j+1} &\sim \Gamma_z^e\left(z_{j+1} \mid z_j\right), \quad \hat{z}_0 \sim \Gamma_0^{LH} \\
q &= \begin{cases} 1 & \text{if } a_j \leq a^* \\ 2 & \text{if } a^* < a_j \leq a^{**} \\ 3 & \text{if } a_j > a^{**} \end{cases}
\end{aligned}$$

The altruistic parent puts weight $\omega \in [0,1]$ on the discounted utility $V^*\left(\hat{a}_0, \hat{\theta}, \hat{z}_0, q\right)$ of her child. At this date, parents know their child's ability $\hat{\theta}$, but need to form expectations about the child's productivity next period in order to choose the transfer $\hat{a}_0$. The transfer determines the initial asset position of the child in the period when she becomes an independent decision maker. Parental wealth determines the child's eligibility status for financial aid (q). The constraint $\hat{a}_0 \geq 0$ means that parents cannot force kids to transfer resources to them.[12]

Work stage between full repayment of government-sponsored loan & inter vivos transfer: Over this period, the household's problem is exactly as in (4). The only difference being that, in the period just before the transfer (age $j = j^{TR} - 1$), the continuation value in (4) is replaced by $\mathbb{E}_{z,\hat{\theta}} W_{j^{TR}}\left(e, a_{j^{TR}}, \theta, z_{j^{TR}}, \hat{\theta}\right)$, defined above in equation (5) where the expectation over $\hat{\theta}$ is computed based on the conditional distribution $\Gamma_\theta\left(\hat{\theta}, \theta\right)$.

Work stage before full repayment of government-sponsored loan: In this stage, the individual solves:

$$\begin{aligned}
W_j\left(e, a_j, \theta, z_j, \pi\right) &= \max_{c_j, l_j, a_{j+1}} u\left(c_j, l_j\right) + \beta \mathbb{E}_z W_{j+1}\left(e, a_{j+1}, \theta, z_{j+1}, \pi\right) \qquad (6) \\
& s.t. \\
\left(1+\tau_c\right) c_j + a_{j+1} &= \left(1-\tau_w\right) w^e \varepsilon_j^e\left(\theta, z_j\right)\left(1-l_j\right) + \psi + \left[1 + r\left(1-\tau_k\right)\right] a_j - \pi \\
a_{j+1} &\geq -\underline{a}, \quad c_j \geq 0, \quad l_j \in [0,1] \\
z_{j+1} &\sim \Gamma_z^e\left(z_{j+1} \mid z_j\right)
\end{aligned}$$

[12] This constraint is here for clarity, but it is not necessary to restrict the solution to the optimization problem since, at age $j = 1$ (high-school), students cannot borrow.

where the main difference with problem (4) is the presence of the additional state variable π, the size of the fixed repayment of the government-sponsored education loan.

College education: Let (a_j, b_j) be private net worth and government education debt, respectively. Furthermore, let ϕ be the idiosyncratic tuition cost faced by a student. College students between ages $j^{HS}+1$ and j^{CL} solve:

$$\begin{aligned} V_j\left(CL, a_j, b_j, \theta, q, \phi\right) &= \max_{c_j, l_j, a_{j+1}, b_{j+1}} u\left(c_j, l_j\right) - \kappa^{CL}\left(\theta, q\right) + \beta V_{j+1}\left(CL, a_{j+1}, b_{j+1}, \theta, q, \phi\right) \\ & \quad s.t. \\ c &\geq 0, \quad l_j \in [0, 1-\bar{t}] \end{aligned} \tag{7}$$

where $\kappa^{CL}(\theta, q)$ is the psychic cost of attending college. Their budget constraint depends on their eligibility status q. A student who qualifies for a subsidized government loan $(q=1)$ faces the budget constraint:

$$\begin{aligned} & (1+\tau_c)\, c_j + a_{j+1} + b_{j+1} - (1-\tau_w)\, w^{HS} \varepsilon_j^{HS}(\theta, 0)\,(1-\bar{t}-l_j) - \psi + \phi - g(q, \theta) = \\ = & \begin{cases} [1 + r(1-\tau_k)]\, a_j & \text{if } a_j \geq 0, \quad b_j = 0 \\ b_j & \text{if } a_j = 0, \quad 0 > b_j \geq -\underline{b}^s \\ -\underline{b}^s + (1+r^u)(b_j + \underline{b}^s) & \text{if } a_j = 0, \quad b_j < -\underline{b}^s \end{cases} \end{aligned} \tag{8}$$

$$a_{j+1} \geq 0 \quad b_{j+1} \geq -\left(\underline{b}^s + \underline{b}^u\right)$$

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

$$\begin{aligned} & (1+\tau_c)\, c_j + a_{j+1} + b_{j+1} - (1-\tau_w)\, w^{HS} \varepsilon_j^{HS}(\theta, 0)\,(1-\bar{t}-l_j) - \psi + \phi - g(q, \theta) = \\ = & \begin{cases} [1 + r(1-\tau_k)]\, a_j & \text{if } a_j \geq 0, \quad b_j = 0 \\ (1+r^u)\, b_j & \text{if } a_j = 0, \quad b_j < 0 \end{cases} \end{aligned} \tag{9}$$

$$a_{j+1} \geq 0 \quad b_{j+1} \geq -\left(\underline{b}^s + \underline{b}^u\right)$$

If the student's parental wealth is high enough that she can also borrow privately $(q=3)$, she faces the following budget constraint:

$$\begin{aligned}
&(1+\tau_c)\,c_j + a_{j+1} + b_{j+1} - (1-\tau_w)\,w^{HS}\varepsilon_j^{HS}(\theta,0)\,(1-\bar{t}-l_j) - \psi + \phi - g(q,\theta) = \\
&= \begin{cases} [1+r(1-\tau_k)]\,a_j & \text{if } a_j \geq 0, \quad b_j = 0 \\ (1+r^p)\,a_j & \text{if } 0 > a_j > -\underline{a}^p, \quad b_j = 0 \\ (1+r^p)\,\underline{a}^p + (1+r^u)\,b_j & \text{if } a_j = -\underline{a}^p, \quad b_j < 0 \end{cases} \qquad (10) \\
&a_{j+1} \geq -\underline{a}^p \quad b_{j+1} \geq -\left(\underline{b}^s + \underline{b}^u\right).
\end{aligned}$$

Finally, the continuation value in the last period of college is replaced by $\mathbb{E}_z W_{j^{CL}+1}\left(CL, a_{j^{CL}+1}, \theta, z_{j^{CL}+1}, \pi\right)$ where $z_{j^{CL}+1} \sim \Gamma_0^{CL}$, and π is determined by equation (2) based on $b_{j^{CL}+1}$ and q.

College decision: At age $j = j^{HS}+1$, the student draws her tuition cost ϕ from the distribution $\Phi(\overline{\phi}, \sigma_\phi)$, and choose whether to attend college. Given this draw they solve

$$V^{**}(a_j, \theta, z_j, q, \phi) = \max\ \left\{V_j(CL, a_j, b_j, \theta, q, \phi), \mathbb{E}_z W_j(HS, a_j, \theta, z_j)\right\} \qquad (11)$$

The dummy variable $d^{CL} \in \{0,1\}$ reflects the college education decision.[13]

High-school education: A high-school student solves:

$$\begin{aligned}
V_j(HS, a_j, \theta, q) &= \max_{c_j, a_{j+1}} u(c_j, 1-\bar{t}) - \kappa^{HS}(\theta, q) + \beta V_{j+1}(HS, a_{j+1}, \theta, q) \qquad (12) \\
& \quad s.t. \\
(1+\tau_c)\,c_j + a_{j+1} &= [1+r(1-\tau_k)]\,a_j + \psi \\
a_{j+1} &\geq 0, \quad c_j \geq 0
\end{aligned}$$

High-school students are not permitted to borrow. In the last period of high-school $\left(j = j^{HS}\right)$, the continuation value is $\mathbb{E}_{z,\phi} V^{**}(a_{j+1}, \theta, z_{j+1}, q, \phi)$ where V^{**} is defined above.

High-school decision: At age $j = 0$, the student chooses whether to enter the labor market as a high-school dropout or stay in school. If she chooses to work she draws $z_0 \sim \Gamma_{z_0}^{LH}$, the initial productivity level. So, each individual solves:

$$V^{*}(\hat{a}_0, \theta, z_0, q) = \max\ \left\{V_0(HS, \hat{a}_0, \theta, q), \mathbb{E}_z W_0(LH, \hat{a}_0, \theta, z_0)\right\} \qquad (13)$$

[13] The presence of discrete education choices introduces non-convexities in the budget sets. This implies that standard results on uniqueness and continuity of optimal policy functions cannot be applied to this problem. For a discussion of related issues and the numerical solution of this problem see Gallipoli and Nesheim (2007).

where $\hat{a}_0$ is the transfer received from the parent, θ is innate ability, and q is eligibility status for college support (grants and loans), which depends on parental wealth. The high-school enrollment decision is denoted $d^{HS} \in \{0, 1\}$.

2.8 Equilibrium

It is useful to introduce some additional notation to simplify the definition of an equilibrium. Let $\mathbf{s}_j \in S_j$ denote the age-specific state vector implicit in the recursive representation of the agents' problems above. We also define $\mathbf{s}_j^e$ to be the state vector minus the education level (the school cycle they are in for students), i.e., $\mathbf{s}_j^e \equiv \{\mathbf{s}_j \setminus e\} \in S_j^e$.

A *stationary recursive competitive equilibrium* for this economy is a collection of: (i) individual decision rules for consumption, leisure, wealth holdings, and college students' debt $\left\{c_j(\mathbf{s}_j), l_j(\mathbf{s}_j), a_{j+1}(\mathbf{s}_j), b_{j+1}\left(\mathbf{s}_j^{CL}\right)\right\}$, inter vivos transfers $\left\{\hat{a}_0\left(\mathbf{s}_{j^{TR}}\right)\right\}$, and education choices $\left\{d^{HS}(\mathbf{s}_0), d^{CL}\left(\mathbf{s}_{j^{HS}}\right)\right\}$; (ii) value functions $\{V_j(\mathbf{s}_j), W_j(\mathbf{s}_j), \Omega_j(\mathbf{s}_j)\}$; (iii) aggregate capital and labor inputs
$\{K, H_{LH}, H_{HS}, H_{CL}\}$; (iv) prices $\left\{r, w^{LH}, w^{HS}, w^{CL}\right\}$; (v) labor income tax $\{\tau_w\}$; (vi) age and education specific measures $\left\{\mu_j^e\right\}$ such that:

1. Decision rules $\left\{c_j(\mathbf{s}_j), l_j(\mathbf{s}_j), a_{j+1}(\mathbf{s}_j), b_{j+1}\left(\mathbf{s}_j^{CL}\right), \hat{a}_0\left(\mathbf{s}_{j^{TR}}\right), d^{HS}(\mathbf{s}_0), d^{CL}\left(\mathbf{s}_{j^{HS}+1}\right)\right\}$ solve their respective individual problems (3), (4), (5), (6), (7), (11), (12) , and (13). And $\{V_j(\mathbf{s}_j), W_j(\mathbf{s}_j), \Omega_j(\mathbf{s}_j)\}$ are the associated value functions.

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

$$\begin{aligned} r + \delta &= F_K\left(K, \mathcal{H}\left(H^{LH}, H^{HS}, H^{CL}\right)\right) \\ w^e &= F_{H^e}\left(K, \mathcal{H}\left(H^{LH}, H^{HS}, H^{CL}\right)\right), \text{ for } e \in \{LH, HS, CL\}. \end{aligned} \tag{14}$$

3. The labor market for each educational level $e \in \{LH, HS, CL\}$ clears

$$H^e = \sum_{j=j^e+1}^{j^{WK}} \int_{S_j^e} \varepsilon^e \left[1 - l\left(e, \mathbf{s}_j^e\right)\right] d\mu_j^e + I_{\{e=HS\}} \cdot \sum_{j=j^{HS}+1}^{j^{CL}} \int_{S_j^{CL}} \varepsilon^{CL}(\theta, 0) \left[1 - \bar{t} - l\left(e, \mathbf{s}_j^{CL}\right)\right] d\mu_j^{CL}$$

where the second term in the sum is the effective labor supply of college students.

4. The intermediation market clears at the price $r^p = r + \iota$.

5. The asset market clears

$$K + D = \sum_{\substack{e \in \{LH, HS\}, j \geq 0 \\ e = CL, j \geq j^{HS}+1}} \int_{S_j^e} a_j \left(e, \mathbf{s}_j^e\right) d\mu_j^e$$

   and the aggregate net worth of all households (right-hand side) equals the capital stock plus government debt (left-hand side).

6. The goods market clears

$$\sum_{e,j} \int_{S_j^e} c_j \left(e, \mathbf{s}_j^e\right) d\mu_j^e + \delta K + G + \Phi + \Upsilon = F\left(K, \mathcal{H}\right)$$

   where Φ is the aggregate amount of private expenditures in educational services by college students

$$\Phi = \sum_{j=j^{HS}+1}^{j^{CL}} \int_{S_j^{CL}} \phi d\mu_j^{CL}$$

   and Υ is the revenue of the intermediating sector

$$\begin{aligned} \Upsilon &= \iota \cdot \sum_{\substack{e \in \{LH, HS\}, j \geq 0 \\ e = CL, j \geq j^{HS}+1}} \int_{S_j^e} I_{\{a_j < 0\}} a_j \left(e, \mathbf{s}_j^e\right) d\mu_j^e \\ &\quad + \iota \cdot \sum_{j \geq j^{HS}+1}^{j^{CL}} \int_{S_j^{CL}} b_j d\mu_j^{CL} + \iota \cdot \sum_{j \geq j^{CL}+1}^{j^{CL}+n} \int_{S_j^{CL}} \left[b_{jCL} - \pi \cdot \left(j - j^{CL}\right)\right] d\mu_j^{CL} \end{aligned}$$

   where the three terms are, respectively, the intermediation services for private loans, student loans during college, and student loans during the repayment phase of working life.

