The Transmission of Credit Scores through the Market for School Loans*

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June 2009

Preliminary and Incomplete

Abstract

In recent years, students and their parents are more frequently borrowing to finance college, and are often turning to private credit markets for these loans. We first consider the case where young agents can finance human capital accumulation through parental transfers and the private market for school loans. When borrowing from the private market, students often use the credit histories of their parents to help qualify for loans. We find that the optimal level of human capital investment of the child depends positively on the parent's credit score and the amount of parental transfers. Thus, our model delivers an interesting finding: parents with low credit scores should transfer more funds to their child to compensate for the fact that his child will face harsher loan conditions as a result of the low credit scores. We then incorporate government school loans where students can borrow from the government to finance their college investment in addition to private credit markets and parental transfers. We quantify the effects of the intergenerational transmission of credit scores and funds on human capital

*The authors would like to thank seminar participants at the Federal Reserve Bank of Atlanta, the 2009 Midwest Macroeconomic Meetings in Indiana, and the 2009 University of Iowa Alumni Workshop. Several people in various financial aid offices and private credit institutions provided us with details about the private student loan market. We thank them for their insight. Special thanks to B. Ravikumar, Eric Smith, Tom Wise, and Lance Lochner for their insights. All errors are are own.

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investment, and analyze the trade-offs between credit scores and parental transfers across generations induced by alternative credit market arrangements.
JEL Codes: I22; J24

Keywords: Educational Finance; Human Capital; Credit Markets

1 Introduction

In recent decades, the cost of attending college has skyrocketed. According to the College Board (2007a), total charges (which includes tuition, fees, room and board) for public, four-year colleges in 2007-08 was $13,589 per year (in 2007 dollars) and $32,307 for private, four-year colleges, up 40.7 and 29.1 percent, respectively, since 1997-98. To pay for college, undergraduate students and their parents face various options. Students often receive institutional, private and government grants to cover some of the costs of their college education. Students also may have savings or current income to draw upon and can borrow directly from the federal government. Parents also contribute to their child's college education, and the sources of these funds come from their current income, college savings plans and retirement accounts. In recent years, students and their parents are more frequently borrowing to finance college, and are often turning to private credit markets for these loans.

Along with the rise in college costs, federal, state, institutional and private grants and tax benefits for higher education have increased. The College Board (2008) reports that average grant aid for full-time equivalent students in financial aid has increased 47.2 percent between 1997-98 and 2007-08. Still, the net price of college, which is total charges net of average grants and tax benefits, for public and private four-year institutions has increased 43 and 27.4 percent, respectively.

Despite the rise in college costs, the amount undergraduate students can borrow from the Federal government was constant between 1993 and 2007. Dependent students could borrow up to $23,000 over the course of their undergraduate career. However, more undergraduate students borrow from the Federal government in recent years: in 2007-08, 42% of all undergraduates borrowed Stafford loans, compared to 33% a decade earlier (College Board, 2008). And more than one-half of all undergraduate student borrowers borrow the maximum amount from federal student loan programs (Berkner, 2000; Titus, 2002), suggesting that a majority of undergraduates are credit constrained (Lochner and Monge-Naranjo, 2008).

As a result, there has been an explosion of lending from private creditors for college: the volume of nonfederal, private student loans increased by an astonishing 592% during the last ten years (College Board, 2008), constituting a $17.6 billion industry in 2007-2008. Estimates from the College Board (20008) and Sallie Mae suggest that approximately 10% of undergraduates borrow directly from private creditors to finance college expenditures.

Thus, to combat the rising costs of college, students and their parents are receiving more from all sources (federal loans and Federal, state and institutional grants), however, the largest increase is taking place in nonfederal (i.e., private) loans. In this paper, we evaluate the three main sources of funding for undergraduate education: parental transfers, government loans and private loans. We develop a model in which parents can transfer money to their children, which is used to pay for college. The child can decide to borrow for college, from both the government and the private credit market. When borrowing from the private market, students can use the credit histories of their parents to help them qualify for loans. The public and private credit markets for school loans mimic what we observe in the U.S. First, interest rates for government loans are lower than in private credit markets since the government partially subsidizes them. Second, the amount borrowed from the government is based on need, and cannot exceed the cost of college less expected parental contributions. The amount borrowed from private creditors cannot exceed the cost of college less any financial aid the student receives. Third, to obtain a government loan, no credit history is required. However, for private creditors, the credit histories of the child and parents are important since often parents serve as cosigners on these loans. Thus, interest rates in the private market depend critically on the credit history of parents.

In particular, children of parents with better credit scores face much lower interest rates in the private market for school loans. This generates a mechanism in which parents may transfer their credit history to their children. Lower interest rates on private education loans will lead to lower debt levels. As a result, children whose parents have better credit scores may be more inclined to invest in their human capital. The reverse holds for children of parents with lower credit histories: they may decide to invest less in human capital accumulation since they face higher interest rates and hence higher debt levels.

In addition, parental wealth affects the borrowing decision of students. If students borrow to finance college, they will first borrow from the government, and then use the private credit markets to make up the difference. Clearly, children with wealthier parents will receive more parental transfers, but they will also qualify for fewer government loans since their expected family contribution is higher. Thus, they may decide to use private education loans to finance part of their college expenses. Children from low-wealth households will be eligible for more government loans, but if they decide to use private credit markets to finance the rest, they may face higher interest rates if their parents credit score is lower. Thus, children and parents in the model are linked through transfers of wealth and credit scores. We focus on the transmission of wealth and credit scores from parents to children, and measure the extent to which these mechanisms affect human capital accumulation.

The college financing literature is rich, with significant contributions by Carneiro & Heckman (2002), Dynarski (2003), Heckman et al. (1998), Hoxby (2004), and Keane & Wolpin (2001). In recent years, the literature has focused on the effectiveness of government student loans, with important contributions by Lucas & Moore (2007), Lochner & Monge (2008), Schiopu (2008) and Ionescu (2009). Of these, only Lochner & Monge-Naranjo (2008) incorporate a market for private school loans in which both the government and the private market charge penalties for default. In their framework, there is a limited commitment problem in the private student loan market, where creditors can reacquire part of the loan in the case of default. Thus, in the private market, credit constraints are endogenous and interest rates vary with the size of loan. Our framework is different in that interest rates vary with credit worthiness, and credit limits are based on the cost of college less financial aid. In Lochner and Monge-Naranjo(2008), ability and family resources matter across generations, while we are most interested in exploiting the transmission of wealth and credit worthiness across generations. The primary goal of Lochner and Monge-Naranjo (2008) is to explain the positive relationship between human capital investment and ability observed in the data, while our goal is to analyze how parental wealth and credit worthiness affect the human capital accumulation of their children.

In related work, Altig and Davis (1989) and Soares (2008) consider the role of altruism (parental transfers) in an environment with exogenous credit constraints. Typically, government policies aimed at relaxing borrowing constraints (such as government school loans) would improve welfare, but Soares (2008) finds that this is not necessarily the case: looser credit constraints for children may lower parental transfers and reduce the child's savings, which lead to less investment in human capital, and reductions in welfare. Schiopu (2008) analyzes various higher education financing policies (including the federal student loan program) in an environment with altruistic parents who transfer resources to their children to finance higher education. Our analysis complements this work by showing how parental transfers of both financial assets and credit worthiness affects human capital accumulation.

Finally, recent work has analyzed the usefulness of credit scores in capital markets. Athreya, Tam and Young (2008) consider the amount of information that can be gleaned from credit scores to explain the rise of unsecured credit, bankruptcy rates and credit discounts. Chatterjee, Corbae and Rios-Rull (2008) develop a theory of unsecured debt and reputation which is motivated by facts regarding the role of credit scores in consumer credit and auto insurance markets.

To our knowledge, we are the first to consider how credit worthiness can be inherited by future generations. In our set-up, the credit scores of parents determine the borrowing conditions for the child (both interest rates and credit limits), which affect the child's human capital accumulation (i.e., college education). Since labor income depends positively on human capital, loan repayments vary with human capital. The loan repayment history of the parent affects their credit score, which filters back to their child's borrowing conditions and hence their child's human capital accumulation. This is precisely the mechanism we set out to analyze in this paper.

2 Institutional Details of Student Loans

College tuition costs are nontrivial in the U.S. The net price (total charges less grants and tax benefits) of attending a public four-year college in 2007-08 was $9,980, while the net price of the average private college was $23,000 (College Board 2007a).

As the costs of attending college rises, more families are sharing the burden of financing undergraduate education. Based on a 2008 study by Sallie Mae and Gallup of undergraduate students and their parents, parents contribute nearly half (48%) of the total amount paid for college, most of which comes from parental income and savings (covering 32% of total costs) and parental borrowing (16%). Students, on the other hand, are picking up 33% of the tab, most in the form of loans (23%) and student income/savings (10%). The remaining college costs are covered by grants and scholarships (15%) and contributions by friends and relatives (3%). Thus, the three largest sources of college financing (in rank order) are: 1) parental income/savings, 2) student borrowing, and 3) parental borrowing.

2.1 Government Student Loans

Federal loans are administered through the U.S. Federal Student Loan Program (FSLP), and includes Perkins, Stafford and PLUS Loans. Complete details on the FSLP, including recent changes to the system, can be found in Ionescu (2009). However, some general features of the program are important in our set-up.[1] First, students and their families can borrow from the U.S. government at partially subsidized interest rates, which varied with the 91-day U.S. Treasury bill rate up until 2006.[2] Second, no credit history is required to obtain a government student loan. Third, Federal student loans are need-based that take into account both the cost of attendance (total charges) and the expected family contribution, which is determined by each college and university. However, there is a limit to how much students can borrow from the government. Lochner and Monge-Naranjo (2008) report that dependent students can borrow up to $23,000 over the course of their undergraduate career using Stafford loans, while independent students can borrow nearly twice that amount. Thus, as college costs continue to rise, the demand for student loans is exceeding the amount supplied by the U.S. government. In fact, approximately 52% of all undergraduate borrowers borrowed the maximum amount from the federal government in 1999-2000 (Berkner, 2000; Titus, 2002).

