American Economic Journal: Economic Policy 2017, 9(4): 313–343
https://doi.org/10.1257/pol.20150079

Liquidity Constraints, Fiscal Externalities, and Optimal Tuition Subsidies†

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A large literature focuses on two important rationales for government subsidies to college students: positive fiscal externalities from a larger tax base, and liquidity constraints. This paper provides a first attempt to gauge the relative importance of these mechanisms. I use US data in combination with two modeling approaches: calibration of a simple structural model of human capital accumulation, and a "sufficient statistics" approach. The resulting optimal subsidies are larger than median public tuition by about $3,000 per year. This finding is driven by fiscal externalities; optimal tuition subsidy policy is not sensitive to the extent of liquidity constraints. (*JEL* H52, H75, I22, I23, I28)

The affordability of a college education and appropriate government education policy is an important and widely-studied subject (see, for example, surveys in Kane 2006 and McPherson and Schapiro 2006). A large body of theoretical and empirical research focuses in particular on two rationales for government subsidies to students: positive fiscal externalities from the higher income tax base that result when subsidies lead to greater human capital accumulation, and liquidity constraints in the market for student borrowing, leading to an inefficiently low level of human capital investment. In this paper, I evaluate their impact on optimal tuition subsidies, providing a first attempt to gauge the relative importance of these two mechanisms.

The economic intuition behind a fiscal externality is simple: governments need to finance a significant amount of spending outside of education and are assumed to be unable to use a lump-sum tax. Greater educational attainment leads to higher wages, and in the presence of a distortionary income tax, it also leads to individuals paying more in taxes. The resulting increase in tax revenues produces an external benefit to other individuals, as it allows for a reduction in tax rates or an increase in spending on other programs; if spending on other programs is set optimally, the marginal welfare effect does not depend on how the added revenues are redistributed

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† Go to https://doi.org/10.1257/pol.20150079 to visit the article page for additional materials and author disclosure statement or to comment in the online discussion forum.

to the population.[1] However, this external benefit is not internalized by an individual making an education investment decision, and thus the education decision is distorted by income taxation. Individuals will underinvest in education, and a subsidy to education produces a fiscal gain as it offsets the preexisting tax distortion, internalizing the externality and increasing efficiency. In this sense—as in the analysis of optimal unemployment insurance in Lawson (2017a), which precedes the current paper—a fiscal externality is an application of the Theory of the Second Best: in the presence of a preexisting distortion in the economy, adding a new distortion may improve efficiency.

Simulations in Trostel (1993) show that proportional income taxation could indeed have a significant negative effect on investment in human capital, and Trostel (2010) quantifies the fiscal benefits of college attainment, finding that net government spending on the average college graduate is negative when added future tax revenues and reduced expenditures on social programs are taken into account. This suggests that subsidies aimed at increasing enrollment and graduation could have important fiscal benefits, but the level of the optimal subsidy is an empirical question that depends on the responsiveness of enrollment to net price: if enrollment is highly responsive to the subsidy, the fiscal gain is larger and the optimal subsidy is higher.[2]

The other important rationale for tuition subsidies that is emphasized in the literature is that there may be significant imperfections in capital markets, so that students are unable or unwilling to borrow to pay for the efficient level of human capital. A large empirical literature aims to study liquidity constraints, often by estimating the causal impact of family income on enrollment, but the existence and quantitative relevance of liquidity constraints among students remains the subject of a persistent empirical controversy. Several papers find little evidence of constraints (Cameron and Heckman 2001, Cameron and Taber 2004), whereas Belley and Lochner (2007) indicate that income has become a much more important determinant of enrollment in recent decades, and Lochner and Monge-Naranjo (2012) also argue that borrowing constraints have become increasingly important.

Each of these two literatures suggests a different perspective on the question of government financial support for college education. If fiscal externalities are important, subsidies for enrollment will internalize the positive fiscal externality generated by the acquisition of human capital, and the important task for future research will be to better understand the extent to which taxes distort schooling decisions in the first place. However, if liquidity constraints are the major inefficiency in the area of college education, the essential goal of policy is to overcome the failure of credit markets, and a particular emphasis should be placed on new strategies to identify

[1] Online Appendix E.1 shows that the results hold when both taxes and other spending are allowed to change. As noted by a referee, if spending on other programs is not set optimally, the benefits of a fiscal externality could vary depending on which program or tax is adjusted; however, this is true regardless of the context, and not specific to a paper studying optimal tuition subsidies.

[2] Bovenberg and Jacobs (2005) present a case in which the optimal policy is tax-deductibility of education expenses, i.e., a subsidy rate equal to the tax rate. However, Richter (2009) and Braun (2010) show that education should be subsidized beyond the first-best if the elasticity of productivity with respect to education is increasing. Additionally, nonmonetary costs such as intrinsic utility costs of education cannot be directly subsidized, potentially implying a higher rate of subsidy on eligible monetary expenses.

such liquidity constraints, as well as studying the optimal mix of policies between subsidies and student loan programs.[3]

A small existing literature evaluates optimal tuition subsidies by focusing only on one of these motives: Trostel (1996), Trostel (2002), Akyol and Athreya (2005), and Bohacek and Kapicka (2008) focus on fiscal externalities, while Caucutt and Kumar (2003) focus on liquidity constraints. However, the only way to gauge the relative importance of these two phenomena is to embed them within a common conceptual framework that is disciplined by estimates of behavioral elasticities and other important empirical quantities from existing literatures and available data.[4] This is precisely what I do in this paper, using two complementary approaches in which the parameters are chosen to ensure that the model matches the evidence on key features of the US education sector. I calculate optimal subsidies in a baseline case, and then I evaluate the relative importance of fiscal externalities and liquidity constraints by varying the strength of each channel and isolating one at a time.

The two approaches used in my analysis are a "sufficient statistics" approach, and the calibration of a structural model—approaches that have both been widely used in the extensive literature on optimal unemployment insurance. Using the sufficient statistics method, I derive an equation for the derivative of social welfare with respect to student grants as a function of a few empirical statistics, which are therefore the sufficient statistics for welfare analysis (see Chetty 2009 for a detailed discussion of the method). Specifically, the effect of income on enrollment is weighed against the impact of subsidies on the tax base.

The sufficient statistics approach provides a transparent illustration of the basic intuition, and allows the use of well-studied empirical moments directly in the welfare equation. As a result, I do not need to specify the underlying structural parameters and functional forms; empirical measurement of the sufficient statistics is all that is needed to make welfare predictions. However, the welfare derivative is only valid locally, and in order to make out-of-sample predictions and solve for the optimal policy, a statistical extrapolation of the sufficient statistics is required. Such an extrapolation can be viewed as ad hoc, and so I complement this analysis by using the sufficient statistics to calibrate and simulate a structural model in order to demonstrate the robustness of my results to alternative assumptions.