7. The government budget constraint holds

$$G + \left(\sum_e p^e \sum_{j=j^{WK}+1}^{J} \int_{S_j^e} d\mu_j^e\right) + \psi + rD + E = \tau_c \sum_{e,j} \int_{S_j^e} c_j \left(e, \mathbf{s}_j^e\right) d\mu_j^e + \tau_w \sum_e w^e H_e + \tau_k r K$$

where E are net government expenditures in college education:

$$\begin{aligned} E &= \sum_{j \geq j^{HS}+1}^{j^{CL}} \int_{S_j^{CL}} \left[g\left(q, \theta\right) - \Delta b_j \right] d\mu_j^{CL} + \iota \sum_{j \geq j^{HS}+1}^{j^{CL}} \int_{S_j^{CL}} b_j d\mu_j^{CL} \\ &- r^u \sum_{j \geq j^{HS}+1}^{j^{CL}} \int_{S_j^{CL}} \left[I_{\{q=1, b_j < -\underline{b}^s\}} \cdot \left(b_j + \underline{b}^s\right) + I_{\{q \geq 2\}} \cdot b_j \right] d\mu_j^{CL} \\ &- \sum_{j \geq j^{CL}+1}^{j^{CL}+n} \int_{S_j^{CL}} \pi d\mu_j^{CL}. \end{aligned}$$

Government outlays (first row) are determined by grants and the total amount of loans extended to college students which is equal to the sum of the Δb_j increments in each year, plus the intermediation cost (ι) incurred on all outstanding loans. Revenues (second and third rows) are determined by interest on unsubsidized loans during college and debt repayments after graduation.

8. Individual and aggregate behaviors are consistent: the vector of measures $\mu = \{\mu_0^e, ..., \mu_J^e\}_{e \in \{LH, HS, CL\}}$ is the fixed point of $\mu\left(S\right) = Q\left(S, \mu\right)$ where (i) $Q\left(S, \cdot\right)$ is a transition function generated by the individual decision rules, the exogenous laws of motion $\left\{\Gamma_\theta, \Gamma_z^e, \Gamma_{z_0}^e\right\}$, the distribution Φ, the institutional rules determining π, q, and p_e, and the survival rates $\{\zeta_j\}$; (ii) and S is the generic subset of the Borel-sigma algebra $\mathcal{B}_S$ defined over the state space $\mathbf{S}$, the Cartesian product of all S_j^e.

3 Parameterization of the model

We describe below how we parameterize the model economy. Some of the parameters are calibrated "internally" from the equilibrium of the model, while others are estimated "externally" directly from data. All parameter values are reported in Table 5.

Demographics: A model period is one year. Individuals become adults at the real age of 16 (i.e. $j = 0$ in the model), and they can live up to age 99, after which death is certain. Retirement occurs at age 65. Inter vivos transfers are made at age 48. The conditional survival rates $\{\zeta_j\}$ are taken from the Actuarial Life Tables for the United States.

Preferences: We specify period utility over consumption and leisure as a CRRA function

$$u\left(c_j, l_j\right) = \frac{\left(c_j^{\nu} l_j^{1-\nu}\right)^{1-\gamma}}{1-\gamma}. \tag{15}$$

The parameters ν and γ jointly pin down (i) the level of labor supply over the life cycle, (ii) the inter-temporal elasticity of substitution of consumption (IES) $1/\left[1-\nu\left(1-\gamma\right)\right]$, and (iii) the Frisch labor supply elasticity $\left[1-\nu\left(1-\gamma\right)\right]/\gamma \cdot \left(l_j/\left(1-l_j\right)\right)$ which, with this preference specification, depends on hours worked.

The weight of leisure in preferences, ν, is set to 0.385 to match average hours worked, estimated to be 35% of the time endowment. Hence, a value of $\gamma = 2$ is required to match an inter-temporal elasticity of substitution of 0.75 as estimated by Blundell, Browning, and Meghir (1994) and Attanasio and Weber (1993). The Frisch elasticity evaluated at the (non-stochastic) average hours worked $\bar{h} = \nu$ implied by this choice of ν and γ is 1.25.[14]

Patience and altruism: The value for β is chosen to reproduce a ratio of median net worth to average income, which is estimated to be 1.64 using the 2001 Survey of Consumer Finances.[15]

To calibrate the degree of altruism towards offsprings ω, we target the size of intervivos transfers in the data. Because we model early inter vivos transfers as one-off gifts from parents to their child, we restrict attention to the cumulative transfer between age 16 and 22. 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 A 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. In our calculations we also include imputed rents for students living in their parents' house.[16] The average inter vivos transfer over the seven-year period considered is $30,566. The data show large heterogeneity of IVTs in the population: for example, college students receive twice as much as high-school dropouts.

[14]This value is on the high end of micro-estimates for men, but on the low end for women. See Keane and Rogerson (2011) for a recent survey.

[15]It is well known that the SCF oversamples the rich households relative to the CPS, PSID, and NLSY, the other surveys we use to parameterize the model. To make the SCF more comparable to the other surveys, we exclude the top 5% of households ranked by net worth. The sample selection is the same as in Kaplan and Violante (2012).

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

	Children					
Mothers	1	2	3	4	5	Total
1	45.5	23.8	19.7	6.5	4.7	100
2	25.8	24.2	24.2	15.7	11.0	100
3	16.0	22.3	27.1	19.0	15.7	100
4	11.4	17.1	25.7	20.9	24.9	100
5	7.2	7.6	19.5	24.2	41.5	100
Total	21.3	19.2	23.2	17.1	19.2	100

Table 1: Ability transition, by quintile. Each cell reports the conditional probability in %. Quintile 1 is the lowest, quintile 5 is the highest. (NLSY79)

Intergenerational transmission of ability: In our model "ability" θ represents a set of permanent characteristics which affect lifetime earnings as well as education attainment. For the purpose of measuring the distribution of ability over the population we use NLSY data. The NLSY79 provides IQ test scores for both mothers and children, which we link in order to estimate an ability transition matrix Γ_θ.

Using the "Children of the NLSY79" survey, we build pairs of mother and child test-score measurements. For mothers we use AFQT89 measurements, whereas for children we choose the PIAT Math test-scores.[17] Mothers and children are ranked based on their own test scores, and then split into quintiles. We then compute a "quintile-transition" matrix, which assigns a probability to the event that a child ends up in a given ability group, given the observed ability rank of the parent.[18] Note that in the model we allow for θ to be continuous by assuming a uniform distribution of abilities within each of the five bins.

The estimated ability transition matrix across quintiles is reported in Table 1. 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 diagonal element is larger.

Disutility of schooling: The psychic costs of attending high-school and college consist of

[17]No AFQT measure is available for children, and the PIAT Math score is generally considered the most accurate measure of future ability among the available test-scores. Often the test was administered at different ages to the same child. We use the latest available measurement, as we wish to approximate the distribution of ability at age 16. Details about the procedure used to compute the ability-transition matrix and the test scores used can be found in Appendix B.

[18]We also estimate transition matrices based on 10 ability bins, and results are similar. Moreover, the transition matrix is virtually identical when we use a smaller sample including only mother-child pairs in which the child was at least 13 years of age at the time of the test.

	Quintile (AFQT89)					
Education	1	2	3	4	5	Total
Less than H.S.	32.0	9.2	3.9	1.0	0.3	9.5
H.S. Graduate	66.2	83.0	78.5	61.9	31.0	65.0
College Graduate	1.8	7.7	17.6	37.1	69.0	26.0

Table 2: Education shares (%) by AFQT89 quintile (NLSY79).

two additive components, respectively changing by ability and family background (wealth) : $\kappa^e(\theta, q) = \kappa^e_\theta(\cdot)+\kappa^e_q(\cdot)$. The first component (5 values, corresponding to the 5 ability quintiles) is set to reproduce high-school and college enrolment rates by ability. The AFQT89 scores (over the entire NLSY79 sample) can be matched with the education level of the subjects to measure education shares by ability level. The NLSY79 education shares by ability bin are reported in Table 2. [19]

Psychic costs based on family background, $\kappa^e_q(\cdot)$, are normalized to zero for $q = 1$ and set equal for $q = 2, 3$. These remaining two parameters (one for high-school students and one for college students) are set to match two ratios: (i) the average transfer received by a college graduate divided by the average transfer received by a high school graduate, which is 1.93 in the data, and (ii) the average transfer received by a high school graduate divided by the average transfer received by a high school drop-out, which is 1.05 in the data.[20] We estimate psychic costs of attending college of a magnitude comparable to that estimated by Heckman, Lochner, and Todd (2006). Moreover, we find that they are decreasing in parental wealth. We return to this result below. Appendix C contains a detailed discussion of the estimated psychic costs.

[19]Because the age and education structure of the NLSY cohort is not representative of the overall working population in any given year, we rescaled the size of each education/ability cell so that their aggregation yields the correct fraction of 16-65 years-old individuals in the three education groups for the year 2000, as estimated in the CPS (26.1 pct of college graduates, 59.8 pct of HS graduates and 14.1 of HS dropouts). The distribution by ability within each education group remains unchanged.

[20]It is important to match these statistics for the following reason. If we do not allow children of rich families to have low psychic cost from acquiring education, the wealth effect on their labor supply is so large that they choose to remain uneducated and their parents make a very large transfer. As a result, the distribution of initial wealth by education level becomes counterfactual (many low educated young individuals are very rich). The model, indeed, calls for a large utility gain of schooling for children of wealthy households. A more direct way to compute these psychic cost terms would be targeting enrollment by parental wealth. However, parental net worth (as reported by parents themselves in the 1997 wave of the NLSY97) is of poor quality, as in our sample, more than 40% of individuals have missing values or non-response codes.

Labor supply of students: A report by the National Center for Education Statistics (1998) documents that full-time college students work on average 15 hours in a typical week during college.[21] To reproduce this statistic in the model, we set $\bar{t} = 0.312$ in (7), i.e., attending college reduces the time endowment of students by 31%.

Individual labor productivity: The model implies the following reduced-form specification for the hourly wage W_{ijt}^{e} of an individual i of age j, and education level e at date t

$$\log W_{ijt}^{e} = \log w_t^e + \lambda^e \log \theta_i + \xi^e(j_{it}) + u_{ijt}^e, \tag{16}$$

where w_t^e is the marginal product of one efficiency unit of human capital of education-type e, λ^e is the gradient on permanent individual heterogeneity, $\xi^e(j_{it})$ is an education specific age-profile (approximated by a 4-th order polynomial), and u_{ijt}^e is a stochastic residual component.

We use the NLSY79 to estimate reduced-form education-specific wage equations like (16) because the NLSY test scores data (a proxy for θ) can be linked to wage data to quantify the effect of measured ability on lifetime earnings. To overcome the problem that the NLSY provides observations only for workers between age 14 and 45, we use wage data from the PSID 1968-2001 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 –assuming that the unobserved error term is uncorrelated with θ_i– 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_i) was fit in order to recover λ^e (see equation 16). [22] These reduced-form results, reported in Table 3, show a steep gradient by education; a 10% increase in ability implies, on average, a 8.9% increase in hourly wages for college graduates but only a 3.6% increase for dropouts.[23]

The residuals from this regression are a consistent estimate of u_{ijt}^e. We model the unobservable shock u_{ijt}^e as the sum of two independent components

$$u_{ijt}^e = z_{ijt}^e + m_{ijt}^e \tag{17}$$

[21]This number is an average between 37.6% of full-time students not working while enrolled, 13.9% working 1-14 hours, 34.8% working 15-33 hours and 13.7% working 34 hours or more. See NCES (1998, Table 6).

[22]We estimate the above equation for the cross-sectional representative sample as well as the full sample of people in the NLSY79, which includes oversamples for minorities and disadvantaged groups. The two samples give essentially the same results and we report the ones for the larger sample.

[23]The unconditional log AFQT89 distribution is normalized to have mean zero in the regression.

Education group	Gradient (S.E.)	# of indiv.	# of obs.
Less than HS	0.36 (0.06)	1,341	8,982
HS Graduate	0.54 (0.03)	5,403	42,270
College Ggraduate	0.89 (0.09)	1,206	8,719
Pooled	0.71 (0.02)	7,954	60,009

Table 3: Estimated ability gradient λ^e (NLSY79)

where z^e_{ijt} is a (persistent) shock assumed to have an AR(1) structure

$$z^e_{ijt} = \rho_e z^e_{i,j-1,t-1} + \eta^e_{ijt}, \quad \eta^e_{ijt} \overset{iid}{\sim} N\left(0, \sigma^e_{\eta t}\right),$$

and $m^e_{it} \overset{iid}{\sim} N\left(0, \sigma^e_{mt}\right)$ is measurement error (and hence noise from the point of view of the model). Finally, we let the initial draw $z^e_{i0t} \sim N\left(0, \sigma^e_{z_0}\right)$. To estimate the parameters of the error-component model $\left\{\rho_e, \sigma^e_{\eta t}, \sigma^e_{mt}, \sigma^e_{z_0}\right\}$, we use a Minimum Distance Estimator (see Rothenberg, 1971; Chamberlain, 1984; Heathcote, Storesletten, and Violante, 2010). Table 4 reports parameter estimates. Details about our sample selection, estimation of quartic age polynomials, and estimation of the error component model are reported in Appendix D.[24]

Overall, we confirm the finding of Meghir and Pistaferri (2006) that the persistent component of wage risk does not vary systematically across education groups.