Typically, repayment of government student loans begins six months after college graduation, and can last up to ten years. In the past, the federal government has allowed for

[1] In our analysis, we focus on Stafford student loans, which represents 80% of the FSLP in recent years.

[2] Recent legislation changed the structure on interest rates for subsidized student loans to be declining, fixed rates over time. The rates on Stafford loans starting in July 2006 were fixed at 6.8%. The rates for loans dispersed starting in 2011 will be set at 3.4%, and then will be reset at 6.8% in July 2012.

consolidation under certain circumstances, where borrowers could lock-in interest rates. This option no longer exists, however. Default in the FSLP is not defined in its traditional sense. Default can occur anytime during the repayment period if borrowers neglect to make a payment in 270 days. National default rates in the FSLP for the 2005 cohort were 4.6% (Department of Education).[3] Students cannot discharge their debt upon default. Dischargeability on public student loans was initially limited in 1990, with further limitations in 1998 unless default would cause "undue hardship" on the debtor. Thus, borrowers file for bankruptcy under Chapter 13, one of the reorganization chapters in which borrowers enter a repayment plan.[4] Penalties on defaulters in the FSLP include: garnishment of their wage, seizure of federal tax refunds, possible hold on transcripts and ineligibility for future student loans.[5] Once the defaulter starts repaying his government loans, bad credit reports are erased and credit market participation is not restricted.

2.2 Private Student Loans

Students and their parents can make up the difference between the cost of college and actual family contribution with government student loans and/or nonfederal, private loans. In some cases, students hit the borrowing limit from the government student loan programs, and need to make up the difference with private school loans. In other cases, students and their parents decide to take out a private loan to finance college rather than meet their expected contribution.

The College Board (2008) reports that nonfederal student loans constituted 23 percent of total student loans taken by undergraduates in 2007-08, which does not include credit card debt and home equity loans used to finance higher education. Using private sources to finance college is a new phenomena in the U.S.: total nonfederal students loans for undergraduates amounted to $17.6 billion in 2007-08, up from $2.54 billion in 1997-98 (in 2007 dollars; College Board, 2008). This represents a 592% increase in nonfederal students loans to undergraduates in the last ten years, compared to a 70% increase in federal loans to undergraduates during the same period.

The system for obtaining private student loans is much different than the FSLP. First, credit history is important. Most private student loans require certain credit criteria, which can be met by enlisting a cosigner that meets the credit criteria. For Sallie Mae, the largest creditor of private student loans, approximately 60 percent of their applicants have a cosigner

[3] http://www.ed.gov/offices/OSFAP/defaultmanagement/cdr.html

[4] As a practical matter, it is very difficult to demonstrate undue hardship unless the defaulter is physically unable to work.

[5] For details, see Ionescu (2009).

(in 2008). Second, loan limits in private school loans are set by the creditor and do not exceed the cost of college less any financial aid the student receives (from all possible sources). Third, interest rates and fees vary significantly across various levels of credit worthiness and interest accumulates while in college. For example, Sallie Mae's leading private loan for students is the Signature Student Loan, where interest rates begin at Libor + 4.8% and cap at Libor + 8.3%.[6] In pricing these loans, various credit characteristics matter, including credit scores, the number of delinquencies and bankruptcy filings within a certain period, debt-to-income ratios, and collections history. There are also some private student loan companies that use non-credit characteristics such as school attended, grade-point average, etc. in pricing a loan. In addition, it is possible to find "credit-ready" loans that are offered to applicants with no credit or a thin credit file. Many college students (especially first-time freshman) tend to fall into this category. These credit-ready loans tend to have higher interest rates and/or fees to compensate for the risk inherent in the population. For traditional private student loans, the unpaid interest is capitalized (i.e., added to the loan balance). For Sallie Mae, the most common reason for denial is creditworthiness. In particular, Sallie Mae does not grant private student loans when the FICO score of the applicant or the co-signer is less than 640 (in 2008).

Thus, the private market for student loans is becoming a larger part of the story for financing college education in recent years. This market is inherently different from the government student loan program in how credit is obtained and at what price. Most importantly, it seems that both public and private loans are used by a vast majority of students to fund their college education. Based on the Sallie Mae/Gallup survey (2008), more than two-thirds of students who use private education loans also borrow from the federal government. This compares to approximately 27% of students who borrow only from private credit markets in that survey. However, in other reports, Sallie Mae and the College Board (2008) report that only 10% of college students participate in private student loans. Schools are not required to report these numbers, and since the private student loan market is relatively new, estimates vary by source.

Nevertheless, it seems as if the majority of borrowing from private sources originates from students (usually using parents as cosigners). Based on Gallup and Sallie Mae (2008), approximately 5% of total college costs are covered with private loans taken by students, compared to only 2% taken by parents. Thus, parents are less likely to use private student loans to fund their child's education than are students. However, parents borrow in other ways to help finance their child's undergraduate education, using the Federal Parent PLUS

[6] The margins represent weighted averages and are from June 2008; they were obtained from: http://www.salliemae.com/about/investors/

loan program (representing 5% of total cost of college)[7], home equity loans or lines of credit (3%), credit cards (1%), retirement plans (0.5%), and "other sources" of borrowing (4%). In our model, we will abstract from parental borrowing via private and public education loans; instead, parents can contribute to their child's education via a lump sum transfer and can borrow in other ways to finance college. However, we believe extending our framework to allow for parental borrowing in public and private markets is an interesting avenue to pursue in future work.

Similar to government student loans, default in the private student loan market is rare. Sallie Mae reports that net charge-offs as a percentage of all of the private loans in repayment are 3.92% (annualized). Instead, lenders work with students to help them manage their student loan repayment responsibility. For example, lenders may offer a number of repayment plans to assist customers with managing their monthly payments. And those experiencing financial hardship may be offered, at the lender's discretion, a period of forbearance, an approved period of time when customers do not need to make payments on their loans. Similar to other credit markets, but unlike the public loans market, late payments, missed payments and default in the private student loan market will adversely affect the borrower's credit score, which will affect their ability to obtain credit in the future and the interest rates offered to them. Like government student loans, private student loans are not dischargeable in bankruptcy.

According to a 2006 report from the Institute of Higher Education Policy, private creditors are participating in the market for student loans for a variety of reasons. For most of the large market participants (Sallie Mae, Citigroup, Bank of America, etc.), credit is issued directly to college students in two distinct markets: the private market of school loans and government-guaranteed student loans (the Federal Family Education Loan Program, FFELP), some of which are subsidized by the federal government. Thus, large lenders typically have both types of assets in their portfolios. Initially, in order to maintain their status on preferred lending lists with colleges and universities, creditors often had to offer both types of loans, even though private loans were less profitable than the FFELP loans. In recent years, the profitability of private loans is outpacing the profitability in government-guaranteed school loans, making private student loans a lucrative business. In addition, the ability to sell these loans in capital markets as asset-backed securities makes it more attractive for creditors to issue private student loans since they do not have to hold onto the loans. Certainly, in light of the credit market tightening that occurred in 2008-09, private creditors have pulled back

[7]PLUS loans are quite similar to private student loans, in that they depend on credit worthiness (but credit requirements are far less stringent), and credit limits are generous. However, in recent years, fees and interest rates on PLUS loans have been higher than private student loans, making them less attractive.

a bit, increasing the credit requirements for these loans (Sallie Mae now requires a 670 FICO score). Still, recent evidence confirms that private student loans are still big business.

2.3 Credit Scores

Credit scores of students and their parents play an important role in the market for private student loans. Similar to other forms of debt such as unsecured debt (i.e., credit cards), personal loans, and mortgages, interest rates are tied to the credit score of the applicant and the cosigner. Credit reporting agencies such as FICO calculate credit scores for individuals based on a large set of information about their past credit history. FICO reports that the following components form part of the credit score calculation: payment history (35%), amount of outstanding debt (30%), length of credit history (15%), new credit/recent credit inquiries (10%), and types of credit used (10%).[8] It is important to note that FICO scores are based on information found in credit reports, and do not explicitly depend on income, employment tenure, education, assets, etc. However, lenders in private student loans will often consider many of these components when making a credit decision. In fact, conversations with lenders confirm this; credit characteristics such as the number of delinquencies within a certain period; bankruptcy within a certain period; debt-to-income ratios, and collections or judgments have been used as criteria in determining credit limits and interest rates. Some private student loan companies tout their ability to use non-credit characteristics such as school attended, grade-point average, etc. to price a loan. It is important to note, however, that government student loans do not depend on credit scores.

3 Private Student Loans

3.1 Model

We start by building a model that incorporates a private student loan market for undergraduate students. We keep the model as simple as possible to focus on the trade-offs that parents face with respect to financing their child's college education. We abstract from government student loans for now.

Consider a model where people live for two periods, as young adults and parents. Agents are heterogeneous in two dimensions: a parental contribution for college, $b^0 \in B$, and parental credit score, $f^0 \in F$, which are drawn independently from the distributions $B(b^0)$ and $F(f^0)$. Parental transfers and credit scores are transferred from the parent to his only child. In

[8] http://www.myfico.com/CreditEducation/WhatsInYourScore.aspx

doing so, the parent gets utility $x(b^1, f^1)$ which represents the discounted expected value of the child's value function. Thus, each young generation is composed of agents with different endowments of physical assets and intangible assets; intangible assets represent the credit worthiness inherited from their parents. Both of these transfers are important in the young agent's human capital accumulation. This is motivated by the observation that in practice, students use their parent's money for college and also borrow funds for college. Loan conditions are determined by the credit scores of their parents. Thus, parental transfers and parental credit scores matter for the young adults human capital investment.[9]

In the first period of life, agents consume c_1 and invest in human capital h using their parental contribution for college b^0. Given the fixed cost of college $\overline{d}$ and their endowment b^0, young agents may need to borrow the remaining amount, d, from private credit markets. To focus on the evolution of credit history across generations, we restrict attention to borrowing through the private market for now. As discussed above, the private market for school loans is where parents often serve as cosigners, such that the parental credit score, f^0, affects the conditions of the private student loan. Specifically, in the case the credit score is very poor, i.e. $f^0 = \underline{f}$, the agent cannot borrow. For any $f^0 > \underline{f}$, the agent is allowed to borrow the entire amount needed, i.e. $d = \overline{d} - b^0$ and the interest rate on his student loan, $R(f^0)$ is assumed to be a decreasing function of the credit score f^0. Thus the set of feasible debt levels is given by $D = \{0, \overline{d} - b^0\}$.