Both approaches suggest large optimal tuition subsidies, considerably larger than the results in the existing literature, in large part because previous calibrations imply values for important moments which appear to be at odds with empirical findings in

[3] Keane and Wolpin (2001) and Johnson (2013) argue that raising borrowing limits in guaranteed loan programs will have very little effect on enrollment or graduation because of a precautionary savings motive; Johnson (2013) thus argues that tuition subsidies will be much more effective than loans in raising college completion. As a result, and for simplicity, I abstract from changes in loan policy in my analysis, assuming a fixed borrowing constraint, and focus on grants to students, which can both offset fiscal externalities and loosen any borrowing constraints that may exist.

[4] This is also the approach of a literature that studies the effects of education policies using comprehensive overlapping-generation models; a recent example is Abbott et al. (2013). This approach is complementary to the current paper: by incorporating multiple dimensions of heterogeneity in their model, the authors can evaluate more complex policies, but at the cost of analytical and computational complexity that makes it more difficult to evaluate an optimal policy. I discuss this literature further in Section IID.

the area of education.[5] In the baseline case, the estimated optimal subsidy is around $3,000 per year greater than median tuition at public universities in the United States, which is predicted to raise college enrollment by between 13 and 24 percentage points depending on the approach used.

When I examine the relative importance of fiscal externalities and liquidity constraints, I find that the result is driven by the former: higher tuition subsidies lead to increased enrollment and a larger tax base, so that a relatively small tax increase is needed to pay for the increased subsidies. Liquidity constraints are of second-order importance for optimal subsidy policy: fiscal externalities are sufficient to justify large increases in subsidies, and enacting such a generous policy would render any liquidity constraints largely irrelevant. This insensitivity of my results to liquidity constraints suggests that it may not be necessary to reach a consensus on the precise magnitude of liquidity constraints in order to make welfare statements about tuition subsidy policy.

Instead, my findings suggest that an important task for future research is to provide additional evidence on the size of externalities from education, and the final section of this paper explores the sensitivity of my results to general equilibrium effects of tuition subsidies on wages. Given the controversy surrounding the existence and size of general equilibrium effects,[6] my baseline partial equilibrium analysis is a natural starting point, but the optimal level of tuition subsidies is sensitive to strong general equilibrium effects. If increased enrollment significantly reduces the college wage premium, then tuition subsidies will be unsuccessful at substantially increasing enrollment, and the optimal subsidy is reduced, though still larger than the current level. However, positive wage spillovers from the educated to other individuals could justify stipends to students of more than $13,000 per year above and beyond the value of tuition. Even so, the main finding of the paper is robust to these extensions: liquidity constraints continue to have a small impact on optimal policy. These findings indicate that future study of the general equilibrium effects of education subsidies would be of great value to policy analysis.

It is also important to note that my finding of a substantial fiscal externality motive for subsidizing college education is not dependent on the fact that I abstract from other margins that could be affected by income taxation: I am not arguing that tuition subsidies are the only way to offset the range of distortions caused by income taxation. Rather, I argue that income taxes can distort a wide variety of margins aside from the intensive margin of labor supply; education is one of these margins, and welfare analysis of policies on any such margin should take the distortions from income taxation into account. In online Appendix F, I demonstrate this using a simple model in which income taxes impact education and job search, as well as intensive labor supply; when the government's revenue requirement increases, the jointly optimal policy features a larger marginal tax rate, a larger education subsidy, and—as in my companion paper, Lawson (2017a)—a lower unemployment benefit.

[5] Previous calibrations often select parameter values from other literatures rather than from important moments of education data; for example, Akyol and Athreya (2005) choose parameters of a production function and individual income persistence process from the macro labor literature.

[6] See, for example, the constrasting conclusions of Heckman, Lochner, and Taber (1998a) and Lee (2005) on the impact of college enrollment on relative wages, and the hypothesis of Acemoglu (1998) on directed skill-biased technological change. Trostel (1996) and Bohacek and Kapicka (2008) also assume a partial equilibrium setting.

The rest of the paper is organized as follows. Section I presents my model, and solves it for a sufficient statistics expression for the derivative of social welfare with respect to student grants. Section II provides the baseline numerical results for optimal tuition subsidies. Section III then performs the experiment of shutting down the liquidity constraint and fiscal externality channels one by one to examine their relative importance. Section IV extends the model to include general equilibrium effects, and Section V concludes. A supplementary online Appendix provides additional analytical and numerical results, including further confirmation of the robustness of my results in online Appendix E.

I. A Simple Model of College Education

In this section, I present my model of college education, followed by the calculations leading to an expression for the derivative of social welfare with respect to student grants. The model is intentionally simple and intuitive in order to highlight the essential tradeoffs of financial aid policy. However, my results hold in a far more general analysis; online Appendix B shows that the result derived from a very general model in Lawson (2015) applies almost exactly to the current model.

Additionally, to be conservative, I abstract away from nonmonetary motivations for government support of students, such as social benefits from better educated citizens, as well as other potential positive externalities from education such as effects on growth. As these factors would tend to raise the optimal subsidy, they would further weaken the relevance of liquidity constraints.

A. *Model Setup*

Time is finite and is divided into two parts: in the first, each individual i in a population of measure one has a choice of attending college or working, while in the second, individuals work at wages which depend on their education level. Since the second part will be far longer than the first, the model will consist of 12 periods, 1 in the first part and 11 in the second, where each period corresponds to 4 years, thus representing a normal working life of 48 years (say, from age 18 to 65 inclusive). This is equivalent in practical terms to a two-period model, but since discounting and comparison of quantities across periods are of great importance in my analysis, the notation and intuition are both simplified when periods of equal length are used.

In the first period, each individual chooses between attending college and working at wage w_{01}, and this choice is represented by $s_i = \{0, 1\}$, where 1 indicates college attendance.[7] In periods $t = 2, \ldots, 12$, the individual works at a wage w_{st} that depends on the education choice in the first period, where $w_{1t} > w_{0t}\ \forall t$.[8] Individuals also choose a labor effort l_{si} and thus receive income $Y_{sti} = w_{st} l_{si}$ per period, where for

[7] In the model, I abstract from the distinction between college enrollment and graduation, as elasticities of enrollment and graduation to net tuition in the empirical literature are quite similar; however, I will provide separate numerical results for the upper and lower bounds of this literature.