Technology: The aggregate production function is Cobb-Douglas and constant returns to scale, i.e.,

$$Y = F(K, \mathcal{H}) = K^{\alpha}\mathcal{H}^{1-\alpha}. \tag{18}$$

We set $\alpha = 1/3$ and let the aggregate human capital stock $\mathcal{H}$ be given by the CES aggregator

$$\mathcal{H} = \left[s^{LH}\left(H^{LH}_t\right)^{\rho} + s^{HS}\left(H^{HS}_t\right)^{\rho} + s^{CL}\left(H^{CL}_t\right)^{\rho}\right]^{\frac{1}{\rho}} \tag{19}$$

where H^e is the stock of human capital associated with education level e, and $s^{LH} + s^{HS} + s^{CL} = 1$. The elasticity of substitution between each pair of labor types is $1/\left(1-\rho\right) \in (0, \infty)$.

[24] By using an observable variable as a proxy for permanent heterogeneity, we avoid selection bias in the estimation of the process for u^e_{ijt}. 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.

Less than HS		HS Graduates		College graduates	
ρ	0.936	ρ	0.951	ρ	0.945
σ_{z0}^2	0.105	σ_{z0}^2	0.101	σ_{z0}^2	0.128
σ_{η}^2	0.020	σ_{η}^2	0.017	σ_{η}^2	0.020
σ_{m}^2	0.070	σ_{m}^2	0.055	σ_{m}^2	0.052

Table 4: Estimated parameters of the process for individual efficiency units u_{ijt} (NLSY79)

From the iso-elastic CES specification for the human capital aggregate in equation (19), and the equilibrium condition in the labor market (14), we can derive expressions for the wage bills ϖ_t^e. For education groups HS and CL, for example, we can write

$$\log\left(\frac{\varpi_t^{CL}}{\varpi_t^{HS}}\right) = \log\left(\frac{s_t^{CL}}{s_t^{HS}}\right) - (1-\rho)\log\left(\frac{H_t^{CL}}{H_t^{HS}}\right) \tag{20}$$

To estimate the above equation, we use wage and hours data from the Current Population Survey (CPS) for 1968-2001 (see Heckman, Lochner, and Taber, 1998a). After computing total aggregate wage bills year by year, we divide them by the (normalized) marginal products of the three types of human capital $\left\{w_t^{LH}, w_t^{HS}, w_t^{CL}\right\}$ estimated from from PSID data (see Appendix D) to obtain point estimates of aggregate efficiency-weighted labor supply (human capital aggregates) by education level and year. Because of the well documented relative demand shifts over the period considered, in the equation above we let share parameters vary over time, i.e., $s_t^e = \exp(s_0^e + g^e t)$, where t denotes calendar year and g^e captures the growth rate in each human capital share of type e.

To account for the endogeneity of schooling choices in the estimation of equation (20), we instrument the human capital aggregates in two ways: in the first, we use lagged variables; in the second, we use the total number of individuals with a given level of education regardless of their labor force status. The latter instruments do not depend on the serial correlation properties of the technology shocks. Results do not change much with the choice of instruments chosen nor with the specification. The estimated value for ρ ranges between 0.36 and 0.68, which corresponds to an elasticity of substitution between 1.6 and 3.1.[25]. See Appendix E for

[25]Many existing estimates in the literature are based on a two-type skilled/unskilled classification for labor. Katz and Murphy estimate the elasticity of substitution to be 1.41; Heckman, Lochner, and Taber (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. 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

additional details. As a baseline value for the elasticity, we choose its higher bound of 3.1 representing also a lower bound for the general equilibrium effects. The values of the shares used in the model's simulation are $s^{LH} = 0.16, s^{HS} = 0.39, s^{CL} = 0.45$, which are the estimated values for the year 2000.

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. Following the method of Goldin and Katz (2007) using model simulated data, the log college/high-school wage differential is 0.58, and the log high-school graduate/dropout wage differential is 0.37. These values are similar 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.

Finally, we set the annual depreciation rate of capital at 6.5% (see Heathcote, Storesletten, and Violante, 2010).

In what follows, we specify values for a number of parameters characterizing the government-sponsored loans and grants in our economy. 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 this calibration.

Private borrowing: We set the liquidity constraint $\underline{a}$ for working-age households to reproduce the fraction of the US population aged 16-65 with zero or negative net worth. From the SCF 2001, we estimate this fraction to be 11.2%.[26] We set the wedge ι on private borrowing (for both students and workers) and the limit to private students' loans a^p to match (i) the fraction of college students enrolled at 4-year institutions who borrow privately, which is 4.9%, and (ii) a ratio between the total volume of private loans and the total volume of federal loans of 0.12.

Cost of college: 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 of $6,710 which we match to the

[26] As reported in Table 5, this limit is close to $85,000 and hence quite generous. However, recall that this model has age and education-type "natural borrowing limits" that may be tighter, especially for the middle aged and the elderly workers. For the young workers, the presence of the guaranteed lump sum transfer ψ implies a sizable borrowing ability.

ex-post average tuition cost in the model by appropriately setting the mean $\bar{\phi}$ of a log-Normal distribution for Φ.[27] We set the dispersion of tuition draws σ_ϕ to reproduce, in equilibrium, the percentage of college student who pay lower than average tuition fees, which is 68% in the data.

Grants: Based on data summarized in Appendix F, we assign a grant of $2,829 per year to the students of type $q = 1$, $668 per year to students of type $q = 2$, while students of type $q = 3$ receive on average a grant of $143 per year. This pattern reflects the need-based formula used in the vast majority of cases to award grants. In the baseline model we do not allow grants to vary by ability.

Education loans: The seven policy parameters $\{n, a^*, a^{**}, r^s, r^u, \underline{b}^s, \underline{b}^u\}$ fully characterize the system of government education loans. We set $n = 20$, as repayment schedules of federal loans are easily extended to 20 years. The remaining six parameters are chosen to replicate as closely as possible the following cross-sectional moments in year 2000: (i) 37.3% of students have subsidized Stafford loans, (ii) 21.2% of students have unsubsidized Stafford loans, (iii) 44.9% of students have a Stafford loan, whether subsidized or not, (iv) the average cumulated amount of federal loans at graduation is $17,016, (v) the ratio between the total volume of subsidized and unsubsidized loans is 1.36, (vi) the maximum cumulative amount of Stafford loans is $35,125.[28]

Fiscal policy: We use flat tax rates for labor and capital income, and consumption. Following Domeij and Heathcote (2003), we set $\tau_w = 0.27$, $\tau_k = 0.4$ and $\tau_c = 0.05$. The lump-sum subsidy ψ is set to replicate the degree of progressivity of the tax/transfer system. In particular, we target the ratio of the variance of log post-government income to the variance of log pre-government income, equal to 0.61 in the US (Heathcote, Perri, and Violante, 2010). Domestic government debt D is set at 20 percent of GDP, its value in 2000, since only half of

[27]Tuition charges vary considerably across institutions: average tuition and fees costs in private institutions were $15,000 versus $4,300 in public institutions. Since the model does not distinguish between them, we use a weighted average. We could allow tuition fees to vary by family income, but we find that variation (before grants and loans) is small. For example, families with annual income in the bracket $20,000-$40,000 face average tuition costs of $4,000 ($15,000) at public (private) colleges; families with income between $80,000 and $100,000 face average tuition costs of $4,400 ($17,000) at public (private) institutions. We chose not to include room and board in the calculation of the cost as these expenses are also borne by working individuals.

[28]Under the Stafford loan program, the student cannot borrow more than the full cost of schooling (tuition, books, room, and board). We did not impose this tighter constraint because our measure of college costs ϕ does not include room and board.

Parameter	Value	Moment to Match	Data	Model
J	79	Length of life cycle (age 16-95)	79	79
j^{RET}	50	Length of working life (age 16-65)	50	50
$\{\zeta_j\}$	-	Survival rates (from US Life Tables)	-	-
ν	0.385	Average hours worked	0.35	0.31
γ	2.0	Elasticity of intertemporal substitution	0.75	0.75
β	0.979	Match median wealth-average income ratio	1.64	1.64
$\bar{t}$	0.312	Average student hours-average worker hours ratio	0.33	0.33
ω	0.131	Average inter vivos transfer	$30,566	$31,256
α	0.35	Capital share of GDP	0.35	0.35
δ	0.065	Depreciation rate	0.065	0.065
ρ	0.677	Elasticity of substitution	3.1	3.1
$\underline{a}$	1.39	Fraction of households with net worth ≤ 0	0.11	0.11
$\underline{a}^p$	0.29	Aggr. private/gov. student loans ratio	0.12	0.12
ι	0.0405	Fraction of students with private loan	0.05	0.05
$\overline{\phi}$	-1.7	Average yearly tuition fees	$6,710	$6,690
σ_ϕ	1.0	Fraction paying less than average tuition	0.68	0.65
n	20	Repayment period for student loans (years)	20	20
a^*	3.10	Fraction of students with subsidized loan	0.37	0.36
a^{**}	5.35	Fraction of students with unsubsidized loan	0.21	0.20
r^u	0.043	Average govt. student debt at graduation	$17,016	$18,905
r^s	0.0295	Fraction of students with govt. student loan	0.45	0.45
$\underline{b}^u$	0.295	Aggr. subs./unsubs. student loans ratio	1.36	1.30
$\underline{b}^s$	0.275	Total govt. loans borrowing limit	$35,125	$35,497
τ_w	0.27	Labor income tax rate	0.27	0.27
τ_c	0.05	Consumption tax rate	0.05	0.05
τ_k	0.40	Capital income tax rate	0.40	0.40
D	0.13	Domestic debt-GDP ratio	0.20	0.20
ψ	0.086	Var. of log post-tax inc./Var. of log pre-tax inc.	0.61	0.61
p^{LH}	0.26	Pension replacement rate - Less than HS	0.26	0.26
p^{HS}	0.42	Pension replacement rate - HS Graduates	0.42	0.42
p^{CL}	0.56	Pension replacement rate - College Graduates	0.56	0.56

Table 5: Parameter values for the benchmark economy. In the model, the price (marginal product) of an efficiency unit of labor for a high school graduate w^{HS} is normalized to one, and hence 1=$62,275 in the model. The model's period is one year.

federal debt is held domestically. Pensions are a lump sum for all agents in a given education group. Table 1 in Mitchell and Phillips (2006) reports replacement rates for three types of workers (low, medium, and high earners) whose average labor income closely corresponds to that of our three educational groups. Expressed as a replacement ratio of average gross earnings for the economy, the pension for LH types is 0.26, for HS types is 0.42, and for CL types is 0.56.[29]

[29] These replacement rates show the progressivity of the social security system: even though average gross earnings of college graduates are roughly three times as large as earnings of high-school dropouts, their pension benefits are only twice as large.

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 income persistence in the model (also, not targeted). Fourth, we examine the role of parental wealth in determining educational achievement. Fifth, we "validate" the model by reproducing, within our structural framework, a randomized experiment where a (treatment) group of high-school graduates receives a college tuition subsidy and a (control) group does not.

4.1 Life-cycle profiles

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

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 much faster for the less educated groups over the life cycle. Hours dispersion is higher for the low-educated, who are the most marginally attached to the labor force, and rises over the life cycle for all three 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, Perri, and Violante, 2010).

The rise in average earnings over the life cycle is more pronounced for more educated workers and the late decline in earnings sharper for the less educated. The rise in the variance of log earnings between ages 25 and 60 (around 0.4 log points) is quantitatively consistent with its empirical counterpart (Guvenen, 2009, Figure 4).