In the second period, agents use their earnings to pay back their student loans, p consume c_2 and leave a parental contribution for education b^1 to their only child. Second-period agents decide how much of their school loan to repay, p, which depends on the interest rate $R(f^0)$, the amount borrowed d, and the fraction of the school loan repaid, $\alpha \in [0, 1]$. Thus, $p = R(f^0)d\alpha$. We allow agents to deliver any payment they wish to their education debt. We assume that the borrower defaults on his loan when he delivers a very small payment $\alpha < \underline{\alpha}$. Based on the agent's payment, α, the credit history that the agents build and leave to his child is given by $f^1 = g(\alpha, f^0)$ with $g(\alpha, f^0) = \underline{f}$ for all $f^0 \in F$ and $\alpha < \underline{\alpha}$. We assume a linear evolution of the credit score, $g(\alpha, f^0) = \alpha a(f^0) + b(f^0)$, for all $\alpha \in [\underline{\alpha}, 1]$, where $a(f^0) > 0$ and $b(f^0) > 0$ and $g(\underline{\alpha}, f^0) = f^0$. Our formulation is motivated by the evolution of the FICO scores in the following sense: the score is updated positively when payments are observed. This upgrade is done gradually: the higher the payment, the higher the upward revision. Eventually, the credit score can be upgraded to a higher range of the FICO scores, which in turn translates into better credit conditions for one's child. Full payment induces a jump in the credit history to the next range of credit scores. If a small ($\alpha < \underline{\alpha}$) payment

[9] We abstract from modeling heterogeneity in ability for now. In the last part of this section, however, we extend the analysis to the case where people differ in ability.

is observed, the score is severely damaged.[10]

For now, we assume that agents cannot borrow from any other markets (such as a risk-free market), and there is no market uncertainty in interest rates for private student loans. Earnings in period 2 for an individual who invested h in human capital in the first period is given by $y(h)$ with $y^{'}(h) > 0$ and $y^{''}(h) = 0$. This formulation captures the idea that each year in college provides a constant return over the life-cycle.

Discounted lifetime utility for the agent consists of $u(c_1) + \beta u(c_2) + \rho x(b^1, f^1)$, where c_t represents the consumption of the agent during period t. The utility function satisfies $u'(.) > 0$ and $u''(.) < 0$. The discount factor is $\beta \in (0, 1)$ and $\rho \in (0, 1)$ reflects the degree of altruism. The function x represents the utility from transferring resources (b^1,f^1) to one's own child. We assume separability in b^1 and f^1: $x(b^1, f^1) = (1 - \phi)\ln(b^1) + \phi\nu(f^1)$ and $\nu' > 0$, $\nu'' = 0$.[11] The parameter $\phi \in (0, 1)$ measures the relative weighting that parents put on transferring funds to their child versus transferring their credit score.

For now, we assume a logarithmic utility function. Thus, the agent solves the following problem:

$$\begin{aligned} \max_{c_1,,c_2,h,p,b_1} \quad & \ln(c_1) + \beta\ln(c_2) + \rho((1 - \phi)\ln(b^1) + \phi\nu(f^1)) \\ s.t. \quad & c_1 + h \leq d + b^0 \\ & c_2 \leq y(h) - p - b^1 \\ & f^1 = g(\alpha, f^0) \\ & d \in D \end{aligned} \tag{1}$$

We focus on the case when $d > 0$, i.e. for any $f^0 > \underline{f}$, otherwise the problem is trivial. Details on the Lagrangian associated with the problem are given in the Appendix. This simplified version of the model is helpful in providing intuition regarding the implications of the parental credit score and funds for human capital accumulation. Also, it can explain the implications of repayment behavior and investment in human capital for the evolution of credit scores between generations under the current private student loan market arrangements. This framework can provide intuition behind the trade-off between parental contribution and credit scores with implications for the incentives to invest in college education. In addition, the model can be adjusted to consider how differences in ability levels across students can affect human capital accumulation and loan repayment behavior. Finally, we use the

[10] This minimum fraction $\underline{\alpha}$ can be interpreted as the per period fixed payment to a console with the present value equal to the total amount of the loan.

[11] We assume that the credit score linearly translates into some utility for one's child, $\nu(f^1)$. We will relax this assumption in the quantitative part of the paper and discuss its implications.

model to discuss the effects of an increase in the college costs in the U.S. in the past several years. Notice that this simplified environment does not incorporate government student loans.

3.2 Analytical Results

Both initial parental transfers and credit scores contribute to human capital accumulation and payments, and consequently have implications for the improvement of credit scores and parental transfers to one's child. Altruistic parents will face, however, a trade-off in leaving a higher credit score versus leaving transfers. We carefully analyze this trade-off, based on the following Euler equations:

$$\begin{aligned} \frac{u_{c_1}}{u_{c_2}} &= \beta y'(h) \\ \frac{u_{c_2}}{u_{b^1}} &= \frac{\rho(1-\phi)}{\beta} \\ \frac{u_{c_2}}{\nu_g} &= \frac{\rho}{\beta}\frac{\phi a(f^0)}{R(f^0)(\bar{d}-b^0)} \end{aligned} \tag{2}$$

These conditions, even though very simple, provide some intuition behind the main trade-off in the model. The shadow price for intertemporal consumption from the first condition simply implies that the agent will invest in human capital and sacrifice current consumption as long as the loss in marginal utility is out-weighed by the marginal utility gain in future consumption, given by $\beta y'(h)$. The second condition implies that the agent will choose to leave funds for one's education at the expense of his own consumption in the second period depending on how the agent values his own future consumption c_2 (as given by β) versus his child's consumption (given by ρ).

A more interesting result is the shadow price delivered by the last condition, which implies that the agent will choose to make a higher payment on his education debt at the expense of his own consumption in the second period if he is more altruistic, or $\frac{\rho}{\beta}$ is high. Leaving a better credit score to his child increases the value attached to his child's consumption. Results also imply that as the weight on the utility the child derives from the inherited score (ϕ) relative to the one he derives from inherited funds $(1-\phi)$ increases, the agent will be more inclined to make higher payments so that he can transfer a better credit score to his child. In addition to the effects of the parameters ρ, β and ϕ, the condition explains two key implications behind the incentives to repay one's debt.

The last condition also provides insight about the consumption costs associated with the transmission of credit scores from parent to child. With a higher credit score (f^0), the agent faces lower interest rates and is more inclined to sacrifice consumption in order to repay his private student loans (since $a(f^0)$ is increasing in f^0), thus he will leave a better score to his child. Finally, the last condition suggests that a higher debt level ($\bar{d} - b^0$) will induce agents to make a lower repayment on their loans and thus deliver a lower credit score for one's child. In this simplified model, where the private market is the only way to make up for the necessary funds to invest in human capital, agents with lower inherited college funds, b^0 will borrow more, and thus will be less inclined to leave a better credit score to one's child.

Human Capital Accumulation

We analyze the factors that affect the optimal level of human capital investment, which is given by:

$$h^* = \bar{d} - \frac{R(f_0)(\bar{d} - b^0)}{y'(h)\rho\phi\nu_g a(f^0)} \tag{3}$$

From Equation 3, we get that $\frac{\partial h^*}{\partial f^0} = -\frac{(\bar{d}-b^0)}{y'(h)\rho\phi\nu_g}\frac{R'(f_0)a(f^0)-R(f^0)a(f^0)}{a^2(f^0)}$. Since $R(f^0)$ is decreasing in f^0, $a(f^0)$ is increasing in f^0 and $y^{'}(h)\phi\nu_g a(f^0)$ and $\bar{d} - b^0$ are positive, it follows that h^* is increasing in f^0. A lower interest rate and a higher sensitivity of the new credit score to one's payment, $a(f^0)$ will induce more human capital investment. Also, we get that $\frac{\partial h^*}{\partial b^0} = \frac{R(f^0)}{y'(h)\rho\phi\nu_g a(f^0)} > 0$. Thus, agents with high initial parental transfers (b^0) and high parental credit scores (f^0) are the one's who will invest more in their human capital.

Next we examine the effect of human capital investment on the loan payment. We write the optimal payment, α^* as a function of optimal human capital investment h^*:

$$\alpha^* = \frac{y^{'}(h^*)(1 + \beta + \rho(1 - \phi))(h^* - \bar{d}) + \bar{d}}{R(f_0)(\bar{d} - b^0)} \tag{4}$$

Equation 4 implies that an increase in human capital investment delivers an increase in payments on education loans, all else constant. Furthermore, the effect of human capital investment on loan payments is larger when the returns to human capital accumulation are higher, and the inherited credit score and parental transfers are higher. Note that $\frac{\partial \alpha^*}{\partial h^*} = \frac{y'(h)(1+\beta+\rho(1-\phi)}{R(f^0)(\bar{d}-b^0)} > 0$ since $R(f^0)$ decreasing in f^0.

Loan Payments and the Evolution of Credit Scores

The incentives to repay on private school loans depend on the agent's characteristics, namely their inherited credit score and parental transfers, which affect the conditions of the loan (i.e., the menu of interest rates tied to credit scores and the sensitivity of credit scores to payments). Next, we study the repayment behavior and discuss the feedback of these incentives in the evolution of the credit scores.