[8] Wages are exogenous, and there is no uncertainty. I allow for uncertainty in future incomes in online Appendix E.5 and endogeneity of wages in the general equilibrium analysis in Section IV.

simplicity l_{si} is constant across all periods of employment.[9] Explicitly modeling labor supply will allow me to incorporate distortionary effects of taxation later in the paper.

The real interest and discount rates are both equal to r, with the discount factor therefore equal to $\beta \equiv \frac{1}{1+r}$. I also allow for wage growth at a rate of g per period, representing economic growth, not individual returns to experience or tenure, as I will use average wages across all age groups in the economy.

A working individual receives utility $v^s(c_i, l_i)$ from consumption c_i and labor supply in each period, and students' utility $u(c_i)$ simply varies with consumption; this specification allows for direct utility or disutility from college attendance as well as different utility from consumption in each state. The utility functions obey the usual properties of $u', v_c^s > 0$, $v_l^s < 0$, and $u'', v_{cc}^s, v_{ll}^s < 0$, where subscripts denote derivatives. If an individual chooses not to attend college, then they will choose a labor supply l_{0i} and, since the interest and discount rates are equal, they will set consumption to a constant value c_{vi}^0 in each period, and receive lifetime utility of $U_{0i} = \sum_{t=1}^{12} \beta^{t-1} v^0(c_{vi}^0, l_{0i})$. If they do attend college, they will choose post-schooling consumption c_{vi}^1 and labor supply l_{1i}, as well as a value c_{ui} of consumption while in school, receiving lifetime utility of $U_{1i} + \eta_i$, where $U_{1i} = u(c_{ui}) + \sum_{t=2}^{12} \beta^{t-1} v^1(c_{vi}^1, l_{1i})$ and where η_i captures any idiosyncratic portion of the utility or disutility from schooling.[10]

To simplify notation, define $R_x \equiv \sum_{t=x}^{12} \left(\frac{1}{1+r}\right)^{t-1}$ and $\gamma_x \equiv \sum_{t=x}^{12} \left(\frac{1+g}{1+r}\right)^{t-1}$. Then the individual's budget constraints, for $s_i = 0$ and $s_i = 1$ respectively, can be written in the following way:

$$R_1 c_{vi}^0 = (1-\tau)\gamma_1 w_{01} l_{0i},$$

$$c_{ui} + R_2 c_{vi}^1 = (b-e) + (1-\tau)\gamma_2 w_{11} l_{1i},$$

where e is the direct and exogenous cost of college to the individual, τ is the marginal tax rate,[11] and b is the government grant given to students. This grant accounts for all financial support provided by the government to reduce the out-of-pocket price of college, and for simplicity I focus on a lump-sum grant, though I also consider two-tier grants in online Appendix E.5.[12]

Students also face a liquidity constraint, which takes the form of a limit A_i to the debt that a student may accumulate

$$c_{ui} - (b-e) \leq A_i.$$

[9] Sufficient statistics results are unchanged if labor supply is allowed to vary by period, but the assumption of constant labor supply simplifies the calculations, particularly in the structural analysis.

[10] I therefore consider a setting in which there is heterogeneity in taste for schooling but not income or returns to education; heterogeneous returns are considered in online Appendix E.7. Heterogeneity in tastes simply captures the fact that there may be many nonmonetary factors affecting educational decisions, which I take as given.

[11] In this simple model, a progressive tax would not change anything; what matters is how much of an increase in tax revenues the government collects when an individual attends college, and even in a more complex model the same intuition would apply.

[12] Partly due to the rising importance of merit aid and tax credits, government financial aid is not universally directed at low-income families; McPherson and Schapiro (2006) state that governments provide "rather little" in the form of grants to low-income students.

A maximum value of accumulated debt is a standard way of modeling liquidity constraints; for example, Caucutt and Kumar (2003) set $A = 0$ by ruling out all educational borrowing. Since there is no on-the-job uncertainty, liquidity constraints do not bind on individuals who have completed their education.

Therefore, the individual's maximization problem is to choose $\{s_i, c_{vi}^0, c_{vi}^1, c_{ui}, l_{0i}, l_{1i}\}$ to maximize $V_i = s_i(U_{1i} + \eta_i) + (1 - s_i) U_{0i}$:

$$V_i = s_i \Big[u(c_{ui}) + R_2 v^1(c_{vi}^1, l_{1i}) + \eta_i - \lambda_{1i}\big(c_{ui} + R_2 c_{vi}^1 - (b - e) - (1 - \tau)\gamma_2 w_{11} l_{1i}\big) - \mu_i(c_{ui} - (b - e) - A_i)\Big] + (1 - s_i)\big[R_1 v^0(c_{vi}^0, l_{0i}) - \lambda_{0i}(R_1 c_{vi}^0 - (1 - \tau)\gamma_1 w_{01} l_{0i})\big].$$

The government chooses b and τ subject to a budget constraint:

$$S(b + p) + G = \tau[S\gamma_2 E(Y_{11i} | s_i = 1) + (1 - S)\gamma_1 E(Y_{01i} | s_i = 0)] = \tau\overline{Y},$$

where $S = E(s_i)$ is the mean of s_i across the population, or the fraction of the population attending college, $\overline{Y}$ is mean total discounted lifetime income, and p is additional government spending required when an additional individual attends college. The value of p could be positive in the form of state appropriations to public colleges, or it could be negative if acquiring education leads individuals to make less use of public services such as social insurance later in life. Finally, G is the discounted total of other government spending over the 12 periods, which is assumed to be exogenous for simplicity, as in that case it does not need to be accounted for in individual utility. However, online Appendix E.1 demonstrates that the welfare derivative is unchanged if G is an optimally-provided public good, because then the marginal benefit of cutting taxes is the same as the marginal value of the public good, so which one is adjusted makes no difference to welfare. Thus, I implicitly assume that G is set optimally.

The essential point of the government budget constraint is that the government needs to finance G, and cannot impose a lump-sum tax. Therefore, with distortionary income taxation, any action of an individual that raises their taxable income provides external benefits to other individuals through an increase in tax revenues, which can be used to cut tax rates. This drives the fiscal externality: an analysis of a program that induces more individuals to attend college must account for the fact that individuals are likely to underinvest in education,[13] and that a subsidy to college enrollment internalizes the fiscal externality. Exactly how the government budget balance is maintained when b changes is second-order relative to the fact that a substantial tax introduces a distortion on the education margin.[14] This amounts

[13] In the presence of distortionary taxation, and absent subsidies, individuals are *certain* to underinvest in education relative to the second-best optimum, but not necessarily relative to the first-best, which could be below the second-best, a point made by Richter (2009) and Braun (2010).