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 by roughly 0.06 log points for all groups, compared to a rise four times larger in the variance of log earnings. The downward jump in average consumption at retirement reflects the nonseparability of con-

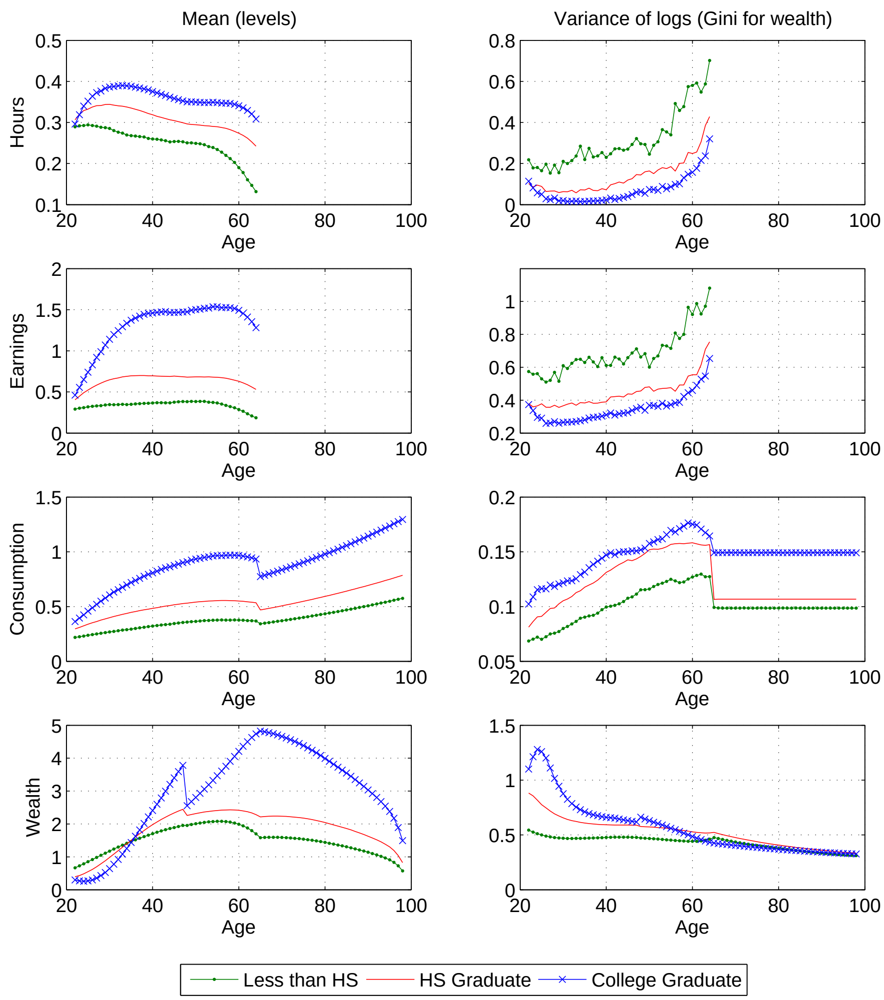

Figure 1: Means and dispersion of log hourly wages (first row), earnings (second row), consumption (third row), and wealth (fourth row).

sumption and leisure. The average drop in expenditures at retirement is around 14%, in line with the empirical evidence. For example, Aguiar and Hurst (2005) estimate a drop of 17%.[30]

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 the 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 aggressively to enrol 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

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

magnitude of this decline is very close to its empirical counterpart, as documented in Kaplan (2011) from SCF data.

4.2 Determination of inter vivos transfers

Two opposing forces shape the parent's decision of how much to transfer to their child. The first purpose is narrowing the gap between parent's and child's lifetime utilities, and the extent to which parents want to close this gap depends on the degree of altruism ω. This motive (intergenerational smoothing) is strongest for low ability (and low earnings potential) children, especially those with rich parents. 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. However, for the reasons discussed above, IVTs are not monotonic in child's ability (right panel). For low levels of ability the intergenerational smoothing 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. Note that this reversal of slope is most pronounced for intermediate wealth levels at which families can afford to make an extra sacrifice that allows their child to earn a college degree.

The right-panel of Figure 2 confirms that the optimal IVT rises fairly steeply with parental wealth. Note that IVTs are zero or very low for a wide range of parental wealth levels (left panel).[31] 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.

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

[31] 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.

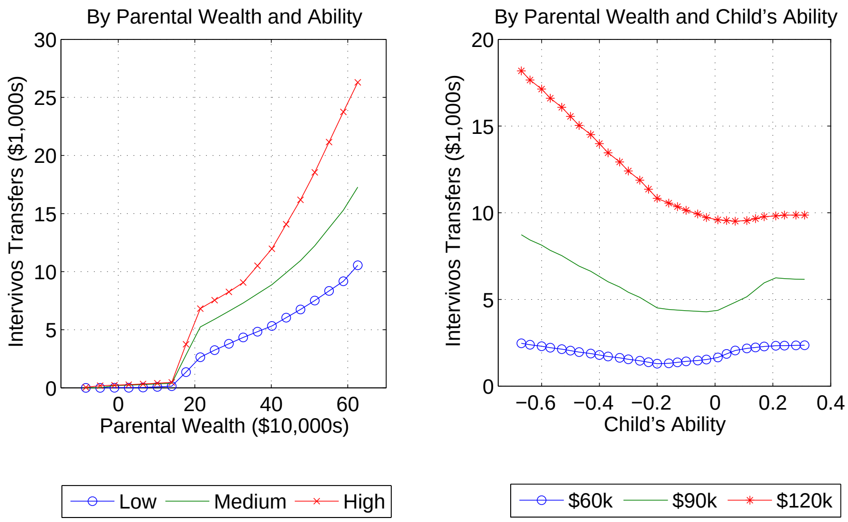

Figure 2: Parental transfers to children as a function of children's ability and parental wealth (left panel) and parental wealth and parent's ability (right panel)

(directly, and through psychic costs). Therefore, it is important to ensure that the correlation among these two variables is consistent with the 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 ability θ for the same age range is 0.37 (0.10, respectively), hence empirically plausible.

In our model there is no insurance market for idiosyncratic productivity risk. As such, future income risk will have adverse welfare effects and will affect all aspects of behavior, including transfers and education choices. In this context transfers play a particularly important role. By offering an initial level of wealth to individuals, they improve their ability to self-insure against future shocks. To understand the interaction between risk, IVT and college enrollment in our model, we perturb the standard deviation of the idiosyncratic wage shock for *new cohorts* of college graduates around its baseline value of 0.141 and plot the impact of this change on college attendance and transfers for different parental wealth levels and different levels of ability.[32] The results are presented in Figure 3.

College enrollment declines with an increase in risk: a rise of 10 percent in σ_η decreases enrollment by roughly 2.5 percentage points. The reason is that education choice is akin to a

[32]In this experiment, we keep prices and taxes fixed.

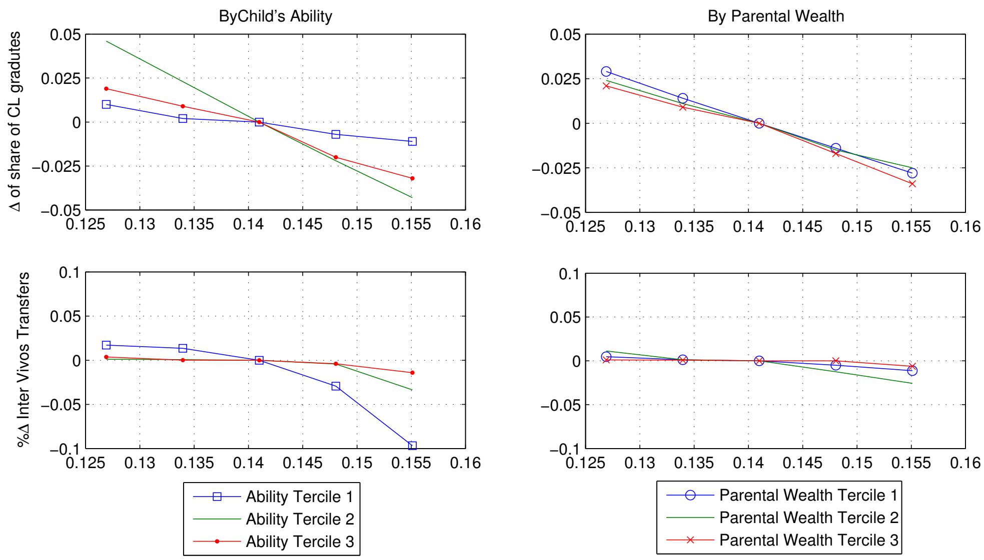

Figure 3: Inter vivos transfers and college attainment as functions of wage risk for college graduates (measured by the S.D. of idiosyncratic productivity innovation σ_η), by child's ability and parental wealth.

risky investment with a sunk cost: if the return becomes more uncertain, investment falls. The effect is strongest on middle-ability children (top-left panel), among which there are many who are marginal in the college decision. The impact of risk on enrollment is, instead, quite similar across wealth levels.[33]

Transfers are not very sensitive to changes in wage risk. On the one hand, a larger labor market risk for new college graduates induces parents whose child goes to college to a higher (precautionary) transfer. On the other hand, the marginal value of transferring resources declines because of lower college enrollment. These two forces tend to offset each other.[34]

4.3 Intergenerational income correlation

Solon (1999) surveys the empirical evidence on intergenerational correlation in earnings for the U.S. and concludes that 0.4, or a bit higher, seems a reasonable estimate of the intergenerational elasticity in long-run earnings, once correcting for the attenuation bias due to the transitory component in earnings dynamics (either genuine or due to measurement error). When we compute the model's correlation between labor earnings of parent and child control-

[33] These similar variations are, however, incremental to different benchmark attainment rates. For example, the share of college graduates from poorer families falls proportionally more with risk.

[34] The drop in inter-vivos transfers to low ability children is sizable in percentage terms, but the average magnitude of the transfer is small in absolute terms.

	Data (NLSY97)	Model
Family Wealth Quartile 2	0.064	0.017
	(0.025)	(0.013)
Family Wealth Quartile 3	0.135	0.051
	(0.026)	(0.013)
Family Wealth Quartile 4	0.236	0.271
	(0.028)	(0.016)

Table 6: Marginal effects of parental wealth on the probability of the child attending college. The column labeled 'Data' reproduces Table 5 in Belley and Lochner (2007). The column labeled 'Model' is the same regression from simulated data. As in Belley and Lochner, the model's regression also controls for parental education and ability quartiles (coefficients not shown).

ling for age (a moment not targeted in the calibration), we obtain 0.43, a value consistent with the empirical estimates.

The model also performs well in terms of intergenerational correlation of educational attainment. The model's correlation coefficient is 0.31. Mulligan (1999), Table 1, summarizes eight empirical studies and reports a range of 0.11-0.45 with an average correlation between parent's and child's education of 0.29.

4.4 Role of family wealth in education outcome

We have modeled government aid to college students through grants and loans in order to reproduce some salient features of the US federal aid system in the year 2000. We now verify that, under this set of institutional rules (and given the distribution of college costs in the same period), the role of parental resources in the determination of college enrollment in the model is consistent with that estimated in the data. Belley and Lochner (2007) measure the marginal effect of family wealth on the probability that their child attends college, conditional on child's ability and parental education from the NLSY97. We do the same in our model, from simulated data. Table 6 summarizes our findings. The model displays a steep parental wealth gradient on college enrollment, in line with the finding of Belley and Lochner (2007): controlling for child's ability, moving from the first to the fourth quartile of family wealth increases the probability of attending college by 27 percentage points.[35] One should keep in

[35] Adding income quartiles to the regression barely changes the marginal effects on wealth, and the coefficients on income are statistically insignificant. Also in Belley and Lochner the income quartile effects are insignificant,

mind that in the data, as our model, parental wealth may be correlated with children's psychic costs of schooling, and therefore significance of parental wealth in this regression may not necessarily indicate a strong role for credit constraints. We return to this point in Section 5.

4.5 Validation through a simulated randomized trial

One of the objectives of our investigation is the comparison between partial and general equilibrium effects of various education policies. To further augment the credibility of our findings, we replicate within our model a randomized trial which is similar in nature to a quasi-experimental policy change: a (treated) group of high-school graduates receives an additional college tuition subsidy of $1,000 per year and a (control) group does not. Group membership is random. When we compute the additional college enrollment of the treated high-school graduates (which occurs in that same period) relative to that of the control group, keeping prices and taxes fixed, we obtain a rise of 3.3 percentage points (from 0.304 to 0.337).[36]

This large response is consistent with the existing empirical evidence. Kane (2003) and Deming and Dynarski (2009) 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 in college of 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).

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and the estimated wealth coefficients drop only by a couple of points. When we run the same regression on the probability of high-school completion, we find that the wealth gradient is much flatter, e.g., the effect of the fourth wealth quartile is only 0.093 (S.E. 0.005). Results in Belley and Lochner, Table 5, are similar. Their estimated coefficient on the fourth family wealth quartile in the HS completion regression is 0.095 (S.E. 0.019).

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

[37] Among the policy changes surveyed in these two 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.

5 Policy Experiments

In this section we conduct two sets of policy experiments aimed at understanding the role of the federal financial aid system: the first focuses on government tuition grants, and the second on government-sponsored loan limits. We are especially interested in the difference between short-run partial equilibrium (PE) and long-run general equilibrium (GE) effects. The gap between the two is mediated by two major adjustments of the benchmark economy to the policy change: (i) the response of the endogenous distribution of inter vivos transfers (which determines the initial resources available to individuals); and (ii) the response of prices clearing input markets, and the fiscal adjustment following the additional educational expenditures. In all our policy experiments, the fiscal instrument that adjusts in equilibrium is the labor income tax τ^w.

We therefore present our results sequentially in three steps. The first step (PE Short run) computes changes in outcomes of interest one year ahead for the cohort treated by the policy. The policy announcement is made just before parents make their IVT, and hence this experiment incorporates only the short-run response of IVTs to the policy. In the second step (PE Long-run), we compute the new steady-state after the policy change where the distribution of parental IVTs (and initial assets for the newborn) has converged, but prices and taxes are fixed at their initial steady-state values. This step fully incorporates the adjustment of parental IVTs to the policy, but abstracts from GE feedbacks. In the third and final step (GE Long run), we incorporate these GE feedbacks and compute the new long run steady-state with the new market clearing prices and the new government budget-balancing taxes. In GE we also compute welfare gains, expressed as changes in expected lifetime consumption of a newborn individual after accounting for all costs associated with the policy.

5.1 Tuition grants

Results of the grants experiments are summarized in Table 7. More detail is provided in Tables G1-G4 in Appendix G.

Removal of grants: We begin by assessing the value of the system of tuition grants currently in place in the US, as described in Section 3. When we remove grants altogether, in the short run college enrollment has a sharp drop of over 5 percentage points (PE Short run).[38] As shown in Table G1, the students who would suffer most are the children of low and middle wealth parents whose college attendance rate falls by 7 points. Children of high wealth parents are not much affected. This reduction in tuition grants is partially compensated by two mechanisms: a significant rise in IVT (which offsets 32% of the decline in grants) among parents whose kids go to college, and a small increase in hours worked by college students. In the long-run PE economy output falls by almost 2% because of the lower supply of educated labor, and this negative wealth effect reduces IVTs and contributes to an additional rise in hours worked by college students.