Consider the optimal level of repayment:

$$\alpha^* = \frac{\bar{d}y^{'}(h)}{R(f^0)(\bar{d}-b^0)} - \frac{(1+\beta+\rho(1-\phi))}{\rho\phi\nu_g a(f^0)}. \tag{5}$$

This equation implies that $\frac{\partial\alpha^*}{\partial f^0} = -\frac{\bar{d}y^{'}(h^*)R'(f^0)}{R(f^0)^2(\bar{d}-b^0)} + \frac{(1+\beta+\rho(1-\phi))a'(f^0)}{\rho\phi\nu_g a^2(f^0)}$. Since $R'(f^0) < 0$ and $a'(f^0) > 0$, it follows that the payment, α^* is increasing in f^0. We show that the updated credit score f_1 is increasing in the inherited credit score f^0.[12] This result implies that parents who have relatively low credit scores hurt the borrowing conditions of their children since the parent's credit worthiness determines the interest rate the child receives on his private school loan. With worse borrowing conditions (i.e. higher interest rates), the child repays less of their private school loans, which leads to lower credit scores for the child. In this way, credit scores are transmitted from parent to children. Thus, in this relatively simple model, we are able to deliver an interesting intergenerational transmission of credit scores via the private market for school loans.

Furthermore, we have that $\frac{\partial\alpha^*}{\partial b_0} = \frac{\bar{d}y^{'}(h)}{R(f^0)(\bar{d}-b_0)^2} > 0$, which implies that f_1 is an increasing function of b^0. Parents who leave relatively low funds also hurt the borrowing conditions of their children since the child needs to borrow more, which makes it more difficult to repay on one's private school loan, which in turn delivers a lower credit score to be further transmitted across generations.

Finally (from Equation 4), note that the agent will deliver higher loan payments when the additional returns to his human capital investment, $y^{'}(h)$ are high enough relative to loan conditions, captured by interest rates, the sensitivity of one's payment to the updates of the credit score, etc. The immediate implication of this observation is that students with inherited low credit scores and low parental funds can make up only if returns to their human capital investment are high enough.

Parental Transfers versus Credit Scores

Next we study the trade-off that parents face when leaving good credit scores and education funds to one's child. As our results above show, agents leave a better credit history, f_1 when they inherited a higher credit score f^0 or higher education funds, b^0. The optimal choice for parental transfers is given by $b^{1*} = \frac{(1-\phi)R(f^0)(\bar{d}-b^0)}{\phi\nu_g a(f^0)}$, which delivers that b^{1*} is decreasing in both the inherited credit score f^0 and inherited education funds, b^0. This suggests that an

[12] The updated credit score is $f_1 = g(\alpha^*(f^0, b^0), f_0)$. Then $\frac{\partial f^1}{\partial f^0} = g_1\frac{\partial\alpha}{\partial f^0} + g_2$ and $\frac{\partial f^1}{\partial b_0} = g_1\frac{\partial\alpha}{\partial b^0}$.

agent with a low credit score and education funds will be inclined to leave more funds to one's child in order to make up for the fact that he cannot leave a good credit score to his child. This trade-off depends on the relative weights he puts on leaving a good credit score, ϕ, versus leaving higher education funds, $(1-\phi)$. Observe that b^{1*} increases in $\frac{(1-\phi)}{\phi}$ whereas f^1 decreases in $\frac{(1-\phi)}{\phi}$.

Heterogeneity in Ability Levels

In this section we relax the assumption that agents do not differ in ability levels and study its implications. We reconsider the earnings function in period 2 to capture differences in rewards to human capital investment across ability levels. Thus the earnings for an individual of ability $a \in A = [\underline{a}, \overline{a}]$ who invested h in human capital in the first period is given by $ay(h)$ with $y^{'}(h) > 0$ and $y^{''}(h) = 0$. In addition to the fact that each year in college provides a constant return over the life-cycle, this formulation captures the idea that high ability people benefit more from investing in human capital relative to low ability people, a fact that is consistent with the literature (Heckman et. al.).

Then the optimal human capital investment simply becomes $h^* = \overline{d} - \frac{R(f^0)(\overline{d}-b^0)}{ay'(h)\rho\phi\nu_g a(f^0)}$. Note the a in the denominator. Thus, a high ability agent will find optimal to invest more in his human capital relative to a low ability agent with the same initial transfers (f^0, b^0) from his parent. It follows that high ability agents are more likely to repay more of their loan via a higher human capital investment.

Also, when the return on education depends on inherent ability, then the repayment decision α^* depends on ability. As discussed before, higher returns to investment in human capital induce a higher repayment on one's loans. The immediate implication is that students with relatively high ability levels will be able to deliver higher payments. Thus, high ability people who inherit both low credit scores and a low level of parental transfers can get better credit scores in the future since their higher earnings and higher investment in human capital allow them to repay their loans at higher rates.

Increases in College Cost

A final exercise that we conduct before introducing the full model is to look at the effects of the increase in the college cost in the U.S. in the past two decades. Data show that even though the cost of college increased dramatically (by 74% between 1987-88 and 2007-08; College Board, 2008), enrollment rates increased steadily over the last two decades in the U.S. by roughly 10 percentage points (Department of Education, 2007). The increase in the college premium during this period is often cited as one explanation for the increase in enrollment rates. However, studies have concluded that the increase in the relative returns to higher education cannot fully explain the increase in enrollment during this period.

We explore these issues in our current model, by simply assuming that there is an increase in $\overline{d}$ and look at the effects on human capital investment. Equation 3 delivers that $\frac{\partial h^*}{\partial \overline{d}} = \frac{y'(h)\rho\phi\nu_g a(f^0) - R(f^0)}{y'(h)\rho\phi\nu_g a(f^0)}$, which implies that an increase in the college cost induces an increase in human capital investment only if the rewards to education are high enough relative to credit market arrangements such as interest rates on education loans or the feedback of loan repayments on one's credit score, i.e. only if $y'(h) > \frac{R(f^0)}{\rho\phi\nu_g a(f^0)}$. We will quantify these effects in Section 4.3 of the paper. Thus, when the cost of college goes up, private student loans relax the credit constraints that agents face, allowing them to increase their human capital accumulation.

Summary

This model, even though simplified in many regards, provides several interesting results about how private student loans affect the college investment decision and the transfer of credit scores across generations. First, we find that college investment is increasing in both the parental credit score and the parental transfer of funds for college. Children with parents with higher credit scores receive lower interest rates on their private student loans, making them more likely to repay their college debt. As such, the credit score of the child is increasing in parental credit scores, our second main finding. Thus, this model delivers an intergenerational transfer of credit scores. In addition, our results suggest that parents with low credit scores find it optimal to transfer more funds to their child to compensate for the fact that his child will face harsher loan conditions as a result of the low credit scores.

In addition, this model can be adjusted so that agents differ in ability and can explain the simultaneous increases in college enrollment, college costs, higher returns to education and lower ability levels for college students. We next consider a richer model, that more closely replicates what we observe in the student loan market.

4 Private and Public Student Loans

4.1 Model

Building on the model in Section 3.1, we extend the model to incorporate government student loans and individual savings in a risk-free market. To more closely mimic an agent's life cycle, we consider a life-cycle economy where agents live for T periods. Time is discrete and indexed by $t = 1, ..., T$ where t represents the time after high school graduation. Each agent's life is characterized by four phases: college, young adult, parent, and retirement. Table 1 illustrates the life-cycle for a typical agent in the model. The first phase represents the time spent in college. For simplicity, we assume that all agents in the model are college-bound (i.e, we do not analyze those who do not attend college.)[13] During this phase, young agents consume and invest in education. To finance their consumption and human capital accumulation, they receive parental transfers and they can borrow from the government and the private market.

Agents in their second phase of life are young, working adults who use their labor earnings to consume, pay off their school loans (both public and private), and save (or borrow). In the next phase, agents use their labor income similarly (to consume and save). In addition, each agent in this phase has one child that goes to college and may transfer some of their resources to their child to use for their child's human capital accumulation (i.e., college education). Also, the credit score in this phase matters for their child's student loans.[14] In the last phase of life, retired agents live off of their savings. We assume that the old agent dies with certainty at the end of this period.

Table 1: Phases of the life-cycle

College ($t = T_1$)	Young Adult ($T_1+1, ..., T_2$)	Parent ($T_2+1, .., T_3$)	Retirement ($T_3+1, .., T$)
Consumption (c_t) Investment in education (h) Earnings/Savings ($I(y_t - s_{t+1})$) Borrow for school $\left(d_t^g + d_t^p\right)$ Parental transfers (b^0) Credit score (f^0)	Consumption (c_t) Earnings ($y_t(h)$) Borrow/Lend (s_{t+1}) Repay student loans (p_t) Credit score (f_t)	Consumption (c_t) Earnings ($y_t(h)$) Borrow/Lend (s_{t+1}) Transfers (b^1, f^1) at $t = T_{child}$	Consumption (c_t) Interest Earnings

Agents are heterogeneous in physical assets, b^0, credit worthiness, f^0 and ability a. As in the simple model, physical assets and credit worthiness are transferred from the parent to his only child. The parent gets utility $x(b^1, f^1)$ which represents the discounted expected value of the child's value function.

Discounted lifetime utility consists of:

$$\sum_{t=1}^{T} \beta^{t-1}[u(c_t) + \rho x(b^1, f^1)] \tag{6}$$

[13]Since the goal of the paper is to consider the transmission of credit scores via the private student loan market, we feel this is a reasonable assumption. Having agents in the model that do not attend college only complicates the computations and does not add anything in terms of qualitative findings.

[14]Since this is a model of college education, we assume the costs and benefits of each child to their parent are 0 until they start college.

where c_t represents the consumption of the agent during period t. All of the parameters and functions have the same properties as in the simple model. We assume a standard utility function with constant relative risk aversion such that $u(c) = \frac{c^{1-\sigma}}{1-\sigma}$ where $\sigma > 0$. Note that during the parent phase, altruistic agents have children who go to college and derive utility from transferring resources to their child, (b^1, f^1). As in the simple model, we assume separability in b^1 and f^1 such that $x(b^1, f^1) = (1-\phi)\omega(b^1)+\phi\nu(f^1)$ and $\nu', \omega' > 0$, $\nu'', \omega'' < 0$. The parameter ϕ measures the relative weighting that parents put on transferring funds to their child versus transferring their credit score. The agent's problem is to maximize his utility (equation 6) subject to his budget constraints.