[14] One referee suggested attempting to perform a distribution-neutral welfare analysis as in Kaplow (2004), in which each individual is charged with an increase in taxes in proportion to the benefits they derive from a program; this eliminates distortionary labor supply responses as well as distributional effects. Aside from the question of

to an application of the Theory of the Second Best: when considering the optimal tuition subsidy, the income tax represents a preexisting distortion on the education decision. Thus, in the presence of this distortion, introducing a new "distortion" in the form of an education subsidy can improve efficiency.

If V_i is total lifetime utility of individual i, and social welfare $V = E(V_i)$ is utilitarian with equal weights, then because individual choices of labor supply, consumption, and college enrollment are chosen optimally by the individual, changes in those variables when b changes do not have any first-order welfare impact. From the perspective of the government, V can thus be written as $V(b, \tau(b))$, and the social welfare gain from increasing the student grant b is

$$(1) \qquad \begin{aligned} \frac{dV}{db} &= \frac{\partial V}{\partial b} + \frac{\partial V}{\partial \tau}\frac{d\tau}{db} \\ &= E\left(\frac{\partial V_i}{\partial b}\right) + E\left(\frac{\partial V_i}{\partial \tau}\right)\frac{d\tau}{db}. \end{aligned}$$

Thus, the government adds up the direct effect on welfare of raising b, and the indirect effect of changing τ to balance the government budget. This division of dV/db into direct and indirect portions also hints at the intuition behind the fiscal externality: an individual making their education decision will account for the tuition subsidy b, but will not account for the indirect effect of their enrollment decision on the budget-balancing tax rate.[15]

B. *Welfare Calculations*

To solve for an empirically-implementable version of (1), I begin by evaluating the relevant terms, making use of the (unwritten) first-order conditions of the individual's maximization problem:

$$(2) \qquad \begin{aligned} \frac{\partial V_i}{\partial b} &= s_i(\lambda_{1i} + \mu_i) = s_i u'(c_{ui}), \\ \frac{\partial V_i}{\partial \tau} &= -s_i \lambda_{1i}\gamma_2 Y_{11i} - (1 - s_i)\lambda_{0i}\gamma_1 Y_{01i} \\ &= -s_i \gamma_2 Y_{11i} v_c^1(c_{vi}^1, l_{1i}) - (1 - s_i)\gamma_1 Y_{01i} v_c^0(c_{vi}^0, l_{0i}), \\ \frac{d\tau}{db} &= \frac{S}{\bar{Y}}\left[1 + \left(\frac{b+p}{b}\right)\varepsilon_{Sb} - \left(1 + \frac{G + Sp}{Sb}\right)\varepsilon_{\bar{Y}b}\right]. \end{aligned}$$

whether such personalized tax adjustments are feasible—and whether it is desirable to consider a policy change in a vacuum rather than packaged with a particular tax adjustment—such an approach is impossible in the current setting: tuition subsidies are explicitly designed to alter labor supply decisions by encouraging more educated labor. Taxes designed to cancel out the distributional effects would in fact cancel out the effects of the policy, absent liquidity constraints: if individuals are offered a subsidy for obtaining education and then charged a tax of equal present value to pay for it, there is no net change in incentives.

[15] This comparison is not exactly accurate, as the individual's decision is on the margin of S rather than b.

Here, ε_{ab} represents the (total derivative) elasticity of a with respect to b, and thus ε_{Sb} measures the effect of student grants on college enrollment, whereas $\varepsilon_{\overline{Y}b}$ measures the effect of grants on average income (accounting for foregone earnings), and thus on the tax base.

Define $E_0[\cdot]$ and $E_1[\cdot]$ as expectations over individuals for whom $s_i = 0$ and $s_i = 1$, respectively. The idiosyncratic taste for schooling, η_i, only affects the choice of s_i, and the debt limit has no effect on the consumption of those who do not attend college; therefore, $c_{vi}^0 = c_v^0$ and $l_{0i} = l_0$ are constant across individuals and $E_0[Y_{01i} v_c^0(c_{vi}^0, l_{0i})] = Y_{01} v_c^0(c_v^0, l_0)$. I can then write $S\gamma_2 E_1[Y_{11i} v_c^1(c_{vi}^1, l_{1i})] + (1-S)\gamma_1 Y_{01} v_c^0(c_v^0, l_0) = \overline{Y} v_c^*$, where v_c^* is the average income-weighted marginal utility, and the intermediate value theorem implies that $v_c^1(c_{vi}^1, l_{1i}) < v_c^* < v_c^0(c_v^0, l_0)$. The welfare derivative thus becomes

$$\frac{dV}{db} = SE_1[u'(c_{ui})] - Sv_c^*\left[1 + \left(\frac{b+p}{b}\right)\varepsilon_{Sb} - \left(1 + \frac{G+Sp}{Sb}\right)\varepsilon_{\overline{Y}b}\right].$$

Finally, I normalize the welfare gain into a dollar amount: define $\frac{dW}{db} \equiv \frac{dV/db}{v_c^0(c_v^0, l_0)}$ as the welfare gain in terms of an equivalent amount of additional consumption among nongraduates, and then

$$(3)\quad \frac{dW}{db} = S\frac{E_1[u'(c_{ui})]}{v_c^0(c_v^0, l_0)} - S\frac{v_c^*}{v_c^0(c_v^0, l_0)}\left[1 + \left(\frac{b+p}{b}\right)\varepsilon_{Sb} - \left(1 + \frac{G+Sp}{Sb}\right)\varepsilon_{\overline{Y}b}\right]$$

$$\simeq S\left[\frac{E_1[u'(c_{ui})] - v_c^0(c_v^0, l_0)}{v_c^0(c_v^0, l_0)} - \left(\frac{b+p}{b}\right)\varepsilon_{Sb} + \left(1 + \frac{G+Sp}{Sb}\right)\varepsilon_{\overline{Y}b}\right].$$

The assumption that $v_c^* \simeq v_c^0(c_v^0, l_0)$ overstates the relative importance of the derivative of the government budget constraint $d\tau/db$. Given that $d\tau/db$ must be positive at the optimum, this will lead to an underestimate of the optimal b.

Equation (3) provides a simple and intuitive illustration of the welfare consequences of tuition subsidies in terms of the magnitudes of liquidity constraints and fiscal externalities. The first term in the square brackets, the ratio of marginal utilities, measures the welfare effect of taking a dollar from workers and giving it to students, which depends on the magnitude of liquidity constraints: if students are highly constrained, their marginal utility of income will be large and redistribution will generate welfare gains. The remaining terms measure the fiscal impact of tuition subsidies: if increased subsidies raise college enrollment, this requires that the government spend more on both b and p, but if the tax base $\overline{Y}$ also increases, the resulting increase in tax revenues will raise welfare. This latter effect comes from the fiscal externality: when an individual obtains a college education, their income increases and they pay more in taxes, with an external benefit measured by the added tax revenues collected by the government.