As the number of college graduates falls the relative price of their labor services goes up, which induces higher enrollment –especially among the wealthy (see Table G1). This GE feedback partially offsets the short-run PE forces, and the final share of college graduates in the long run GE economy is only 1.2 points below the initial steady state share. We conclude that long-run GE effects are weaker than short-run PE ones (roughly 4 times smaller). The GE impact on output associated to the long-run loss in productivity (due to the less skilled educated labor input) is negative and sizable (-1.4%). The welfare loss from scrapping the grant program, computed as the consumption-equivalent change in the expected lifetime utility of a newborn individual, is 0.38%, or roughly $1,500 per year.

General expansion of tuition grant: In this experiment, the government provides an extra $1,000 of yearly tuition subsidy to all college students, independently of their needs or ability. In the short-run PE economy, college enrollment rises by almost 3 percentage points.[39] Table G2 shows that the composition of the college graduates shifts in favor of middle and high ability students, but is roughly unchanged by wealth level. The experiment reveals a substantial short-run crowding out of IVT in response to the grant: lower IVT of parents whose children go to college offset 30% of the grant.[40]. In the long-run PE experiment output increases substantially (+1.5%) because of the additional college-educated labor input in production.

[38]The college enrollment rate is expressed as a fraction of the the treated cohort in the PE short run experiment, and as a fraction of any cohort in the long-run steady-state experiments.

[39]The first column of Table G2 in the Appendix labeled 'Treatment' corresponds to the simulation in Section 4.5 where we have validated the model based on quasi-experimental evidence.

[40]Table G2 shows that the crowding out is especially sharp for wealthy parents, while for poor families in the lowest wealth tercile there is a small crowding-in effect as, for some parents, raising the IVT means now being able to afford the tuition fees and send their kid to college

Removal of grants				
	Benchmark	P.E. Short-run	P.E. Long-run	G.E. Long-run
College enrollment	0.261	0.209	0.223	0.249
Price of CL/HS labor	1.335	–	–	1.364
Crowding out of IVTs	–	+32%	-34%	+17%
Student labor supply	–	+3.1%	+5.4%	+4.5%
Aggregate output	–	–	-1.9%	-1.4%
Welfare gain	–	–	–	-0.38%

General tuition grant expansion ($1,000)				
	Benchmark	P.E. Short-run	P.E. Long-run	G.E. Long-run
College enrollment	0.261	0.290	0.295	0.267
Price of CL/HS labor	1.335	–	–	1.319
Crowding out of IVTs	–	-30%	+30%	-17%
Student labor supply	–	-0.4%	-4.8%	-4.3%
Aggregate output	–	–	1.5%	0.4%
Welfare gain	–	–	–	0.15%

Means-tested grant expansion				
	Benchmark	P.E. Short-run	P.E. Long-run	G.E. Long-run
College enrollment	0.261	0.294	0.297	0.273
Price of CL/HS labor	1.335	–	–	1.313
Crowding out of IVTs	–	-28%	+19%	-25%
Student labor supply	–	-2.8%	-2.8%	-2.1%
Aggregate output	–	–	1.5%	0.7%
Welfare gain	–	–	–	0.20%

Ability-tested grant expansion				
	Benchmark	P.E. Short-run	P.E. Long-run	G.E. Long-run
College enrollment	0.261	0.287	0.286	0.268
Price of CL/HS labor	1.335	–	–	1.317
Crowding out of IVTs	–	-33%	+23%	-24%
Student labor supply	–	-0.6%	-4.9%	-3.6%
Aggregate output	–	–	1.1%	0.4%
Welfare gain	–	–	–	0.14%

Table 7: Results of tuition grants experiments. 'PE Short-run' incorporates only the short-run response of parental IVTs. 'PE long-run' is the new steady state, with the new ergodic distribution of parental IVTs, but where prices and taxes are fixed at their initial values. 'GE Long-run' is the new steady-state where prices clear input markets and tax rates balance the government budget constraint. "%" denote percentage changes from the benchmark value. The welfare gain is expressed in terms of changes in expected lifetime consumption for a newborn agent. 'Crowding Out' of IVT is defined as the average change in IVTs as a percentage of the average change in the grant (in absolute value) for all the individuals who attend college in the experiment. See Appendix G for more detailed results.

This adds wealth to the economy, which causes IVTs to increase and labor supply of college students to fall.

The long-run GE response to the general expansion of tuition subsidies is much more muted, roughly 0.6 points, i.e. five times smaller than its short-run PE counterpart. The main margin of adjustment is the change in relative labor price of college labor, which is larger than the the equilibrium fiscal adjustment or the interest rate adjustment. Note that in the long-run GE economy IVTs fall somewhat because the subsidy is now paid for by higher taxes, which is in contrast to the long-run PE economy. Finally, aggregate output rises by 0.4% and welfare of the newborn by 0.15% in lifetime consumption equivalent units, when the government expands its tuition subsidy program this way.

Means-tested expansion of tuition grant: In this experiment, grants are expanded proportionally by 56% for each student in an attempt to amplify the gap (in absolute value) between college tuition subsidies for poor families relative to those for rich families.[41] The factor of proportionality is chosen so that the total cost of this policy to the government equals that of the general grant expansion of $1,000 in the short run PE economy.

Relative to the general grant expansion, the impact of this policy on college enrollment is somewhat larger. The short-run PE economy shows a rise in college enrollment of 3.3 percentage points. Table G3 reveals that it is mostly kids from low and middle wealth families, and middle ability levels, who increase their rate of college attendance. It remains true, also in this experiment, that relative price effects tend to strongly counteract the forces at work in PE, and in the long run GE economy the share of college graduates increases only by 1.2 percentage points. Overall, the impact of this need-based grant expansion on enrollment, output, and welfare is larger compared to the general grant expansion.

Ability-tested expansion of tuition grant: In this experiment grants are expanded by amounts proportional to students' abilities. A student in the bottom decile of the ability distribution receives $700 extra per year in federal grants, while someone in the top decile receives almost twice as much.This experiment is also designed so that its cost equals the cost of the general grant expansion in the short run PE economy.

This policy has smaller effects on enrollment, output, and welfare than the means tested expansion. The main reason is that, even in the absence of this additional transfer from the

[41]The additional cumulative 4-year grant for a student with $q = 1$ ($q = 3$) is $4,740 ($243, respectively).

government, a large share of the high ability students (those targeted by the subsidy) would choose to attend college and reap the high return for college graduates, by borrowing through the federal loan system.

Taking stock of these results yields several important lessons. First, the existing federal grant program is welfare improving and adds about 1.5% to aggregate output. Second, every additional dollar of government tuition grants crowds out 20-30 cents of parental IVTs. Third, expansions of this program may have sizeable effects on enrollment in the short run, but long-run GE effects are 3-4 times smaller because of relative price adjustments in the labor market. Interestingly, strong GE effects are triggered by small changes in relative skill prices.

5.2 Education loans

Removal of government-sponsored loans: We begin, as we did for grants, by assessing the value of the federal loan program. We remove from the economy all government-sponsored loans (i.e., we set both $\underline{b}^u$ and $\underline{b}^s$ to zero). From Table 8 it appears that the short run PE effects of eliminating federal loans are huge: college enrollment drops from 26% to 11%. Table G5 shows that college attendance rates collapse especially among high-ability students (from 56.8% to 27.4% in the highest ability tercile): it is the high ability students facing high tuition fees who borrow the most to attend college and take advantage of the high market returns for their type.

Enrollment in the long-run PE economy is already back to 0.237. This adjustment takes place largely through a much higher labor supply in college (which increases by 1/3). Although IVTs fall on average, this is entirely driven by reduced net worth at the high end of the parental wealth distribution. In particular, college-educated parents transfer nearly 7 times the average amount transferred by their HS-educated counterparts, and the long-run drop in their number results in a strong negative impact on average transfers in the economy. Moreover, aggregate output falls by 2.4% due to the large loss in labor productivity from the lower enrollment, especially of high-ability types. The relative price adjustment in GE contributes to setting the new long-run steady-state share of college graduates just 0.3 percentage points below its initial value, but output remains 1.5% lower, and the welfare of a newborn is reduced by 0.4%. Average inter vivos transfers also recover in GE, although they are substantially lower than in the benchmark: this derives from the changes in the composition of the college

Removal of government loans				
	Benchmark	P.E. Short-run	P.E. Long-run	G.E. Long-run
College enrollment	0.261	0.113	0.237	0.258
Price of CL/HS labor	1.335	–	–	1.353
Crowding out of IVTs	–	+13%	-39%	-29%
Student labor supply	–	+3.1%	+33.1%	+32.3%
Aggregate output	–	–	-2.4%	-1.5%
Welfare gain	–	–	–	-0.38%

Expansion of government loans limits ($10,000)				
	Benchmark	P.E. Short-run	P.E. Long-run	G.E. Long-run
College enrollment	0.261	0.281	0.263	0.263
Price of CL/HS labor	1.335	–	–	1.334
Crowding out of IVTs	–	-29%	-2%	+1%
Student labor supply	–	-21.1%	-2.0%	-2.4%
Aggregate output	–	–	+0.2%	+0.1%
Welfare gain	–	–	–	+0.02%

Table 8: Results of loan limits experiments. 'PE Short-run' incorporates only the short-run response of parental IVTs. 'PE long-run' is the new steady state, with the new ergodic distribution of parental IVTs, but where prices and taxes are fixed at their initial values. 'GE Long-run' is the new steady-state where prices clear input markets and tax rates balance the government budget constraint. "%" denote percentage changes from the benchmark value. The welfare gain is expressed in terms of changes in expected lifetime consumption for a newborn agent. 'Crowding Out' of IVT is defined as the average change in IVTs as a percentage of the average change in the borrowing limit (in absolute value) for all the individuals who attend college in the experiment. See Appendix G for more detailed results.

educated group, which now includes relatively more low ability individuals. In fact, despite recovery of aggregate enrollment in GE, output, welfare and IVTs are all below their benchmark level because of the reduced sorting in ability by education.

Because we assume that the private lenders do not respond to this policy, this experiment yields an upper bound. In a separate experiment, we let the private market pick up the demand for loans unmet by the government, i.e., we allow everyone to borrow from the private market at the rate $r + \iota$ and increase the private education loan limit $\underline{a}^p$ up to $\underline{b}^u + \underline{b}^s$. In this case, effects are smaller but still sizable. For example, in the long run GE economy, output falls by 1 percentage point.[42]

[42] This experiment is likely to be a lower bound for the value of government-sponsored loans. In an extended model where private lenders are profit-maximizing agents who take into account students' default risk, the removal of government loans would lead to an expansion of private lending, but possibly at a higher cost, which

Finally, when we remove the entire financial aid system of loans and grants at the same time, in the long-run GE economy, enrollment falls by over 2 percentage points, output falls by 2.5%, and welfare by 0.5%. Hence the effects of the two separate experiments cumulate to some extent.

Expansion of government-sponsored loans: In this experiment, the government expands unsubsidized loan limits by $10,000 (but keeps interest rates r^u and r^s fixed at their initial values).[43] In the short-run, enrollment increases by 2 percentage points.[44] The higher ability to borrow induces students to work significantly less during college, and their parents to reduce their IVTs by 30 cents for each dollar of additional borrowing capacity. However, the long-run GE price adjustments offset entirely these forces, and enrollment and output remain virtually unchanged. How does one reconcile this finding with the result highlighted in Section 4.4 that parental wealth is a significant determinant of college attendance, conditional on child's ability? In our model parental wealth is negatively correlated with the non-pecuniary psychic costs of schooling. The effect of family resources on college enrollment outcomes is, indeed, largely determined by the fact that they proxy for psychic costs, an omitted variable in the regression of Table 6. When we add them to the regression, the marginal effect of parental wealth drop by half.

In summary, the current government-sponsored loan program is welfare improving, especially for high-ability children, and adds 1.5 percentage points to aggregate output. Moreover, borrowing limits for college students appear to be generous: expanding them would have negligible consequences on enrollment and output in the long run. The key reason is that able students from low-wealth households –who could potentially benefit from relaxed federal loan limits– choose not to attend college because they have a large disutility cost of schooling. While we do not model explicitly the relationship between family assets and taste for college, a natural candidate is the fact that parental wealth determines the neighborhood and the quality of local public schools in which students mature and acquire the taste and capacity for further

would reflect the entry of more risky borrowers into the private education loan market. Simpson and Ionescu (2010) model the private education loan market with some of these features.

[43]For the reasons discussed above (no reaction from private markets), this experiment is an upper bound on the effects of expanding public credit. In simulations of a model with endogenous private credit limits, Lochner and Monje-Naranjo (2011) find small crowding out, which offers a justification for our assumption.

[44]In line with this result, Johnson (2011) finds that the virtual elimination of limits on student loans has small effects on attainment.

learning (see, e.g., Fernandez and Rogerson (1998)).

6 Discussion

The design of education policy is an issue at the top of the policy and research agenda. Over the years we have learned a lot about the sensitivity of individual education outcomes to small policy changes as well as about the incidence and impact of liquidity constraints that justify policy interventions. However, most of what we know can only contribute partially to the design of policy because longer term adjustments, that take some time to play out, have been largely neglected. Moreover, the magnitude and direction of these adjustments differ substantially across the distribution of wealth and ability.