In the first phase of life, the college student consumes (c_t), invests in human capital (h), receives transfers from his parents (b^0) and borrows from the government (d_t^g) and the private market (d_t^p). Thus, the budget constraint for the college student is:

$$c_t + h \leq b^0 + d_t^g + d_t^p + I(y_t(h,a) - s_{t+1}); \quad t = T_1. \tag{7}$$

With regards to human capital accumulation, we allow students to choose to complete 4 years of college or 2 years of college, that is attend college for half of this period. Thus, I is an indicator function, taking the value 1 if the agent completes 2 years of college, and 0 otherwise. Agents who complete only 2 years of college $(I = 1)$ will earn labor income $(y_t(h, a))$ and save/borrow for next period (s_{t+1}). If the agent completes 4 years of college (ie, $I = 0$), the opportunity cost of college completion is his foregone earnings. Agents who complete 2 years of college can be interpreted as students who attend 2-year colleges or those who drop-out from 4-year institutions. In addition, we assume all students attend college full-time. [15] We assume that there is aggregate uncertainty in income, which follows an exogenous stochastic process.

The rate at which the college student borrows from the government, R_t^g, is exogenous and does not vary across individuals, but evolves stochastically over time. The amount the student can borrow from the government, d_t^g, depends on the cost of college per year $\bar{d}$ and the parental contribution, b^0. The cost of college reflects the actual cost of college (sticker price minus institutional and government grants), and is assumed to be fixed.[16] Parental contributions for college depend on parental income and assets. Thus, the borrowing limit for a young agent from the government is: $d_t^g = min\{\bar{d} - b^0, d_{\max}\}$, where $d_{\max}$ is the exogenous borrowing limit imposed by the government for each year in college.

[15] Since most of the data on participation in student loans programs (both private and public) significantly vary with full-time and part-time enrollment, we needed to focus on one group.

[16] Certainly, a nice extension would be to consider different types of colleges (such as private versus public). However, that is beyond the scope of this paper.

The young agent can also borrow from private credit markets, d_t^p, at the interest rate R_t^p. In the data, the rate students pay for private school loans depends on their credit score and the credit score of their parents, since parents frequently serves as cosigners. Students with parents with better creditor scores receive better rates on private school loans. In this way, the parent's credit worthiness, f^0, is transferred to their child, such that $R^p(f^0)$ with $R^{p'}(f^0) < 0$. The interest rate on private loans evolves stochastically over time according to a two-stage Markov process. The transition probability matrix is the same for all agents. The mean of the process, however, and thus, the actual interest rates, are adjusted by credit score. Since interest rates and the supply of loans are exogenous, this is a partial equilibrium analysis. [17] The amount students can borrow from private credit markets for school is the difference between the cost of college $\overline{d}$ and what they receive in government loans. Thus, the borrowing limit in private credit markets is: $d_t^p \leq \overline{d} - d_t^g$.

In the next phase of life as young adults, agents consume (c_t), save/borrow (s_{t+1}), earn labor income and pay back part or all of their school loans (p_t). Hence, the budget constraint is:

$$\begin{aligned} c_t + s_{t+1} &\leq y_t(h,a)(1-\mu_i) - \Lambda - p_t; \quad i \in g,p; t = T_1+1,...,T_2; \\ \mu_i = \Lambda = 0 & \quad \text{if } p_t^g \geq \underline{p}^g \\ s_{t+j} \geq 0 & \quad \text{if } p_t^p < \underline{p}^p, \text{ for } j = 1,...,J \end{aligned} \tag{8}$$

Labor income depends on human capital, ability and an exogenous shock. Human capital accumulates during college such that $y_t'(h) > 0$, $y_t''(h) < 0$.[18] The agent enters repayment on both the public and the private loans. The loan amounts at the beginning of this repayment period are given by d_t^g for the public loans and $d_t^p R_t^p$. Note that the interest on government loans does not accumulate during college, but it does accumulate for private loans. This is consistent with what we observe in the data.[19] We assume α_t^i is the share of total debt the agent pays in period t toward loan i, where $i \in g,p$ and $\alpha_t^i > 0$. Thus, the size of payment on student loans (both government and private) at time t is represented by:

$$p_t = \sum_i \alpha_t^i d_t^i R_t^i; \quad i \in g,p; \tag{9}$$

[17] Considering the various mechanisms that could affect the supply of private student loans is beyond the scope of this paper, but would be interesting to pursue in future work.

[18] We abstract from modeling human capital accumulation after college in order to focus on the role of parental funds and credit scores in the college investment decision.

[19] In some cases, students pay interest on their private student loans while in college (to shorten the life of the loan). We abstract from this possibility.

where R_t^i represents the interest rate in period t for market $i = \{g, p\}$. According to the Department of Education and Sallie Mae, the agent needs to repay a minimum amount per period on each of these loans, i.e. $p_t^i \geq \underline{p}^i$. However, the agent can choose to pay any amount of the loan in every period. When the agent chooses to make no payment to his school loans, $\alpha_t^g = \alpha_t^p = 0$. When the agent repays all of his remaining school loans in period t (both government and private), $\alpha_t^g = \alpha_t^p = 1$.

When the agent does not repay any of his government student loan, there are consequences to default captured by the wage garnishment μ_g and pecuniary cost Λ; this occurs when payments are less than the required amount, $p_t^g < \underline{p}^g$. The pecuniary cost incorporates legal fees, time costs and stigma associated with defaulting. There is no effect on credit scores when students default on government student loans, which is consistent with what we observe in the data. When the agent makes the required minimum payment on government student loans ($p_t^g \geq \underline{p}^g$) , there is no wage garnishment or pecuniary costs, thus $\mu_g = \Lambda = 0$.

Agents default on private student loans when payments in each period are less than the required amount, ($p_t^p < \underline{p}^p$). In this case, wages are garnished at the rate $\mu_p > 0$. In addition, the default is reported to credit agencies. As a result, credit scores are revised downward in the case of default. Thus, when the agent chooses $\alpha_t^p < \underline{\alpha_t^p}$, the score becomes $g(\underline{\alpha}, f^0) = \underline{f}$. When the borrower pays the exact amount that it is required ($\alpha_t^p = \underline{\alpha_t^p}$), his score does not change, $g(\underline{\alpha_t^p}, f^0) = f^0$. For any payment $\alpha_t^p \in [\underline{\alpha_t^p}, 1]$), the score is gradually updated according to the function $g(\alpha, f^0) = \alpha a(f^0) + b(f^0)$, where $a(f^0) > 0$ and $b(f^0) > 0$. When he pays his entire loan in period t ($\alpha_t^p = 1$), his score improves to the next bin, $g(1, f^i) = f^{i+1}$ for $i \in \{1, ..., 6\}$.

In addition, the agent cannot borrow in the risk free market in the case of default for J periods from when default occurs; thus, $s_{t+j} \geq 0$ for $j = 1, ..., J$. We require that agents must pay off their school loans at the end of this period; thus, for $t = T_2$, $p_{t+1} = \sum_i (d_t^i - p_t^i) R_{t+1}^i \quad i \in g, p$.

As a parent, agents consume (c_t), borrow/lend (s_{t+1}), earn labor income ($y_t(h, a)$), and earn/pay the risk-free rate on their last period savings/borrowings, according to:

$$c_t + s_{t+1} \leq y_t(h, a) + R^f s_t; \quad t = T_2 + 1, ...T_{child} - 1, T_{child} + 1, ...T_3. \tag{10}$$

Additionally, in period $t = T_{child}$, the parent transfers assets to their child (b^1) so that the budget constraint is:

$$c_t + s_{t+1} \leq y_t(h, a) - b^1 + R^f s_t - p_{t+1}; \quad t = T_{child}. \tag{11}$$

Finally, the budget constraint in the last phase of life (retirement) is:

$$c_t + s_{t+1} \leq R^f s_t; \quad t = T_3 + 1, ..., T \tag{12}$$

where the agent consumes c_t using his return on past period savings (s_t).

Thus, the agent maximizes utility (equation 6) subject to his budget constraints (equations 7 - 12) by choosing $\{c_t, s_{t+1}, h, \alpha_t^g, \alpha_t^p, b^1, f^1\}$ taking prices $\{y_t, R^f, R_t^g, R_t^p, \mu_g, \mu_p, \Lambda\}$ as given. Overall, the economic problem of the agent is to optimally convert assets into human capital, use his human capital to earn income and pay back his education debt, and transfer resources across periods to smooth consumption. Additionally the agent must optimally transfer resources to the next generation, in the form of both physical assets and credit worthiness, since he values his child's utility. Note that both of these transfers are important in the young agent's human capital accumulation.

4.2 Calibration

The model period and phases are detailed in Table 2. Each model period represents one year, and agents live for 55 years ($T = 55$). The first phase (college) lasts 4 years, the young adult phase lasts 10 years, the parent phase lasts 24 years, and the retirement phase lasts 20 years. Thus, $T_1 = 1$, $T_2 = 11$, $T_3 = 35$, $T = 55$. The period when parental transfers are made to their child is $T_{child} = 22$ and is set to match the average parental age of college students (which is 43 years old).

Table 2: Model periods and phases

Phase	**Age**	**Years**	**Periods** (t)
College	18-22	4	1
Young Adult	23-32	10	2-11
Parent	33-56	24	12-35
Retirement	57-76	20	36-55

The parameter values are given in Table 3. The discount factor is set to match the risk free rate (R^f) of 4%, thus β =0.96. The coefficient of risk aversion is standard in the literature, $\sigma = 2$.