Although the model has been simple and stylized, the result in (3) is in fact very general; Lawson (2015) derives a related formula that can be applied to any government transfer program, and in online Appendix B, I show that it applies unchanged to the current setting except for my conservative assumption that $v_c^* \simeq v_c^0(c_v^0, l_0)$. This is a standard feature of sufficient statistics analysis: a broad range of models give nearly identical welfare expressions, because the underlying functional forms and structure of the model do not matter if the model generates the sufficient statistics observed empirically.[16] However, the current model was made conspicuously simple for two reasons: ease of interpretation and intuition, and to provide a starting point for the next step in my analysis. Similar to the analysis of unemployment insurance in Chetty (2008), I will decompose the ratio of marginal utilities into two empirically observable quantities, which I call liquidity and substitution effects (Chetty refers to the latter as moral hazard in the context of unemployment insurance).

For simplicity, let me first assume that debt limits are the same for all individuals; the result is robust to a distribution of debt limits under certain assumptions, as I show in online Appendix C as well as in a sensitivity analysis in online Appendix E.6, but the intuition is clearer in the simplest case. Then, since the only heterogeneity enters in the form of the personal taste for schooling η_i, consumption choices and labor supply if schooling is undertaken are identical for all individuals: $c_{ui} = c_u$, $E_1[u'(c_{ui})] = u'(c_u)$, $c_{vi}^1 = c_v^1$, $l_{1i} = l_1$ for all i. An individual chooses to attend college if $U_1 + \eta_i \geq U_0$, or if the taste for schooling exceeds a critical value η^*:

$$\eta^* = R_1 v^0(c_v^0, l_0) - u(c_u) - R_2 v^1(c_v^1, l_1).$$

I assume that the taste for schooling η_i follows some continuously differentiable distribution $F(\eta)$, with a density given by $f(\eta)$. It follows that $S = 1 - F[R_1 v^0(c_v^0, l_0) - u(c_u) - R_2 v^1(c_v^1, l_1)]$, and therefore

$$\frac{\partial S}{\partial b} = f(\eta^*)u'(c_u),$$

$$\frac{\partial S}{\partial a_1} = f(\eta^*)[u'(c_u) - v_c^0(c_v^0, l_0)],$$

where a_1 is an additional lump-sum of cash in the first period, representing changes in initial assets. The effect of income on enrollment depends on the gap between $u'(c_u)$ and $v_c^0(c_v^0, l_0)$: if income is more valuable to a student than to a first-period worker, it will raise utility by more for the student, and will thus make an individual more likely to attend college.

It follows that I can rewrite (3) in the following way:

$$\frac{dW}{db} \simeq S\left[L - \left(\frac{b+p}{b}\right)\varepsilon_{Sb} + \left(1 + \frac{G+Sp}{Sb}\right)\varepsilon_{\bar{Y}b}\right], \tag{4}$$

[16] See Chetty (2006) and Chetty (2009) for further discussion of this point. Thus, my formula applies unchanged, for example, to a setting in which there is a nonconstant life-cycle profile of earnings; what matters is the direct redistributional gain and the effect of subsidies on S and on the tax base.

where $L = \frac{\partial S/\partial a_1}{\frac{\partial S}{\partial b} - \frac{\partial S}{\partial a_1}}$. The $\partial S/\partial a_1$ in the numerator of L is the liquidity effect, as it is the effect on enrollment of changing initial assets, whereas I call the $\frac{\partial S}{\partial b} - \frac{\partial S}{\partial a_1}$ in the denominator the substitution effect, as it represents the effect on enrollment of changing relative prices without providing immediate income to students. Therefore, L is the liquidity-substitution ratio, and a higher value of L indicates more severe liquidity constraints and a greater welfare gain from redistributing to students. I will use (4) in my sufficient statistics analysis in the next section, as it allows me to estimate the welfare gain from a marginal change in b, given values of the quantities which appear in the equation.

II. Numerical Results

This section provides the baseline numerical results for optimal tuition subsidies. First of all, estimates of each of the sufficient statistics in (4) are used to calculate an estimated value of dW/db, to determine if financial aid ought to be increased or decreased. To go beyond this local derivative, additional assumptions are required, and I begin by performing statistical extrapolations of the quantities in (4), predicting their values out of sample. As an alternative, I use the sufficient statistics to calibrate my model and simulate to find the optimum, to demonstrate that similar results can be obtained from both methods. The section concludes with a discussion of the robustness of the results.

A. *Sufficient Statistics Method*

The idea of the sufficient statistics method is to use a welfare expression such as (4), defined in terms of observable empirical values, to estimate the marginal welfare impact of the program in question. The researcher does not need to know the exact underlying functional forms and primitive parameters; the empirical quantities in (4) are the sufficient statistics for welfare, and so estimates of those quantities are all that are required.

Therefore, I must specify values for the statistics appearing in (4); these values are summarized in Table 1. Throughout the numerical analysis, I use estimates derived from American data. To begin with, I use $S = 0.388$, which is the estimated enrollment rate of 18–24-year-olds in 2007 from the National Center for Education Statistics (NCES 2011, table 213).[17]

To calculate a baseline value of b, I estimate the average direct support from government to students using data on federal aid and state grants from Wei et al. (2009): in 2007–2008, 27.6 percent of undergraduates received federal grants averaging \$2,800, 34.7 percent received federal loans averaging \$5,100, 5.6 percent received federal work-study averaging \$2,300, and 16.4 percent received state

[17] This value is a compromise between the proportion of individuals ever enrolled (Lovenheim 2011 finds that 52 percent of his sample has completed more than 12 years of schooling) and the proportion actually completing a degree, which was 28.7 percent in 2007 according to table 8 of NCES (2011).

Table 1—Baseline Values of Sufficient Statistics

Statistic	Definition	Value
S	Enrollment rate	0.388
b	Per year student grant	2
p	Net additional expenditures per student	0
ε_{Sb}	Elasticity of enrollment with respect to b	{0.1, 0.2}
$\frac{\partial S}{\partial a_1}$	Effect of income on enrollment	{0, 0.0021}
r	Interest and discount rate per period	0.12
g	Wage growth per period	0.04
$\varepsilon_{\bar{Y}b}$	Elasticity of mean income with respect to b	{0.0063, 0.0142}
$\frac{G}{Sb}$	Ratio of exogenous spending to grant spending	88.410

grants averaging \$2,500. Epple, Romano, and Sieg (2006) suggest a formula of $aid = grants + 0.25 \times loans + 0.5 \times workstudy$, which gives a per person average of \$1,690. Lacking data on other government aid and tax credits, I round this total up to \$2,000 or, denoting monetary amounts in thousands of dollars per year, $b = 2$.