We have stressed two key channels of adjustment that are not allowed for in the usual policy evaluation literature. The first is the adjustment of relative wages and returns to different levels of education, an issue that has been studied before by Heckman, Lochner, and Taber (1998b,c), Lee (2005), Lee and Wolpin (2006). We confirm that allowing for equilibrium prices to change is crucial for quantifying the long run effects of policy. The second channel is the adjustment of funding by parents, which is a major source of support for college and reacts to policy. Its level, and the way it responds to public funding interventions, varies both with wealth and with child ability and as a result induces substantial heterogeneity in the effects of policy. For example, we find that while for wealthy parents with high ability children public subsidies crowd out private transfers, poorer parents tend to reinforce government subsidies since the expected return to their transfers increases when college becomes more attainable, particularly for those with high ability children. These two channels of adjustment interact strongly with each other, resulting in differences in policy outcomes both cross-sectionally and over time. To buttress the credibility of our estimates and to understand the extent to which liquidity constraints can affect education outcomes we have modelled the public grant and loan system in some detail. This, together with funding from parents, are central elements of a student's budget constraint.

Our policy experiments illustrate the role of an array of existing policy instruments and the complexity of their long run effects. The final outcomes after transfers have adjusted and further, after prices have been allowed to move to the new equilibrium, are substantially different from both the direct treatment effect and the short run PE effect before the entire output and distributional consequences have played out. Indeed any conclusions about the magnitude of the impact of policy based on immediate impacts are likely to overestimate the impacts in a serious way.[45] Based on our estimates, the largest long-term adjustments come from changes in returns rather than from transfers' behavior; in part this is because the latter are affected in counteracting fashion by wealth effects due to aggregate output changes. However, it is important to stress that the way IVTs change differs substantially depending on the level of parental wealth and on the ability of the child, determining large distributional impacts of policy.

The other conclusion of our policy experiments is that educational subsidies are welfare improving even after accounting for changes in taxation to fund them and after allowing the economy to adjust to its new equilibrium. This is a clear indication that there are still individuals who are prevented from attending because of liquidity constraints and that this does have welfare implications, justifying interventions. Importantly, the result is demonstrated in a context where we have allowed for the existing set of public programs as well as parental financing and self-financing through work while in college. As we might expect, the most effective policies are means tested grants, a finding consistent with the presence of some liquidity constraints. The gains are particularly large when returns to education are kept fixed (as in an open economy with free trade and factor price equalization) and are mitigated when prices adjust, but do not disappear. Our welfare results might understate the true value of government support during college because we restrict transfers to take place at a given age over the lifecycle. In reality families may have children at different points in their lifecycle and if poorer families were to have kids earlier they might need to transfer resources when they are relatively younger. With imperfect credit markets this additional heterogeneity would make it harder for them to help their kids, implying even larger welfare gains from government subsidies.[46]

Finally, we also find that a non-trivial margin for education financing at the individual level is work while in college, which responds strongly when all other types of education finance

[45] As emphasized, given our conservative choice for the elasticity of substitution in production, our GE effects are a lower bound.

[46] To correctly identify these additional transfer margins one would arguably need a much richer model allowing for quantity, quality and timing of fertility choices and transfers over the entire life cycle, including at death.

are exhausted. This adjustment is different from the others, as it is relatively less dependent on ability and family background, and therefore available to more people; its importance however should be investigated further, allowing also for potential disruptions to schooling effort associated with working while in college.[47]

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 cross-sectional and intergenerational distribution of income (see Becker and Tomes, 1979; Loury, 1981). Education investments respond to the prevailing economic environment and contribute to shape it. The long-run nature of these relationships motivates the study of education policies within a general equilibrium framework.

To analyse these lifecycle decisions we set up a dynamic lifecycle model of individual behaviour in a context of altruistically linked overlapping generations. Our parameter estimates are based on estimation from various data sets, and when traditional microeconometric estimation is not feasible, we use calibration to make sure the model can replicate key features of the US economy.

We contribute to the debate on the increasing importance of family resources by modelling inter vivos transfers as equilibrium outcomes that respond to changes in market returns and to prevailing policy and credit conditions. In particular, we show that increases in college grants can displace IVTs in different proportions depending on family wealth, with the transfers made by wealthy families being generally crowded out the most. This finding suggests that means-tested policy expansions may be preferable also because they displace parental transfers to a lesser extent than more general expansions of aid.

Our analysis provides a sequence of snapshots of the economy after a policy change, revealing why the short-run partial equilibrium effects of education policies can be very different from their long-run general equilibrium effects. By accounting for the intricate patchwork of policies that compose the federal financial aid system, we are able to assess its value. Our results indicate that existing grant and loan programs improve welfare, and the changes in the

[47]See Garriga and Keightley (2009) for a model where time devoted to work competes with time needed to cumulate credits in college.

distribution of human capital induced by these policies increase GDP in the long run. Our results also indicate that increased progressivity in grant programs would imply greater benefits than a generalized transfer expansion, although the incremental benefits from any aid expansion would be smaller than the gains from the current system. A means-tested grant expansion would generate greater selection into education among high-ability individuals than a general expansion, implying greater welfare gains.

Some of the methods and findings of this paper are promising for future research. Recent work (see Ionescu and Simpson, 2012; 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 more complex, could answer interesting questions about how private markets should be designed and regulated. Another promising direction for future research would involve looking at the role of early skill investment. We study college-age policies which take the ability distribution at age 16 as given. Different research (e.g., Caucutt and Lochner, 2012) stresses the importance of complementarities between college-age policies and interventions that release parental constraints in the critical phase of early skill accumulation, arguing that early investments may improve the effectiveness of tertiary education policies. Explicitly modelling sequential human capital investments within a rich environment, with endogenous skill and credit prices, might offer a natural way to relate the existence of early credit constraints with the observation that parental financial resources at the time of college choice matter much more now than they did in the past. Finally, one interesting generalization would account for heterogeneity in college types (e.g. Fu, 2012) allowing for the endogenous determination of returns based on demand and supply of different college types. This would require the careful modelling of the supply side with many heterogeneous types of education providers, as well as the possibility of differential credit access, to account for variation in the riskiness and returns of alternative education choices.

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APPENDIX NOT FOR PUBLICATION

A 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.[48]

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 data 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 the inter-vivos transfers from both living mother/mother figure and father/father figure.[49] 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.[50] 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.[51] 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 youths 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.[52]

[48]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.

[49]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.

[50]Additional details are available from the authors.

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

[52]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

	Not in College	In College	Share
Less than HS	$3,385	N/A	14.1%
HS Graduate	$3,534	N/A	59.8%
College Graduate	$5,469	$7,807	26.1%
Average	$4,366		

Table A1: Yearly inter-vivos transfers by educational attainment and by current college enrollment status (for college graduates) of the child. Amounts are expressed in year 2000 dollars and include allowances.

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.[53] 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, 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 A1 summarizes the average yearly transfer received by people with different ed-

un-weighted sample.

[53]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.

ucation achievement (in 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.[54]

Using the average transfers in Table A1 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.

This procedure results in a total transfer of \$23,697 for HS drop-outs, \$24,735 for HS graduates and \$47,637 for College graduates. These figures are used to target transfers-by-education-achievement in the benchmark economy. Weighting each transfer level by the share of workers of a given education type in the benchmark economy results in an economy-wide average transfer of \$30,566. Transfers reported in Table A1 include allowances. Reported allowances are small, adding only \$135 dollars to the average yearly transfer.

B Ability transmission and distribution

Intergenerational transmission: To estimate the Markov transition matrix that dictates the intergenerational transmission of ability between parents and children, we use the expanded mother-child data collection from the NLSY79. The NLSY79 is a representative sample of 12,686 American young men and women who were 14-22 years old when they were first surveyed in 1979. Data was collected yearly from 1979 to 1994, and biennially from 1996 to the present. The "Children of the NLSY79" survey began in 1986 and has occurred biennially since then. This survey consists of 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 Recogni-

[54]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.

Age	Number	Percent	Age	Number	Percent
5	98	2.2	12	331	7.4
6	202	4.5	13	1,208	27.1
7	194	4.4	14	1,081	24.3
8	231	5.2	15	87	2.0
9	251	5.6	16	49	1.1
10	301	6.8	17	45	1.0
11	368	8.3	18	9	0.2

Table B1: Child's age at time of test (relative frequency). Total number of mother-child pairs: 4,455 (NLSY).

tion, 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. Table B1 reports the distribution of children's age at the time of test in our final sample.

The fact that children took the PIAT test at different ages should have no relevance because we use standardized 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 in 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.[55]

[55]The ASVAB consists of 10 tests that measure knowledge and skill in the following areas: (1) general sci-

	High School graduates						College graduates				
	$\theta(1)$	$\theta(2)$	$\theta(3)$	$\theta(4)$	$\theta(5)$		$\theta(1)$	$\theta(2)$	$\theta(3)$	$\theta(4)$	$\theta(5)$
$q(1)$	15.5	17.4	18.7	18.7	24.7	$q(1)$	30.2	33.7	35.7	35.0	35.0
$q(2)$	10.2	12.5	14.0	13.9	20.4	$q(2)$	9.2	14.3	16.3	14.8	14.6
$q(3)$	11.0	13.1	14.6	14.5	21.8	$q(3)$	9.5	14.6	16.6	15.2	15.3

Table C1: Estimates of psychic costs $\kappa(\theta, q)$ by ability and parental wealth (measured by the indicator q). We report them here as a percentage of average lifetime consumption of, respectively, high-school and college graduates, after graduation.

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 (AFQT89 for mothers, PIAT Math for children) 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. Results are reported in Table 1 in the main text.

For each maternal quintile, the first row reports the number of sample children in each quintile, the second row reports the conditional probability of ending up in that quintile.

Empirical distribution: The distribution of AFQT scores among mothers is extremely similar to the distribution of AFQT scores in the entire cross-sectional sample, which we use in the estimation of the wage-ability gradient.

C Psychic costs

The psychic costs entering the decision problems of potential high-school and college students consist of two additive components: a preference for education by ability, and a preference for education by family background. Thus we can write $\kappa^e(\theta, q) = \kappa^e_\theta(\cdot) + \kappa^e_q(\cdot)$.

Table C1 reports the the consumption equivalent values (CEV's) of the psychic costs associated to graduating from High School and to graduating from College for each pair of parental wealth (summarized by the variable q) and ability θ. The CEV's are expressed, respectively, as

ence; (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.

a share of average lifetime consumption of high school graduates and college graduates after education is completed. The CEV incurred by individuals to graduate from college includes both high school and college costs, and should be interpreted as the total psychic cost faced by college graduates over the life cycle.

By comparing the top and the bottom table, it appears that college graduates of wealthy families ($q = 2, 3$) face psychic costs of schooling mostly during high-school, whereas the additional cost of college is small, or even negative for some types. In contrast, children of low-wealth families incur a large additional psychic cost of college, on top of that incurred during high-school. One could interpret this finding as saying that the quality of high-school education for children of low-wealth households is poor and they are less well prepared for college, or as saying that children of low-wealth parents have been inculcated with less of a taste for education.

The CEV of the average psychic costs of attending college implied by the model gives us an average value of \$335,000. This magnitude is comparable to the values suggested by Cunha, Heckman, and Navarro (2005) and Heckman, Lochner, and Todd (2006), who estimate average psychic costs of graduating from college at around \$375,000 (see, e.g., Table 19 in Heckman, Lochner, and Todd, 2006).

D 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 2002 (referring to calendar years 1967 to 2001). Since 1997 the PSID has become biannual. We follow closely the sampling criteria of Meghir and Pistaferri (2006) and restrict attention only to heads of household in the the SRC sample, which was originally nationally representative, so we use no sample weights in the calculations. By selecting only heads of household (mostly men or single women) we restrict our attention to individuals with relatively strong attachment to the labor force. After selecting the observations on household heads we are left with 19,583 individuals. Dropping people younger than 25 or older than 65 leaves us with 18,186 individuals. Dropping the self-employed leaves 14,866 persons in the sample. We then select only individuals with at least 8 (possibly non continuous) observations, which further reduces the individuals in the sample to 6,228. Dropping individuals with unclear education records leaves 6,213 people in sample. Disposing of individuals with missing, top-coded, or zero earnings reduces the sample to 5,671 individuals and dropping those with zero, missing or more than 5,840 annual work hours brings the sample size to 5,660 individuals. We then eliminate individuals with outliers in earnings growth, defined as changes in log-earnings larger than 4

Dependent variable: Log hourly wages				
	Less than HS	**HS Graduate**	**College Graduate**	**Pooled**
	Coefficient	Coefficient	Coefficient	Coefficient
	(S.E.)	(S.E.)	(S.E.)	(S.E.)
Age	0.2	0.41	0.67	0.46
	(0.015)	(0.06)	(0.10)	(0.05)
Age^2	-0.01	-0.013	-0.02	-0.014
	(0.001)	(0.002)	(0.004)	(0.002)
Age^3	1.e-4	2.e-4	3.e-4	2.e-4
	(1.e-5)	(4.e-5)	(6.e-5)	(3.e-5)
Age^4	-8.e-7	-1.e-6	-1.6e-6	-1.2e-6
	(2.e-7)	(2.e-7)	(3.7e-7)	(1.8e-7)

Table D1: Estimated age polynomials' coefficients (PSID)

or less than -2, which leaves 5,477 individuals in the sample. Finally, dropping people connected with the original SEO sample (which oversamples low income households) reduces the number of individuals to 3,085.

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.[56] 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.