In setting the parameter for altruism, ρ, we use estimates from Nishiyama (2002). He calibrates the altruism parameter in a inter-generational model where agents live 4 periods, each lasting 15 years. He sets the parameter to match the relative size of inter-generational transfers (both the sum of bequests and inter vivos transfers), as a percentage of total household wealth, which is 1.32%. His calibrated altruism parameter varies with the level of relative risk aversion. For a coefficient of relative risk aversion of 1, the altruism parameter is set to 0.792. For a coefficient of relative risk aversion of 2, the altruism parameter is 0.626.

Recall that the utility function of a parent depends on how much they transfer to their child in the form of college funds and credit scores, $x(b^1, f^1) = (1-\phi)\omega(b^1) + \phi\nu(f^1)$. The parameter ϕ measures the relative weighting that parents put on transferring funds to their child versus transferring their credit score, and we set it to $\phi = 0.5$.

Table 3: Parameter Values

Parameter	Name	Value	Target/Source
β	Discount factor	0.96	Real avg rate=4%
σ	Risk aversion coeff	2	Literature
ρ	Coef of altruism	0.626	Nishiyama (2002)
ϕ	Weighting of credit scores	0.5	Avg outstanding debt
T_{child}	Transfer period	22	Avg age of college students' parents
$\overline{d}$	Net price of 4-year college	57,294*	College Board
	Net price of 2-year college	13,930*	
d_{max}	Limits on public loans	40-44% of $\overline{d}$ *	College Board
R^f	Risk-free rate	1.04	Average rate
μ_g	Wage garnish for govt loans	0.10	Set to data
μ_p	Wage garnish for private loans	0.00	Default rate for private loans - 3.9%
Λ	Pecuniary cost	37	Default rate for govt loans - 5.4%
J	Exclusion period	0	

* Values are normalized such that the present value of earnings is 300.

4.2.1 College costs, grants, loan limits, and expected parental contributions

Recall that the amount agents can borrow from the government is represented by: $d_0^g = min\{\bar{d} - b, d_{\max}\}$, where $\bar{d}$ is the total cost of college net of institutional and government grants, b represents parental contributions to college, and $d_{\max}$ is the exogenous borrowing limit imposed by the government.

Total college cost is estimated as an enrollment weighted average for public and private colleges between the academic years 2003-2004 and 2007-2008. The net price of college is total student charges (tuition, fees, room and board) net of grants and education credits, as reported by the College Board (2007a). The enrollment-weighted net price for these four years of college was \$88,380 for private universities and \$38,080 for public universities (in 2007 dollars). Among the students enrolled in college, 47.7% enrolled in 4-year public universities, 29.7% in 4-year private universities, and 22.6% in 2-year colleges (Digest of Education Statistics, 2007). Thus, the enrollment-weighted average net price for attending a 4-year institution (private and public) is \$57,294 during this period. For 2-year public institutions, the net price of attendance was \$13,930 for the years 2006-2007 and 2007-2008 (College Board, 2007a). Thus, the total net price for attending a 2-year college is approximately one-quarter of the total net price of attending a 4-year institution, on average.

With respect to government student loans, there is a maximum amount that the government will lend to students. Between 1993 and 2007, the Stafford loan limit for dependent undergraduates remained constant at $23,000 for up to five years of post-secondary education.[20] Dependent students in two-year colleges were eligible for $6,125 in Stafford loans during this period. As a percent of net college price (as reported in the previous paragraph), students enrolled in 4-year institutions could therefore borrow approximately 40% of the net college price from the federal government. Students enrolled in 2-year institutions could borrow 44% of the cost from the government.

Loan limits in the private market for school loans are set by the creditor and do not exceed the cost of college less any financial aid the student receives, including government student loans. Thus, the borrowing limit in private credit markets is: $d_0^p \leq \overline{d} - d_0^g$. (Recall that the supply of loans is fixed in our model.)

For the distribution of expected parental contribution for college, we use the High School and Beyond data from the U.S. Department of Education.[21] We get a mean expected family contribution of $52,250 (over four years of college) and a standard deviation of $37,943 in 2007 constant dollars. The sample consists of 3,721 seniors in high school.

4.2.2 Lifetime Earnings and Ability

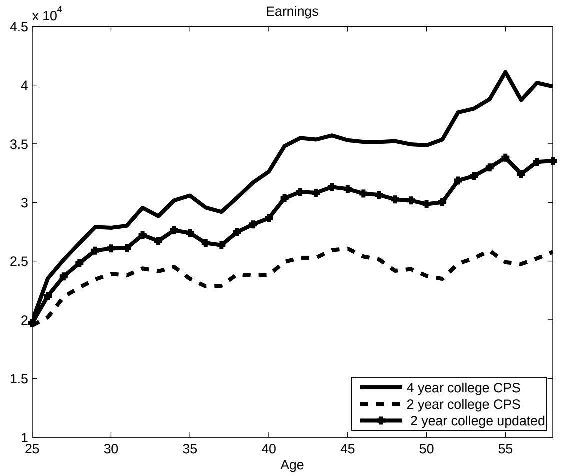
Lifetime earnings are based on earnings data from the CPS for 1969-2002 with synthetic cohorts. For each year in the CPS, we use earnings of heads of households age 25 in 1969, age 26 in 1970, and so on until age 58 in 2002. We consider a five-year bin to allow for more observations, i.e., by age 25 at 1969, we mean high school graduates in the sample that are 23 to 27 years old. We include all adults who completed at least 12 years of schooling. There are an average of 5000 observations in each year's sample. We consider people with 16 years of education for the earnings of people with 4 years of college in the model. For individuals with 2 years of college in the model we use a combination of earnings for people with exact 16 years and 14 years of education in the data. We pick the parameter in the linear combination between these two streams of earnings in the CPS data to match the 62% enrollment in 4 year colleges out of everyone who enrolls in college.[22] The life-cycle profiles for the two education groups are given in Figure 1. Real values of earnings are calculated using the CPI 1982-1984. We set the earnings in the first period in the model to 0 for people who enroll in 4 year colleges (in our model everyone fully enrolls in college) and to $30,000

[20] In 2008, the aggregate loan limit was increased by $8,000.

[21] http://nces.ed.gov/surveys/hsb/index.asp

[22] If we directly use the life-cycle earnings in the CPS data for people with 14 years of education for the earnings stream of people with 2 years of college in the model, no one will enroll in the benchmark economy to 2 year colleges.

Figure 1: Lifetime Earnings



in 1982-1984 constant dollars for people who enroll in 2 year colleges. This last parameter matches the earnings in the CPS data in the first two years in the job market for people with some college education, but less than 4 years. We obtain a lifetime premium between 4 year and 2 year college of 1.33.

We allow for heterogeneity in ability levels. Thus, we extend the earnings calibration such that the estimated return of 1.33 corresponds to the average level of ability as measured by the SAT scores. We assume that the return to the investment in human capital is linear in the ability level and for the agent with the lowest ability level there is no extra return from going to a 4 year college. This is motivated by the fact that for the least gifted student, college education is not a worthwhile investment and high ability people benefit more from the college experience (see Huggett et. al. (2006)). Thus we use these two points and estimate a linear return to college investment across ability levels $a \in [0, 1]$. We calibrate the distribution of ability, $A(a)$ to the SAT scores of high school seniors in 1999. The mean is 1016 and standard deviation is 226 (College Board, 2007). In our model, this translates to 0.51 for the mean and 0.18 for the standard deviation.

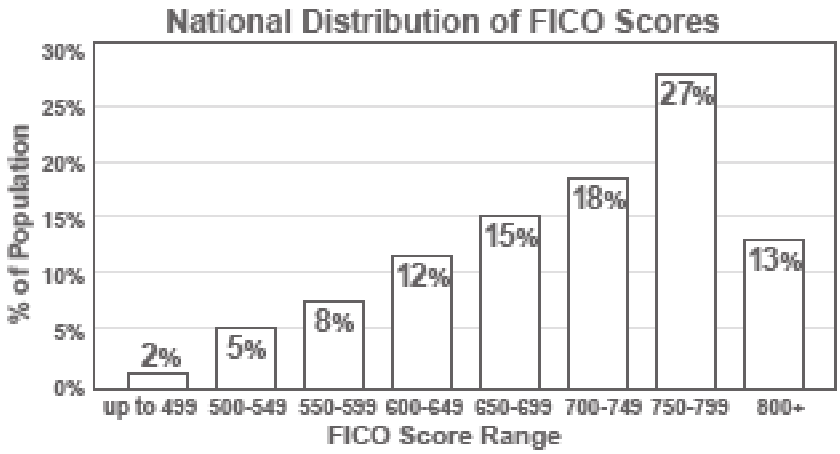
4.2.3 Interest Rates, Credit Scores and Default

For the distribution of credit scores, we use the national distribution of FICO scores, which is given in Figure 2.[23]

The interest rate on government loans and private loans follow a stochastic process, given

[23]While it is true that FICO scores are not the only credit bureau scores used to determine credit, FICO scores are by far the most commonly used for all types of credit. For student loans in particular, Sallie Mae uses FICO scores to determine the credit conditions for each borrower.

Figure 2: Credit Scores



Source: http://www.myfico.com/CreditEducation/Credit Scores.aspx

by a 2 by 2 transition matrix $\Pi(R^{g'}, R^g)$ on $\{\underline{R^g}, \overline{R^g}\}$ and $\Pi(R^{p'}, R^p)$ on $\{\underline{R^p}, \overline{R^p}\}$. As stated before, the interest rates on private loans depend on credit scores, whereas the interest rate on government loans do not.

The government sets the interest rates based on the 91-day Treasury-bill rates plus a margin of 3.1%. We use the time series for 91-day Treasury-bill rates for 2000-2007, adjusted for inflation. We fit the time series with an AR(1) process: $R_t = \mu(1-\rho) + \rho R_{t-1} + \varepsilon$, $\varepsilon \sim N(0, \sigma^2)$. The estimates of the two moments are given by $\rho = 0.9902$ and $\sigma = 0.2097$ and the mean is 2.56%. We aggregate this to annual data; the autocorrelation is given by 0.213 and the unconditional standard deviation by 1.49. We approximate this process as a two-state Markov chain. The support is $R^g \in \{1.033, 1.063\}$. The transition matrix is $\begin{bmatrix} 0.7 & 0.3 \\ 0.3 & 0.7 \end{bmatrix}$.