Meanwhile, p captures any additional net government expenditures required when an individual attends college that do not directly provide cash to students. There are two possible components: expenditures on appropriations to public colleges, and the expenditure savings generated when educated individuals use public services such as social assistance and corrections less intensely. Trostel (2010) finds that additional expenditures on appropriations per degree are approximately offset by reductions in other government spending,[18] and therefore, for the rest of the analysis in the main body of the paper, I assume $p = 0$. However, my conclusions are not sensitive to this assumption, as the effects of education on other program expenditures are dwarfed by the effect on income; in online Appendix E.3, I redo the calculations using Trostel's most pessimistic estimates, and the results are only slightly changed.

Deming and Dynarski (2009) summarize the literature on the price response of college attendance, and conclude that the general consensus is that a \$1,000 increase in price leads to a 4 percentage point decline in attendance, with a similar proportional impact on completion. This implies an elasticity of $\varepsilon_{Sb} \simeq 0.2$, which will be my baseline case. However, Dynarski (2008) estimates that \$2,500 of financial aid leads to a 4 percentage point increase in degree completion from a base of 27 percent, which suggests a value closer to 0.1, so I will present results for this case as well.

As discussed in the introduction, numerous papers argue that income has no causal effect on enrollment, so $L = 0$ will be my preferred estimate. However, several

[18] Trostel (2010) liberally estimates the cost to government per degree at \$71,378 in present value, or about \$16,000 per year of education beyond direct subsidies, and conservatively estimates the reduction in expenditures on such things as Medicaid, Unemployment Insurance, and corrections per degree as \$55,821 in present value, or about \$14,000 per year of education. Of course, the cost of the marginal degree is not the same thing as the cost of a marginal increase in tuition subsidies, as the latter must also be paid to inframarginal students.

papers do find a positive income effect; results in Acemoglu and Pischke (2001) imply that a \$1,000 increase in family income increases enrollment by 0.21 percentage points, an effect that they describe as large.[19] Therefore, I will also produce results using $\partial S/\partial a_1 = 0.0021$, which implies $L = 0.057$ or 0.121 depending on the value of ε_{Sb};[20] the comparison to $L = 0$ will provide a first test of the relevance of liquidity constraints to optimal policy.

I assume that the interest and discount rates are 3 percent per year, and since a period is equal to four years, I use $r = 0.12$ for the interest rate and $\beta = \frac{1}{1.12} \simeq 0.893$ for the discount factor. For real wage growth, I use the average net compensation series used by the Social Security Administration for the computation of the national average wage index, deflated using the consumer price index; the average real growth rate over 1991–2008 is almost exactly 1 percent, so wages grow at $g = 0.04$ per period to capture economic growth.

To calculate a value for the elasticity of the tax base with respect to grants, I assume that each year of schooling increases earnings by a constant 8 percent,[21] and that the elasticity of taxable income to the net-of-tax rate is 0.4, as found by Gruber and Saez (2002). In online Appendix D, I solve for an expression for $\varepsilon_{\bar{Y}b}$ as a function of the other sufficient statistics, assuming that the only effects of b on $\bar{Y}$ are the direct effect from increased education and the response of taxable income to any change in the tax rate. I find that the baseline value is either 0.0142 or 0.0063, depending on the value of ε_{Sb}.

For G/Sb, I need to estimate $\tau\bar{Y}$ in order to be able to compute G. For the tax rate, what matters is the typical marginal tax faced by agents in the model, as that determines how much of the added income from education they must "share" with other workers through added tax payments. I use $\tau = 0.23$, which incorporates a 15 percent federal tax rate, a 5 percent state tax, and 3 percent for the Medicare tax; to be conservative, I abstract from Social Security taxes on the ground that they are more of a pension contribution than a tax. For $\bar{Y}$, the CPS 2008 Annual Social and Economic Supplement estimates the mean earnings of a high school graduate in 2007 to be \$33,609, which I round up to $Y_{01} = 34$, meaning that $Y_{11} = 34(1.08)^4 = 46.26$ and $\bar{Y} = 301.661$. Therefore, $G = 68.606$, and the ratio of G to grant spending is $G/Sb = 88.410$.

Plugging in each of these values, I find values for dW/db as displayed in panel A of Table 2. Notice that dW/db is the gain in welfare in dollar terms relative to the annual amount within a period, so it is equivalent to the present-value welfare gain per year over the four years of a period. The values are positive and substantial,

[19] Acemoglu and Pischke (2001) find that a 10 percent increase in income raises enrollment by 1.4 percentage points; I report results in terms of 2007 dollars. Meanwhile, Belley and Lochner (2007) find that the income difference between the first and fourth quartiles of family income can explain 16 percentage points of difference in enrollment, which implies that \$1,000 in income raises enrollment by 0.15 percentage points.

[20] I assume that ε_{Sb} is the partial derivative elasticity to make this approximation.

[21] Most of the estimates summarized in Card (1999) are between 6 percent and 11 percent, but more recent estimates are higher; see the summary in Dynarski (2008). Heckman, Lochner, and Todd (2006) and Carneiro, Heckman, and Vytlacil (2010) estimate "policy relevant treatment effects" of tuition subsidies that range from 9 percent to 25 percent, and combined with the fact that I ignore unemployment—which is generally higher among less-educated groups—this strongly suggests 8 percent is a conservative estimate. A literature studying changes in the college wage premium over time, and how they relate to shifts in supply and demand for skilled workers, is briefly summarized in Section IVA.

TABLE 2—RESULTS FROM SUFFICIENT STATISTICS AND EXTRAPOLATION USING (4)

	$\frac{\partial \hat{S}}{\partial a_1}$	
ε_{Sb}	0	0.0021
Panel A. Estimate of $\frac{dW}{db}$ at $b = 2$		
0.1	0.1811	0.2282
0.2	0.4148	0.4370
Panel B. Optimal student grants		
0.1	\$5,843	\$8,371
0.2	\$8,093	\$8,355
Panel C. Welfare gains from moving to optimum		
0.1	\$947 (30.5%)	\$1,750 (56.4%)
0.2	\$3,138 (101.1%)	\$3,471 (111.8%)

Notes: Panel A presents the one-period per year increase in welfare, expressed in dollars of consumption from a per year \$1 increase in b. Panel C expresses welfare gains as a one-time lump-sum increase in consumption, and as a percentage of baseline spending on student grants. This format is used throughout all subsequent tables of this form.

suggesting that a \$1 per year increase in student grants from the baseline of \$2,000 would provide a welfare increase equivalent to between 18 and 44 cents per person per year for 4 years. Spreading the gains out over an entire lifetime and aggregating up to an economy-wide level, this means that a 1 percent increase in b to \$2,020 would provide a net welfare gain of \$101 to \$245 million per year for an increase in yearly grant spending of about \$126 million,[22] indicating a very large return to public investments in education. The fiscal benefits of subsidizing college education are substantial even if gains from redistribution to constrained individuals are zero.