The estimated age polynomials are presented in Table D1 for different education groups and for the pooled sample. As commonly found, these estimates imply a steeper efficiency profile for more educated workers: between ages 22-52, productivity doubles for HS dropouts, but it triples for college graduates.

Price of labor inputs from PSID: Once we filter out age effects from hourly wages, we can construct first-differences in logs and also filter 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 group is not constant over time due to composition changes within the group. Therefore, we can easily estimate, through time dummies, the time series of price growth in each education group, i.e., the term $\Delta \log w_t^e$. Given a normalization one can recover spot prices year by year.[57]

[56]In the PSID the head of the household is a male whenever there is a cohabiting male/female couple. The earnings variable includes the labor part of both farm and business income, wages, bonuses, overtime, commissions, professional practice and others.

[57]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

Wage-ability gradient from NLSY: Ability is approximated by the AFQT89. For hourly wages, we use the wage variable corresponding to the hourly rate of pay on the current or most recent job, available only from 1979 to 1994. We start with the 11,878 individuals for which we have AFQT89 scores. We drop those individuals who are unemployed or out of the labor force, or employed but reporting zero wage or with annual work hours missing, below 400 or larger than 5,840: this reduces the sample to 10,592 individuals. Dropping individuals who report (at least once) hourly wages above $400 or below $1 further reduces the sample to 10,202. We also eliminate individuals who report log wage increases larger than 4 or smaller than -2, which leaves 10,056 workers in the sample. Finally, we drop individuals who change their education level during their working life, which gives us a final sample of 7,954 individuals. When we split this sample in 3 education groups, we get a HS drop-outs' sample of 1,341 individuals, a HS graduates' sample of 5,403 individuals and a college graduates' sample of 1,206 individuals. [58] Table 3 reports estimates of the ability gradient by education group, and for the pooled sample. All standard errors are corrected for individual clustering.

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 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 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 very close to, and falls between, 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 com-

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.

[58]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.

ponent and the ability component, calculated as explained above. For estimation, we use the Minimum Distance Estimator originally proposed by Chamberlain (1984), as implemented in Heathcote, Storesletten, and Violante (2010). In a nutshell, as moments we use the covariances of wage residuals at various lags for different age groups. Table 4 reports the estimates of these parameters obtained for the 15-year period between 1979 and 1993.[59]

E Aggregate technology parameters

The estimation of the aggregate technology parameters is based on data from the Current Population Survey (CPS) March supplement, a survey conducted by the Bureau of the Census for the Bureau of Labor Statistics. 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). Since earnings data are top-coded in the CPS, we extrapolate the average of the top-coded values by using a tail approximations based on a Pareto distribution.[60] We compute total wage bills in billions of dollars for the three education groups. Dividing the wage bills by the (normalized) marginal products of human capital estimated from PSID data (see discussion in Appendix D), we obtain point estimates of total, efficiency-weighted, labor supply (human capital aggregates) by education and year.

With wage bills and human capital aggregates in hand, we can estimate the elasticity of substitution among labor inputs, using equations like (20), for the three relative wage bills. We use two different specifications: the first one is based on first-differences of equation (20), while the second is in levels. In both cases 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 E1 reports results for both specifications (first-differences and levels) and both types of instruments. 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). Panel (A) reports the results using as instruments, respectively, lags (columns 1 to 4) or education 'stocks' (levels in column 5 and relative growth rates in column 6). Panel (B) reports tests of the null hypothesis of iso-elasticity for a set of specifications (more speci-

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

[60]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.

Panel (A): Estimation						
Specification	Growth rates		Levels			
	(1)	(2)	(3)	(4)	(5)	(6)
First stage IV	Up to 4 lags	Up to 3 lags	Up to 5 lags	Up to 4 lags	Edu. stock (L)	Edu. stock (G)
Number of obs.	75	78	75	78	90	87
	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
	(S.E.)	(S.E.)	(S.E.)	(S.E.)	(S.E.)	(S.E.)
$\rho^{HS,LH}$	.54	.14	.58	.47	-9.84	1.23
	(.18)	(.32)	(.20)	(.22)	(10.51)	(.37)
$\rho^{CL,HS}$	.58	.54	.50	.44	.26	.42
	(.35)	(.35)	(.11)	(.11)	(.64)	(.20)
$\rho^{CL,LH}$	.45	.39	.89	.90	.93	.49
	(.19)	(.26)	(.11)	(.11)	(.65)	(.16)
$\rho^{CL,HS,LH}$	.51	.35	.67	.64	.57	.48
	(.12)	(.17)	(.07)	(.07)	(.07)	(.03)

Panel (B): Hypothesis Testing				
Specification	Growth rates	Levels		
	(1)	(3)	(5)	(6)
First stage IV	Up to 4 lags	Up to 5 lags	Edu. stock (L)	Edu. stock (G)
Null Hypothesis	F-stat.	F-stat.	F-stat.	F-stat.
$\rho^{HS,LH} = \rho^{CL,HS}$	$F_{(1,69)} = .01$	$F_{(1,66)} = .12$	$F_{(1,81)} = .92$	$F_{(1,78)} = .32$
	$Pr. > F = .92$	$Pr. > F = .73$	$Pr. > F = .34$	$Pr. > F = .57$
$\rho^{CL,HS} = \rho^{CL,LH}$	$F_{(1,69)} = .10$	$F_{(1,66)} = 5.54$	$F_{(1,81)} = .54$	$F_{(1,78)} = .02$
	$Pr. > F = .75$	$Pr. > F = .02$	$Pr. > F = .47$	$Pr. > F = .88$
$\rho^{HS,LH} = \rho^{CL,LH}$	$F_{(1,69)} = .10$	$F_{(1,66)} = 1.63$	$F_{(1,81)} = 1.05$	$F_{(1,78)} = .27$
	$Pr. > F = .75$	$Pr. > F = .21$	$Pr. > F = .31$	$Pr. > F = .60$
$\rho^{CL,LH} = \rho^{CL,HS} = \rho^{HS,LH}$	$F_{(2,69)} = .08$	$F_{(2,66)} = 2.87$	$F_{(2,81)} = .76$	$F_{(2,78)} = .16$
	$Pr. > F = .93$	$Pr. > F = .07$	$Pr. > F = .47$	$Pr. > F = .84$

Table E1: 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. (L) and (G) in columns (5) and (6) indicate whether the education stock enters in Level or Growth rate in the estimated equation, respectively. (B): Tests for equality of elasticities of substitution among labor inputs. P-values are reported below the F-statistic.

fications and tests are available from the authors). Overall, all specifications give remarkably similar results and we are unable to reject the null hypothesis that the aggregate technology is iso-elastic at 5% level of significance (see Table E1). 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). Estimated shares of different human capital types in production (unreported) are also remarkably robust across specifications.

	Institutional Grants		Private Grants		Average Amount
Income	% receiving	Amount	% 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 F1: Summary of institutional and private grants data used for the computation of the net tuition fees (NCES)

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 not 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 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 F1 which is based on the SFUE, Table 1.2-G.

	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 F2: Summary of federal and state grants by family income level (US Department of Education)

To arrive at our estimate of average net tuition ($6,710) we subtract average private and institutional grants from average tuition expenses. Our measure of dispersion comes from Figure 12 of National Center for Education Statistics (2000), which provides the entire distribution of college costs. From this figure we determine that only 68% of college students pay less than the average amount of net tuition. To calibrate the standard deviation of tuition draws in the model we match this proportion. It turns out that a standard deviation of 1.0 captures this. Importantly, it is the ex-post distribution of college costs for which 68% of the mass is below $6,710, not the actual distribution of costs. Selection on realized costs causes the ex-post distribution of costs to have a smaller average than the actual distribution of draws. The mean of the ex-post distribution of costs is $6,710, but the mean ex-ante tuition draw is higher.

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 F2.

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 $g(q, \theta)$

on assets (through the state variable q). In the baseline experiment, we do not allow g to depend on θ. However in one of our policy experiments we consider an expansion 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 $18,000.

Since it is largely up to the institution and the federal government to determine the maximum subsidized amount that each student can borrow, in the calibration we use $\underline{b}^s$ to match some moments of the cross-sectional distribution of loans (see below), and we make sure it does not exceed \$17,125. We do fix the total cumulative (subsidized and unsubsidized) Stafford debt limit $\underline{b}^s+\underline{b}^u$ to \$35,125. 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. In the model, we set a fixed repayment plan with duration $n = 20$ years.

According to the SFUE, in the year 2000, 44.9% of students in 4-year institutions had (subsidized or unsubsidized) Stafford loans, 37.3% had subsidized Stafford or Perkins loans, and 21.2% had unsubsidized Stafford loans (Tables 1.5A, 1.6-A). Moreover, among borrowers, the average cumulated amount of student loans at graduation was \$17,016 (Table 1.1-A). Finally, the College Board (1998) reports that the ratio of total volume of subsidized to unsubsidized federal loans is 1.36.

We have six parameters related to the federal loan program $(a^*, a^{**}, \underline{b}^s, r^s, r^u, \underline{b}^s, \underline{b}^u)$ that we use to target six moments: (i) 37.3% of students have subsidized Stafford loans, (ii) 21.2% of students have unsubsidized Stafford loans, (iii) 44.9% of students have any Stafford loans, (iv) the average cumulated amount of federal loans at graduation is \$17,016, (v) the ratio between the total volume of subsidized and unsubsidized loans is 1.36, (vi) the maximum cumulative amount of Stafford loans is \$35,125.

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, 4.9% of students enrolled in 4-year institutions received private loans (Figure 4.2), and the average amount received was \$4,767 (Table A.4).

We calibrate two parameters related to private borrowing: the wedge ι, and the wealth threshold $\underline{a}^p$. To capture some general features of access to private loans we target two moments: (i) 4.9% of students have private loans, and (ii) the ratio of the volume of private to federal loans is 12%.

G 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 Grants

		Benchmark	Treatment	P.E. Short-run	P.E. Long-run	G.E. Long-run
Policy Cost		n/a	-100%	-100%	-100%	-100%
College	Ability Tercile 1	0.038	0.035	0.034	0.037	0.047
Attainment	Ability Tercile 2	0.178	0.112	0.113	0.132	0.159
Rates	Ability Tercile 3	0.568	0.476	0.48	0.500	0.541
	Par. Wealth Tercile 1	0.197	0.128	0.127	0.133	0.166
	Par. Wealth Tercile 2	0.191	0.120	0.124	0.138	0.164
	Par. Wealth Tercile 3	0.396	0.375	0.375	0.397	0.417
	Aggregate	0.261	0.208	0.209	0.223	0.249
Labor Tax Rate		0.270	0.270	0.270	0.270	0.274
Price of CL/HS Labor		1.335	–	–	–	1.364
Log of College Premium		0.62	n/a	n/a	+3.1%	+3.4%
Student Labor Supply		n/a	+3.5%	+3.1%	+5.4%	+4.5%
Aggregate Output		n/a	n/a	n/a	-1.9%	-1.2%
Interest Rate		0.0438	0.0438	0.0438	0.0438	0.0439
Intergenerational Correlation of Education		0.308	–	–	0.327	0.326
Welfare (CEV)		n/a	n/a	n/a	n/a	-0.384%
Average Inter Vivos ($)		31,256	31,256	30,967	29,585	31,202
Crowding-Out	Aggregate	n/a	n/a	+32%	-34%	+17%
	Par. Wealth Tercile 1	n/a	n/a	11%	-11%	+1%
	Par. Wealth Tercile 2	n/a	n/a	37%	-33%	-4%
	Par. Wealth Tercile 3	n/a	n/a	65%	-76%	+123%
	Ability Tercile 1	n/a	n/a	127%	-136%	+117%
	Ability Tercile 2	n/a	n/a	62%	-39%	+31%
	Ability Tercile 3	n/a	n/a	28%	-31%	+15%

Table G1: Response to the elimination of all government grants. 'Treatment' identifies the direct immediate effect of the policy on the child's education decision. 'PE Short-run' incorporates the short-run response of parental IVTs. 'PE long-run' is the new steady state, with the new ergodic distribution of parental IVTs, but where prices and taxes are fixed at their initial values. 'GE Long-run' is the new steady-state where prices clear input markets and tax rates balance the government budget constraint. "%" denote percentage changes from the benchmark value. The welfare gain is expressed in terms of changes in expected lifetime consumption for a newborn agent. 'Crowding Out' of IVT is defined as the average change in IVTs as a percentage of the average change in the grant (in absolute value) for all the individuals who enroll in college in the experiment.