Sallie Mae sets the interest rates based on the 3-month LIBOR rates plus a margin that differs across credit scores, which are described in Table 4.[24] We consider 6 bins of credit scores on the set $F = [\underline{f}, \overline{f}]$ corresponding to the 5 groups of FICO scores in Table 4, including the group with FICO scores less than 640.[25] The minimum FICO score that Sallie Mae would accept for private student loans was 640 in 2008; thus, for any credit scores below 640, $d^p = 0$. We use the time series for 3-month LIBOR rates between 2002-2007 and fit it with an AR(1) process. The estimates of the two moments are given by $\rho = 0.9888$ and $\sigma = 0.2117$ and the mean is 2.65%. We aggregate this to annual data; the autocorrelation is given by 0.227 and the unconditional standard deviation by 1.4114. We have approximated

[24]The margins are from June 2008 and were obtained from: http://www.salliemae.com/about/investors/
[25]We compute the interest rate on private college loans based on the mean of 3-month LIBOR rate for the period December 2000-December 2007.

this process as a two-state Markov chain. The support for each of the bins of credit scores is $R_1^p \in \{1.071, 1.096\}, R_2^p \in \{1.089, 1.114\}, R_3^p \in \{1.095, 1.12\}, R_4^p \in \{1.105, 1.13\}$, and $R_5^p \in \{1.106, 1.131\}$. The transition matrix is $\begin{bmatrix} 0.71 & 0.29 \\ 0.29 & 0.71 \end{bmatrix}$.

We calibrate the evolution of the credit score to mimic the one in the data: credit reporting agencies update credit scores for individuals regularly based on a large set of information about their past credit history. As mentioned in section 2.2, FICO uses several components to formulate credit scores, including payment history, amount of outstanding debt, length of credit history, new credit/recent credit inquiries, and types of credit. In our model, the first two components are most relevant. Both of these factors are captured in the model by the fraction of the private student loan that is paid, α_t^p. Thus, the score is updated positively when effort payments are observed. This upgrade is done gradually: the higher the payment, the higher the upward revision. In particular, if full payment is delivered, $\alpha_t^p = 1$, then the score is updated to the next bin. In the data, default occurs when the debtor does not deliver a payment on his loans. In the model, when the agent chooses α_t^p such that $p_t^p = \alpha_t^p d_t^p < \underline{p}^p = \underline{\alpha}_t^p d_t^p$, the score is severely damaged and becomes $\underline{f}$. For any payment $\alpha_t^p \in [\underline{\alpha}_t^p, 1])$, the score is gradually updated according to the function $g(\alpha, f^i) = \alpha a(f^i) + b(f^i)$, where $a(f^i) > 0$ and $b(f^i) > 0$. When the borrower pays the exact amount that it is required, his score does not change, $g(\underline{\alpha}_t^p, f^i) = f^i$ and when he pays his entire loan in period t, his score improves to the next bin, $g(1, f^i) = f^{i+1}$ for $i \in \{1, ..., 6\}$. We use these upper and lower bounds for each bin of credit scores and compute the linear function for the credit score evolution on a finer grid of credit scores: $g(\alpha_t^p, f_t^i) = \frac{\alpha_t^p (f_t^{i+1} - f^i) + (f_t^i - \underline{\alpha}_t^p f^{i+1})}{1 - \underline{\alpha}_t^p}$. Note that this function depends on the minimum required payment, which depends on the loan amount due each period, which in turn depends on the inherited parental funds and credit score. In fact, this evolution delivers that the cut-offs of payments that induce an improvement in the credit score are decreasing in the inherited parental funds and increasing in the inherited score. This implies that a lower payment is required from individuals with low credit scores in order to increase their credit score relative to the payment required from individuals with high credit scores. This feature of the model is consistent with the fact that people with low credit scores can improve their credit scores more than people with high credit scores with the same repayment behavior (see Chattarjee et. al. (2008)).

We set the penalties upon default in the government student loan market as a wage garnishment, $\mu_g = 0.10$ to match what we observe in the data. In practice these punishments vary across agents, depending on collection and attorney's fees, and can be as high as 15%.[26] The pecuniary cost of defaulting in the government student loan program (Λ) is set to match

[26]The Debt Collection Improvement Act of 1996 raised the wage garnishment limit to 15%.

Table 4: Credit Scores and Interest Rates

FICO	Margin	R^p	% of loans
640-669	8.3	10.95%	16%
670-699	8.2	10.85%	21%
700-729	7.2	9.85%	19%
730-759	6.6	9.25%	17%
760-850	4.8	7.45%	27%

the default rate for government student loans of 5.4% in 2007.

For now, we assume that agents are not excluded from the private student loan market in the case of default. Since private student loans are a relatively new market, we do not have a good sense of the length of the exclusion period. The wage garnishment for private student loans (μ_p) is set to match the default rate for private student loans, which is 3.92%. In addition, agents in default will face a severe reduction in their credit score. We assume that default in the private student loan market will push their credit score to the lower bound, $\underline{f}$.

Finally, we calibrate $\nu(f_i^1)$ to match the utility function one derives from consuming the maximum level of debt one can obtain $\overline{d}$ for the inherited credit score, evaluated at the interest rate R_i^p. Thus, parents with better credit scores (which translates into lower interest rates and higher debt limits) will have children who borrow more and hence consume more.

5 Quantitative Results

Next, we analyze the benchmark case, based on the calibration from section 4.2. If you recall, the benchmark economy is set to match features generally consistent with the entering cohort of college students in the year 2000. Then, we consider two policy experiments. First, we consider the case in which the government increases the maximum borrowing limit on government student loans. Second, we shut down the government student loan program. This allows us to isolate the effects of private student loans on the human capital accumulation decision.

5.1 Benchmark

To understand the main mechanisms in the model, we first analyze how well the model does in replicating the data with respect to college completion rates, participation in the public and private markets for school loans, default rates in each market, and the amount borrowed in each market. Table 5 reports the results. The model does quite well in replicating college completion rates and participation rates in private and government student loan markets.

Approximately two-thirds of college students complete four years of college, one-third of college students participate in private student loans, and more than half of college students take out a government student loan. It is important to note that the participation rate and debt level for private student loans are very uncertain in the data. Estimates range wildly by school type (private vs public, 2-year vs. 4-year), year, and student type (full- or part-time). Still, the model does well in mimicking average debt levels in each market, and especially in government student loan programs. The model overstates both default rates right now. This is due to a relatively sparse grid for parental transfers and debt levels.

Table 5: Model Predictions vs. Data

Variables	**Model**	**Data**
College completion rates (4 years)	64%	62%
Participation rate in private student loan market	33%	30%
Participation rate in govt student loan market	50%	55%
Default rate in private market	7%	4%
Default rate in govt market	11%	5.5%
Average debt in govt market	$10,617	$10,200
Average debt in private market	$5,797	$4,200

Next, we analyze the model's predictions in terms human capital accumulation, the evolution of credit scores from parent to child, and parental transfers used to finance human capital accumulation. The model produces a mean credit score of 728 and a median of 718.

Similar to the findings from the model presented in section 3, which did not include government student loans, our results indicate that human capital accumulation is increasing in both the parental credit score and parental transfer. Agents who invest in 4 years of college compared to those who invest in 2 years of college had higher parental credit score (721 vs 711) and received $3,650 more parental transfers (in 1982-84 dollars).

In the model, students who invest in 2 years of education pay half the total cost of college. Recall that the limit students face on government student loans is either the net college cost minus parental transfers or $23,000, whichever is smaller. Thus, students who complete 2 years college are eligible for smaller government student loans, compared to students who complete college (assuming the same amount of parental transfers). As a result, they borrow 40% less from the government compared to college graduates in the model. However, these students use the private student loan market to make up the difference, borrowing 30% more from private student loans markets than college graduates. But private student loans are more costly, due to their higher interest rates. Thus, the private student loan market encourages fewer students to complete college. Put differently, the government student loan market encourages human capital investment, because college graduates find it optimal to borrow more from the government (which is cheaper) and less from private markets (which is more expensive), compared to students who complete two years of college.

The model predicts that the transmission of credit scores from parent to child is important in the human capital accumulation decision. Since college graduates borrow less from the private credit market and earn higher wages than agents with two years of education, they repay their student loans at higher rates, and as a result, increase their credit score over their lifetime. This does not happen for agents with only 2 years of education: higher debt levels in the private market, combined with lower lifetime earnings, make them much less likely to repay their student loans.

In the model in Section 3, we found that higher parental transfers (b^0) and higher parental credit scores (f^0) lead to higher credit scores (f^1) for the child. The richer model delivers the same qualitative findings but suggests that these intergenerational transmissions are quantitatively important. For example, a child who receives fewer parental transfers (i.e., less than the mean) ends up with a credit score of 688, while a child who receives more parental transfers (above the mean) ends up with a credit score of 776. Thus, the amount of funds that a child receives from their parent to fund college has large quantitative effects on their credit score. Similarly, a child whose parent has a relatively low credit score (between 646-682) will have a credit score of 727; this compares to a child whose parent has a high credit score (between 754-790) ending up with a credit score of 743.

However, our quantitative results suggest that initial parental transfers (b^0) and parental credit scores (f^0) do not have a significant impact on the amount of transfers left to one's child for education (b^1). Thus, if the parent's goal is to increase human capital accumulation, they should focus on ways to improve their child's credit score by transferring more funds to them, since that mechanism seems to have more bite in the college investment decision.

It is not surprising, then, that defaulters look very different than non-defaulters in the model. Defaulters have almost twice as much debt in both the private and government market for school loans. In addition, they are among the poorest of households. Average initial assets for defaulters in the government market is less than 40% of non-defaulters, while defaulters in the private market have less than half of the initial assets as non-defaulters.