B. *Statistical Extrapolation*

The results above are based on inputting the current estimates of the sufficient statistics into (4). However, to solve for an optimal level of student grants, I must account for the possibility that the empirical values of these statistics are likely to change as b is changed. Therefore, to make predictions out of sample and estimate the optimal level of student grants, functional form assumptions are required. In this subsection, I make functional form assumptions about the sufficient statistics themselves: I make my best estimate of how each of the sufficient statistics in (4) will change as b changes. This approach is proposed in Chetty (2009), and has previously been used in sufficient statistic studies of unemployment insurance, including my companion paper (Lawson 2017a).

First, denote the baseline values of quantities using hats, i.e., $\hat{b} = 2$ and $\hat{S} = 0.388$. As above, p is assumed to be fixed at zero. I assume a constant elasticity of enrollment with respect to grants, $\varepsilon_{Sb} = \{0.1, 0.2\}$, implying that $S = \phi b^{\varepsilon_{Sb}}$, where $\phi = \frac{\hat{S}}{\hat{b}^{\varepsilon_{Sb}}}$. I can then write the government spending ratio as $\frac{G}{Sb} = 88.41 \frac{\hat{S}\hat{b}}{Sb}$, and $\varepsilon_{\bar{Y}b}$ is given the same equation as before (see online Appendix D) but with τ held

[22] I use the Census Bureau's April 2010 estimate of the 18–64 population as 194,296,087.

fixed at 0.23 for simplicity (that is, assuming that $\partial \bar{Y}/\partial \tau$ is constant with respect to τ).

This leaves only the liquidity-substitution ratio L to be extrapolated. Belley, Frenette, and Lochner (2011) find that 16 percentage points of the gap in attendance at four-year colleges between the highest and lowest family income quartiles is explained by income, so I follow their simple approach and assume that a 16 percentage point increase in enrollment is needed to reduce L to zero. I assume that the effect of income on enrollment (as a fraction of the effect of b on enrollment) declines linearly in enrollment until it reaches zero; therefore, given an initial $\hat{L}$, $\frac{\partial S}{\partial a_1} = \frac{\hat{L}}{\hat{L}+1} \frac{0.16-(S-\hat{S})}{0.16} \frac{\partial S}{\partial b}$, which implies $L = \max\left\{\frac{\hat{L}(0.16-(S-\hat{S}))}{0.16+\hat{L}(S-\hat{S})}, 0\right\}$.

This produces the results displayed in panels B and C of Table 2. To estimate the net welfare gain from moving to the optimum, I numerically integrate dW/db from $b = 2$ to the optimum, and express the welfare gain in two ways: I multiply by four to calculate the dollar amount of an equivalent one-year per person consumption increase, and I also divide by $\hat{S}\hat{b}$ to express the gain as a percentage of the initial size of the student grant program (the latter values are shown in brackets in panel C).

The results indicate that student grants should be increased substantially, by at least \$3,800 per year. Table 351 of NCES (2011) estimates that median tuition at public four-year universities was \$5,689 in 2007–2008, so my results could be interpreted to mean that net tuition should be eliminated, and government appropriations increased accordingly.[23] With a larger responsiveness of enrollment to tuition or more serious borrowing constraints, optimal grants are even larger. With the preferred estimates of $\varepsilon_{Sb} = 0.2$ and $\partial\hat{S}/\partial a_1 = 0$, the optimal stipend is about \$2,400 per year above and beyond the value of tuition, and college enrollment S is predicted to reach 0.513, an increase of 12.5 percentage points from baseline.

Meanwhile, the estimated welfare gains are substantial, particularly in comparison to the size of the policy change; aggregated to an economy-wide level, they indicate annual net welfare improvements of between \$6.6 billion and \$24.3 billion, or as much as 0.17 percent of GDP. These welfare gains are possible even though the tuition subsidy is given to all college students; more complex, better targeted subsidy programs may well achieve even greater welfare improvements, as discussed in Section IID, but substantial improvements on the current situation are possible even with very simple policy instruments.

Additionally, the results indicate that, at least with the standard assumption of $\varepsilon_{Sb} = 0.2$, liquidity constraints have a very small impact on the optimal subsidy: a shift from $\partial S/\partial a_1 = 0$ to the estimate from Acemoglu and Pischke (2001), described in that paper as a "large effect," raises the optimal subsidy by less than \$300, which is second-order next to the large increase in subsidies indicated in the baseline case.

[23] Although this is outside the scope of the current analysis, a policy of abolishing tuition may be more effective than offsetting tuition with financial aid, for reasons of salience and reduced administration. Courant, McPherson, and Resch (2006, 307) argue that the "old tradition of making public higher education 'free' has much to recommend it," and claim that this policy might be efficient if enrollment is sufficiently sensitive to tuition, but they do not evaluate the welfare implications of the policy themselves.

The results for optimal subsidies are considerably larger than those found in the existing literature, with estimated optimal subsidy rates of about 40 percent of the total cost of education in Trostel (1996), 53 percent in Trostel (2002), 25–80 percent in Akyol and Athreya (2005), around 70 percent in Caucutt and Kumar (2003), and 0–20 percent in Bohacek and Kapicka (2008). These differences are due to variation in assumptions: Trostel (1996), Trostel (2002), and Akyol and Athreya (2005) choose parameters which imply that enrollment is relatively unresponsive to subsidy rates, to an extent that appears to be at odds with empirical findings on the subject (however, Akyol and Athreya 2005 use a general equilibrium model). Meanwhile, Caucutt and Kumar (2003) abstract from fiscal externalities, and Bohacek and Kapicka (2008) use a model in which there are no direct costs of education and specify the "subsidy rate" as a reduction in taxes for a one-unit increase in education, making it difficult to translate their results into the usual framework. As mentioned in footnote 2, subsidy rates higher than the tax rate will tend to be optimal if there are nonmonetary costs of education, or if the elasticity of productivity with respect to education is increasing; both are empirically plausible and are true in my model.[24]

C. *Simulation of Calibrated Model*

Previous welfare analyses of college tuition subsidies have relied on simulations of parameterized structural models, and so the analysis to this point represents the first application of the sufficient statistics method to this subject. As discussed earlier, the welfare derivative is very general, applying to a wide variety of models. In this subsection, I will further demonstrate that the results above are not an artifact of the method, by calculating optimal subsidies from a calibrated version of my simple structural model. However, unlike previous analyses, I will calibrate the model parameters using the sufficient statistics, to ensure that the moments of the model match the most important empirical quantities in the education sector.