General Tuition Subsidy

		Benchmark	Treatment	P.E. Short-run	P.E. Long-run	G.E. Long-run
Policy Cost		n/a	90%	87%	88%	67%
College Attainment Rates	Ability Tercile 1	0.038	0.052	0.051	0.053	0.040
	Ability Tercile 2	0.178	0.229	0.230	0.236	0.184
	Ability Tercile 3	0.568	0.601	0.589	0.596	0.577
	Par. Wealth Tercile 1	0.197	0.230	0.230	0.230	0.201
	Par. Wealth Tercile 2	0.191	0.223	0.217	0.221	0.194
	Par. Wealth Tercile 3	0.396	0.430	0.423	0.434	0.405
	Aggregate	0.261	0.294	0.290	0.295	0.267
Labor Tax Rate		0.270	0.270	0.270	0.270	0.271
Price of CL/HS Labor		1.335	–	–	–	1.319
Log of College Premium		0.62	-2.1%	-2.9%	-2.1%	-2.3%
Student Labor Supply		n/a	-4.2%	-0.4%	-4.8%	-4.3%
Aggregate Output		n/a	–	–	1.5%	0.4%
Interest Rate		0.0438	0.0438	0.0438	0.0438	0.0439
Intergenerational Correlation of Education		0.308	–	–	0.304	.305
Welfare (CEV)		n/a	n/a	n/a	n/a	0.25%
Average Inter Vivos ($)		31,256	31,256	31,127	32,332	30,930
Crowding-Out	Aggregate	n/a	n/a	-30%	+30%	-17%
	Par. Wealth Tercile 1	n/a	n/a	+1%	+8%	+2%
	Par. Wealth Tercile 2	n/a	n/a	-41%	+14%	-2%
	Par. Wealth Tercile 3	n/a	n/a	-43%	+57%	-31%
	Ability Tercile 1	n/a	n/a	-17%	+61%	-8%
	Ability Tercile 2	n/a	n/a	-21%	+22%	-19%
	Ability Tercile 3	n/a	n/a	-36%	+32%	-14%

Table G2: Responses to an additional $1,000 per-year tuition subsidy. ‘Treatment’ identifies the direct immediate effect of the policy on the child’s education decision. ‘PE Short-run’ incorporates the short-run response of parental IVTs. ‘PE long-run’ is the new steady state, with the new ergodic distribution of parental IVTs, but where prices and taxes are fixed at their initial values. ‘GE Long-run’ is the new steady-state where prices clear input markets and tax rates balance the government budget constraint. “%” denote percentage changes from the benchmark value. The welfare gain is expressed in terms of changes in expected lifetime consumption for a newborn agent. ‘Crowding Out’ of IVT is defined as the average change in IVTs as a percentage of the average change in the grant (in absolute value) for all the individuals who enroll in college in the experiment.

Means-Tested Grants

		Benchmark	Treatment	P.E. Short-run	P.E. Long-run	G.E. Long-run
Policy Cost		n/a	91%	87%	87%	66%
College	Ability Tercile 1	0.038	0.05	0.049	0.050	0.035
Attainment	Ability Tercile 2	0.178	0.240	0.241	0.242	0.200
Rates	Ability Tercile 3	0.568	0.604	0.592	0.599	0.585
	Par. Wealth Tercile 1	0.197	0.244	0.243	0.242	0.216
	Par. Wealth Tercile 2	0.191	0.236	0.230	0.233	0.208
	Par. Wealth Tercile 3	0.396	0.414	0.409	0.415	0.396
	Aggregate	0.261	0.298	0.294	0.297	0.273
Labor Tax Rate		0.270	0.270	0.270	0.270	0.269
Price of CL/HS Labor		1.335	–	–	–	1.313
Log of College Premium		0.62	-2.7%	-3.1%	-3.1%	-2.7%
Student Labor Supply		n/a	+0.3%	-2.8%	-2.8%	-2.1%
Aggregate Output		n/a	1.6%	1.3%	1.5%	0.7%
Interest Rate		0.0438	0.0438	0.0438	0.0438	0.0439
Intergenerational Correlation of Education		0.308	–	–	0.304	0.304
Welfare (CEV)		n/a	n/a	n/a	–	0.23%
Average Inter Vivos ($)		31,256	31,256	31,167	31,893	30,790
Crowding-Out	Aggregate	n/a	n/a	-28%	+19%	-25%
	Par. Wealth Tercile 1	n/a	n/a	-0%	+4%	+4%
	Par. Wealth Tercile 2	n/a	n/a	-29%	+11%	-1%
	Par. Wealth Tercile 3	n/a	n/a	-97%	+89%	-151%
	Ability Tercile 1	n/a	n/a	-27%	+27%	-211%
	Ability Tercile 2	n/a	n/a	-23%	+17%	-31%
	Ability Tercile 3	n/a	n/a	-30%	+20%	-13%

Table G3: Responses to a 56% increase in tuition subsidy for every student (i.e., extra $1,580, $374 and $81 per year for students of type $q = 1, 2, 3$, respectively). The cost of this policy matches that of the $1,000 general grant expansion in the 'PE Short-run'. 'Treatment' identifies the direct immediate effect of the policy on the child's education decision. 'PE Short-run' incorporates the short-run response of parental IVTs. 'PE long-run' is the new steady state, with the new ergodic distribution of parental IVTs, but where prices and taxes are fixed at their initial values. 'GE Long-run' is the new steady-state where prices clear input markets and tax rates balance the government budget constraint. "%" denote percentage changes from the benchmark value. The welfare gain is expressed in terms of changes in expected lifetime consumption for a newborn agent. 'Crowding Out' of IVT is defined as the average change in IVTs as a percentage of the average change in the grant (in absolute value) for all the individuals who enroll in college in the experiment.

Ability-Tested Grants

		Benchmark	Treatment	P.E. Short-run	P.E. Long-run	G.E. Long-run
Policy Cost		n/a	92%	87%	82%	68%
College Attainment Rates	Ability Tercile 1	0.038	0.044	0.046	0.044	0.041
	Ability Tercile 2	0.178	0.233	0.227	0.216	0.187
	Ability Tercile 3	0.568	0.604	0.590	0.598	0.577
	Par. Wealth Tercile 1	0.197	0.239	0.230	0.222	0.203
	Par. Wealth Tercile 2	0.191	0.231	0.216	0.215	0.194
	Par. Wealth Tercile 3	0.396	0.412	0.417	0.422	0.407
	Aggregate	0.261	0.294	0.287	0.286	0.268
Labor Tax Rate		0.270	0.270	0.270	0.270	0.271
Price of CL/HS Labor		1.335	–	–	–	1.317
Log of College Premium		0.62	-2.1%	-2.4%	-1.1%	-1.8%
Student Labor Supply		n/a	-4.7%	-0.6%	-4.9%	-3.6%
Aggregate Output		n/a	1.5%	1.0%	1.1%	0.3%
Interest Rate		0.0438	0.0438	0.0438	0.0438	0.0440
Intergenerational Correlation of Education		0.308	–	–	0.309	0.307
Welfare (CEV)		n/a	n/a	n/a	–	0.14%
Average Inter Vivos ($)		31,256	31,256	31,086	31,925	30,636
Crowding-Out	Aggregate	n/a	n/a	-33%	23%	-24%
	Par. Wealth Tercile 1	n/a	n/a	+1%	5%	-1%
	Par. Wealth Tercile 2	n/a	n/a	-42%	12%	-8%
	Par. Wealth Tercile 3	n/a	n/a	-51%	42%	-46%
	Ability Tercile 1	n/a	n/a	-35%	59%	-61%
	Ability Tercile 2	n/a	n/a	-25%	22%	-24%
	Ability Tercile 3	n/a	n/a	-36%	21%	-22%

Table G4: Responses to an increase in tuition subsidies equal to 0.054*exp(θ), e.g., extra $723, $979 and $1,098 per year for students in the bottom, middle, and top ability tercile, respectively). The cost of this policy matches that of the $1,000 general grant expansion in the 'PE Short-run'. 'Treatment' identifies the direct immediate effect of the policy on the child's education decision. 'PE Short-run' incorporates the short-run response of parental IVTs. 'PE long-run' is the new steady state, with the new ergodic distribution of parental IVTs, but where prices and taxes are fixed at their initial values. 'GE Long-run' is the new steady-state where prices clear input markets and tax rates balance the government budget constraint. "%" denote percentage changes from the benchmark value. The welfare gain is expressed in terms of changes in expected lifetime consumption for a newborn agent. 'Crowding Out' of IVT is defined as the average change in IVTs as a percentage of the average change in the grant (in absolute value) for all the individuals who enroll in college in the experiment.

Removal of Government-Sponsored Loans

		Benchmark	Treatment	P.E. Short-run	P.E. Long-run	G.E. Long-run
College	Ability Tercile 1	0.038	0.017	0.016	0.035	0.047
Attainment	Ability Tercile 2	0.178	0.077	0.050	0.184	0.218
Rates	Ability Tercile 3	0.568	0.217	0.274	0.490	0.515
	Par. Wealth Tercile 1	0.197	0.003	0.032	0.160	0.187
	Par. Wealth Tercile 2	0.191	0.014	0.042	0.172	0.198
	Par. Wealth Tercile 3	0.396	0.292	0.266	0.377	0.395
	Aggregate	0.261	0.103	0.113	0.237	0.258
Labor Tax Rate		0.270	0.270	0.270	0.270	0.277
Price of CL/HS Labor		1.335	–	–	–	1.353
Log of College Premium		0.62	n/a	n/a	-0.9%	-1.6%
Student Labor Supply		n/a	-19%	+3.1%	+33.1%	+32.3%
Aggregate Output		n/a	n/a	n/a	-2.4%	-1.5%
Interest Rate		0.4038	0.0438	0.0438	0.0438	0.0444
Intergenerational Correlation of Education		0.308	–	–	0.326	0.323
Welfare (CEV)		n/a	n/a	n/a	n/a	-0.377%
Average Inter Vivos ($)		31,256	31,256	29,618	25,647	27,265
Crowding-Out	Aggregate	n/a	n/a	13%	-39%	-29%
	Par. Wealth Tercile 1	n/a	n/a	5%	-0.1%	1.5%
	Par. Wealth Tercile 2	n/a	n/a	15%	0.2%	6.3%
	Par. Wealth Tercile 3	n/a	n/a	14%	-79%	-63%
	Ability Tercile 1	n/a	n/a	17%	-18%	-7.8%
	Ability Tercile 2	n/a	n/a	30%	-24%	-17%
	Ability Tercile 3	n/a	n/a	10%	-51%	-37%

Table G5: Elimination of all government-sponsored loans. ‘Treatment’ identifies the direct immediate effect of the policy on the child’s education decision. ‘PE Short-run’ incorporates the short-run response of parental IVTs. ‘PE long-run’ is the new steady state, with the new ergodic distribution of parental IVTs, but where prices and taxes are fixed at their initial values. ‘GE Long-run’ is the new steady-state where prices clear input markets and tax rates balance the government budget constraint. “%” denote percentage changes from the benchmark value. The welfare gain is expressed in terms of changes in expected lifetime consumption for a newborn agent. ‘Crowding Out’ of IVT is defined as the average change in IVTs as a percentage of the change in the borrowing limit (in absolute value), i.e., $35,497, for all the individuals who enroll in college in the experiment.

Expansion of Government-Sponsored Loan Limit

		Benchmark	Treatment	P.E. Short-run	P.E. Long-run	G.E. Long-run
College Attainment Rates	Ability Tercile 1	0.038	0.040	0.038	0.037	0.037
	Ability Tercile 2	0.178	0.214	0.210	0.179	0.178
	Ability Tercile 3	0.568	0.613	0.602	0.574	0.573
	Par. Wealth Tercile 1	0.197	0.228	0.228	0.200	0.199
	Par. Wealth Tercile 2	0.191	0.220	0.213	0.187	0.191
	Par. Wealth Tercile 3	0.396	0.418	0.408	0.403	0.399
	Aggregate	0.261	0.289	0.281	0.263	0.263
Labor Tax Rate		0.270	0.270	0.270	0.270	0.270
Price of CL/HS Labor		1.335	–	–	–	1.334
Log of College Premium		0.62	n/a	n/a	-0.1%	-0.1%
Student Labor Supply		n/a	-24.2%	-21.1%	-2.0%	-2.4%
Aggregate Output		n/a	n/a	n/a	+0.2%	+0.1%
Interest Rate		0.0438%	0.0438%	0.0438%	0.0438%	0.0439%
Intergenerational Correlation of Education		0.308	–	–	0.302	0.304
Welfare (CEV)		n/a	n/a	n/a	n/a	0.002%
Average Inter Vivos ($)		31,256	31,256	30,469	31,335	31,220
Crowding-Out	Aggregate	n/a	n/a	-29%	-1.7%	0.5%
	Par. Wealth Tercile 1	n/a	n/a	-3.3%	0.6%	0.1%
	Par. Wealth Tercile 2	n/a	n/a	-37%	-3.8%	0.6%
	Par. Wealth Tercile 3	n/a	n/a	-39%	-1.9%	0.7%
	Ability Tercile 1	n/a	n/a	-19%	-30%	2.4%
	Ability Tercile 2	n/a	n/a	-17%	2.2%	-0.2%
	Ability Tercile 3	n/a	n/a	-34%	-1.1%	0.6%

Table G6: Responses to a $10,000 expansion of the unsubsidized government sponsored loan cumulative limit. 'Treatment' identifies the direct immediate effect of the policy on the child's education decision. 'PE Short-run' incorporates the short-run response of parental IVTs. 'PE long-run' is the new steady state, with the new ergodic distribution of parental IVTs, but where prices and taxes are fixed at their initial values. 'GE Long-run' is the new steady-state where prices clear input markets and tax rates balance the government budget constraint. "%" denote percentage changes from the benchmark value. The welfare gain is expressed in terms of changes in expected lifetime consumption for a newborn agent. 'Crowding Out' of IVT is defined as the average change in IVTs as a percentage of the change in the borrowing limit (in absolute value), i.e., $10,000, for all the individuals who enroll in college in the experiment.

H Computational Algorithm

This appendix 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 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 Section 2.6 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.

3. Simulate the life-cycles of 10,000 agents who start with initial wealths given by $\tilde{\mathbf{a}}_0$. Each of the 10,000 simulated agents is exogenously matched with another agent who represents her child. The abilities of the parents and children in these matches are consistent with the transition matrix for 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 10,000 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 the benchmark economy, adjust residual government expenditure G to solve the government budget constraint. If computing a policy experiment, update the labor tax rate appropriately if 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, tables, and figures of interest.