In terms of initial credit scores, defaulters do not look that different from non-defaulters. Defaulters in the private market have credit scores that were initially 5 FICO points lower than non-defaulters in the private market. This is straightforward: those with higher credit scores have more to lose when defaulting in this market, since their credit score will be damaged. However, defaulters in the government market have higher initial credit scores than non-defaulters. Thus, agents with relatively high credit scores prefer to default in the government market than the private market since they face no consequences to their credit scores when they default in the government market. Thus, the existence of private credit markets is actually making default in the government loan market more attractive (or at least less costly) for agents with high initial credit scores.

5.2 Policy Experiment: Increase the Limit on Government Student Loans

In this experiment, we increase the limit on government student loans so that students can borrow up to 75% of the total cost of college net grants and aid, up from 48% in the benchmark. This represents a policy change in that the government would better meet the demand for student loans so that fewer students will use private student loans to finance college. This situation is certainly plausible for the U.S. government to consider if it feels that private student loans are doing more damage than good, or if the government's goal is to increase college completion rates.

This is exactly what we find. Having a more generous government student loan program leads to higher rates of college completion (from 64% in the benchmark to 82% now). And students are using private student loans much less: the participation rate drops from 33% to 13% with a higher government borrowing limit. In fact, only students who complete college are using the private market. Thus, the increase in the government borrowing limit is fully meeting the needs for students who attend two years of college.

Not surprising, all students (2-year and 4-year) borrow more from the government in this experiment. However, the largest change is for those who complete 4 years of college; average government debt increases by almost 43% (relative to the benchmark); those who complete 2 years of college borrow approximately 10% more from the government. College graduates also borrow more from private credit markets: average private debt increases by 39% (but is zero for students who complete 2 years of college). Not surprising, default rates in the more generous government student loan program increase by almost 30% compared to the benchmark, and fall by 10% in private credit markets.

Thus, it seems as if the increase in the government borrowing limit leads to more borrowing from both the government and private markets for those who complete college. Thus, the government student loan program is not crowding out borrowing from private markets for those students. However, for those who complete only two years of college, the more generous government program is entirely crowding out borrowing from private markets.

Since only those who complete college borrow from the private market, and they earn more and repay the student loans at higher rates, the distribution of credit scores in this economy shifts right, compared to the benchmark. However, since the private student loan market is playing a smaller role in this economy, the transmission of credit scores from parent to child is much less important. In addition, since the government is more generous, there is less incentive to leave parental transfers. As a result, mean parental transfers fall. Thus, there is a leftward shift in the distribution of parental transfers.

The main finding from this experiment is that if the government wants to increase college completion rates, an increase in the government borrowing limit would certainly do the trick, however, it comes with a significant increase in default rates in government student loan programs. In addition, more college graduates borrow from the private market in this case, but no students with only 2 years of college find it optimal to borrow from private creditors. Thus, overall participation rates in private student borrowing falls.

5.3 Policy Experiment: No Government Student Loans

In this experiment, we shut down the government student loan market. This counterfactual example represents the case in which the government decides to let private markets fully supply student loans. It is important to note that our model assumes private creditors will meet the demand of student loans (which is a strong assumption, especially in the recent financial environment). If this is the case and no government student loan program exists, we find that college completion rates rise from the benchmark, from 64% to an astonishing 81% (almost as high as the more generous government program in section 5.2).

Compared to the benchmark, participation rates are higher for all students, and both groups of students borrow more from the private market. As a result, the default rates for private student loans doubles (from 7% to 14%). If we impose a wage garnishment and/or exclusion from credit markets, college completion rates would be similar to those in the benchmark.

In this environment, the transmission of credit scores is very important to the human capital accumulation decision, however, parental transfers matter less, compared to the benchmark. Thus, the distribution of credit scores shifts right (relative to the benchmark), but less than in the first experiment, since debt levels are higher in the private market. Similarly, the distribution of parental transfers exhibits a small leftward shift, compared to the benchmark.

These results indicate that human capital accumulation will increase if we abolish the government student loan program. This result hinges on the fact that more borrowing occurs in this environment, leading to higher college completion rates. Recall that we do not impose any borrowing limit. However, if private creditors decide to limit borrowing to levels similar as the government currently does, college completion rates will be similar to the benchmark case. Thus, our findings suggest that credit limits are extremely important in human capital

Table 6: Net college price (for entire enrollment period) by income quartile, in 2007 dollars

Income Quartile	**Net price, 4-year public**	**Net price, 4-year private**	**Net price, 2-year pu**
Low	$21,827	$75,915	$9,862
Low-middle	$41,849	$86,203	$15,639
Middle-high	$44,296	$93,147	$16,845
High	$46,291	$100,801	$17,185
Mean	$38,080	$88,380	$13,930

accumulation. As borrowing limits bind for more and more students over time, the U.S. will ultimately face a reduction in college completion rates in the near future, unless college costs start leveling off.

5.4 Need-based Aid

In the model, agents are homogeneous in terms of the net cost of college. In reality, need- and merit-based financial aid vary across individuals and families, making the net price of college different. Based on data from the College Board (2007) and Heller (2008), approximately two-thirds of all U.S. education grants in 2007-08 (all forms) depend on need (i.e., income), while one-third depends on merit (i.e., ability).[27] Thus, we set net college prices to vary by income but abstract from net college prices as a function of ability.[28] For the academic year 2003-04, the College Board (2007) reports education grants by income quartiles for 4-year public and private institutions, and 2-year public institutions. Assuming that the grant/total charges ratio has remained fixed over time in each quartile, we are able to calculate net college cost by income and school type for the entire enrollment period (i.e, for 4 years or 2 years). Table 6 provides the details.

When we allow the net price of college for individuals to vary by income, we find some interesting results.

6 Summary

In this paper, we explore the link between credit scores and human capital accumulation in an environment where children finance college through parental transfers and borrowing from the government and private student loan markets. The model mimics what we observe in the data, in that the credit scores of the parents often determine the conditions of the

[27] Authors' calcuations.

[28] Refer to Caucutt and Kumar (2003) and Hanushek et al. (2004) for careful theoretical examinations of merit- and need-based aid.

loan and specifically, the interest rate the child receives on their private school loan. Thus, parents can help their child acquire human capital through two mechanisms, by transferring resources to the child to pay for college and through credit scores.

We find that higher initial credit scores raises the amount repaid on the private student loans since the student will receive better loan conditions (i.e., lower interest rates) when the parent's credit score is higher. In addition, higher repayment on private student loans leads to higher future credit scores. The more the student repays on his student loan, the better his credit score will be. Thus, credit scores are transmitted from parent to child through the private market for school loans. This is the first model that we know of that delivers an intergenerational link of credit scores.

Our model delivers another interesting and new finding regarding the college investment decision. We find that the child's optimal level of human capital investment depends positively on parental credit score and parental transfers. However, children from parents with relatively bad credit scores can still acquire human capital as long as parental transfers are relatively high. Alternatively, children from parents with relatively high credit scores do not need large parental transfers to acquire human capital. The worst case scenario is not surprising: when parents have low credit scores and do not help finance college through transfers. In this situation, the child's human capital may not improve; as a result, fewer students complete college.

In terms of student loans, children and their parents will first borrow from the government before turning to the private student loan market since interest rates are lower. However, government student loans are not meeting the financial need for many undergraduate students, thus they are turning to the private student loan market to finance the remaining difference. Our quantitative results suggest that parental transfers and credit scores do not have a significant impact on the amount of transfers left to one's child for education but that they do have large effects on the child's credit score. Thus, our results indicate that higher levels of college investment can be achieved via credit scores.

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A Appendix

The Lagrangian for the model in Section 3 is given by:

$$\Lambda = \ln(c_1)+\beta\ln(c_2)+\rho(1-\phi)\ln(b^1)+\rho\phi\nu(f^1)+\lambda_1(\overline{d}-c_1-h)+\lambda_2(y(h)-b^1-c_2-(\overline{d}-b^0)R(f^0)\alpha) \tag{13}$$

The agent chooses the optimal level of human capital accumulation h^*, the amount of loan repayment α^*, the transfer of resources to one's child b^{1*}, consumption when young c_1^* and old c_2^*, given the initial heterogeneity (f^0, b^0), prices and the loan market arrangement $(R(f^0), y^{'}(h), a_{f_0})$ and the discount factor, altruism parameter, and the relative weighting of parental transfers versus credit scores (β, ρ, ϕ).

The Equation (13) delivers the following conditions:

$$\begin{aligned}
\partial c_1 : \lambda_1 &= \quad u_{c1} \\
\partial c_2 : \lambda_2 &= \quad u_{c2}\beta \\
\partial b^1 : \lambda_2 &= \quad v_{b^1}\rho(1-\phi) \\
\partial \alpha : \lambda_2 &= \quad \frac{\nu_g \rho\phi a_{f_0}}{R(f^0)(\overline{d}-b^0)} \\
\partial h : 0 &= \quad \lambda_1 - \lambda_2 y'(h) \\
\partial \lambda_1 : 0 &= \quad \overline{d} - c_1 - h \\
\partial \lambda_2 : 0 &= \quad y(h) - b^1 - c_2 - (\overline{d}-b^0)R(f^0)\alpha
\end{aligned} \tag{14}$$

The solution to this problem is given by the following optimal choices:

$$\begin{aligned}
c_1^* &= \frac{R(f^0)(\overline{d}-b^0)}{y'(h)\rho\phi\nu_g a(f^0)} \\
c_2^* &= \frac{\beta R(f_0)(\overline{d}-b^0)}{\rho\phi\nu_g a(f^0)} \\
b'^* &= \frac{(1-\phi)R(f_0)(\overline{d}-b^0)}{\phi\nu_g a(f^0)} \\
h^* &= \overline{d} - \frac{R(f^0)(\overline{d}-b^0)}{y'(h)\rho\phi\nu_g a(f^0)} \\
\alpha^* &= \frac{\overline{d}y^{'}(h)}{R(f^0)(\overline{d}-b^0)} - \frac{(1+\beta+\rho(1-\phi))}{\rho\phi\nu_g a(f^0)}.
\end{aligned} \tag{15}$$