I assume that η follows a logistic distribution with mean μ and scale parameter σ. I then assume a utility function with no income effects, as is common in the optimal income taxation literature: $v^s(c, l) = \frac{\left(c - \frac{\alpha_s}{\delta} l^\delta\right)^{1-\rho}}{1-\rho}$. This simplifies the first-order condition for labor supply to $l_s = \left(\frac{(1-\tau)\gamma_{s+1} w_{s1}}{\alpha_s R_{s+1}}\right)^{\frac{1}{\delta-1}}$. α_s is set to make $l_s = 1$ at baseline, and $\delta = \frac{ETI+1}{ETI} = 3.5$, where $ETI = 0.4$ is the elasticity of taxable income. Utility among students takes a similar form, with α_1/δ subtracted from c to scale utility at a comparable level to v^1: $u(c) = \frac{\left(c - \frac{\alpha_1}{\delta}\right)^{1-\theta}}{1-\theta}$. Since $l_s = 1$ at baseline, I specify starting wages as $w_{01} = 34$ and $w_{11} = 34(1.08)^4$.

I use $e = 5.7$ to represent public tuition, and $p = 0$ and exogenous spending $G = 68.606$ as described earlier. I assume that all individuals face the same debt limit A; online Appendix E.6 shows that results are nearly identical when

[24] Productivity in any particular period can be written as $X = Y_0 + S(Y_1 - Y_0)$, and thus the elasticity of X with respect to S is $\frac{S}{X}\frac{dX}{dS} = \frac{S(Y_1 - Y_0)}{Y_0 + S(Y_1 - Y_0)}$, which is increasing in S.

allowing for heterogeneity in liquidity constraints. I have to solve for 5 parameters: $\{A, \theta, \rho, \mu, \sigma\}$. However, I only have three sufficient statistic conditions: $\hat{S} = 0.388$, $\varepsilon_{Sb} = \{0.1, 0.2\}$, and $\partial\hat{S}/\partial a_1 = \{0, 0.0021\}$, so I need to incorporate additional data.

One piece of data I can use is some comparison of the values of consumption: $\hat{c}_u$, $\hat{c}_v^0$, and $\hat{c}_v^1$. Any ratio of two of these, along with the equation for the debt limit and the first-order conditions, will define all three. One possibility is to use consumption values from the Consumer Expenditure Survey, where college graduates consumed 73.9 percent of their pretax income and high school graduates consumed 83.4 percent on average in 2007. The National Bureau of Economic Research's TAXSIM calculator for 2007 allows me to transform these into percentages of after-tax income (ignoring state taxes and assuming a single-earner married couple), and applying those values to Y_{01} and Y_{11}, I find that consumption of college graduates is 27.58 percent higher than that of high school graduates: $\hat{c}_v^1 = 1.2758\,\hat{c}_v^0$. An alternative is to use results in Keane and Wolpin (2001) implying student consumption (not including room and board) of \$8,077 in 1987, plus average room and board expenses in 1987–1988 of \$3,037 from table 349 of NCES (2011), compared to average per-equivalent-person consumption of \$15,816 in 1988 from Cutler and Katz (1991). Student consumption is then 73.18 percent of average consumption across a steady-state of individuals, which implies $\hat{c}_v^1 = 1.2437\,\hat{c}_v^0$. These estimates are very similar, so I will take a value halfway in between: $\hat{c}_v^1 = 1.26\,\hat{c}_v^0$.

Finally, I use an estimate of relative risk aversion to pin down ρ. A constant relative risk aversion parameter of 1 is typical, so I assume $v_s(c, l) = \ln\left(c - \frac{\alpha_s}{\delta}\, l^{\delta}\right)$; in online Appendix E.2 I show that although optimal subsidies are somewhat lower if $\rho = 2$, the effect of liquidity constraints is very similar to the baseline results.

My calibration method begins by using $\hat{c}_v^1 = 1.26\,\hat{c}_v^0$ to solve for the debt limit A, and then using $u'(c_u) = (\hat{L} + 1)v'(c_v^0)$ to solve for θ. I use these results and the conditions that $\hat{S} = 0.388$ and $\varepsilon_{Sb} = \{0.1, 0.2\}$ to find the parameters of the preference distribution: $\hat{S}$ primarily identifies the level μ of the preference distribution, whereas the responsiveness of enrollment ε_{Sb} is informative about the dispersion of the distribution as measured by σ. All parameters are available upon request. I then simulate the model for various values of b to find the optimum, and the results are displayed in Table 3.

The results for the optimal b are a bit larger than those in Table 2, except for a drop of nearly \$2,000 in the case where $\varepsilon_{Sb} = 0.1$ and $\partial\hat{S}/\partial a_1 = 0.0021$, in which my statistical extrapolations implied that the liquidity ratio goes to zero quite slowly. The estimated welfare gains are also larger than before in every case but one, varying from a low of \$8.6 billion to a high of \$31.5 billion in the baseline case, or 0.21 percent of GDP. The higher estimates in Table 3 are not surprising, given that a conservative assumption was made in reaching the sufficient statistics equation (3), overstating the importance of $d\tau/db$, as well as the fact that S rises faster with b in the calibrated model.[25] However, the qualitative conclusions are very similar, in

[25] On the other hand, the statistical extrapolations involve the assumption that L does not drop below zero, whereas in simulations of the model, L can drop below -0.2 at high values of b.

TABLE 3—RESULTS FROM CALIBRATION AND SIMULATION

	$\frac{\partial \hat{S}}{\partial a_1}$	
ε_{Sb}	0	0.0021
Panel A. Numerical estimate of $\frac{dW}{db}$ at $b = 2$		
0.1	0.1953	0.2424
0.2	0.4114	0.4336
Panel B. Optimal student grants		
0.1	\$6,974	\$6,475
0.2	\$9,176	\$9,069
Panel C. Welfare gains from moving to optimum		
0.1	\$1,224 (39.4%)	\$1,405 (45.3%)
0.2	\$4,492 (144.7%)	\$4,410 (142.1%)

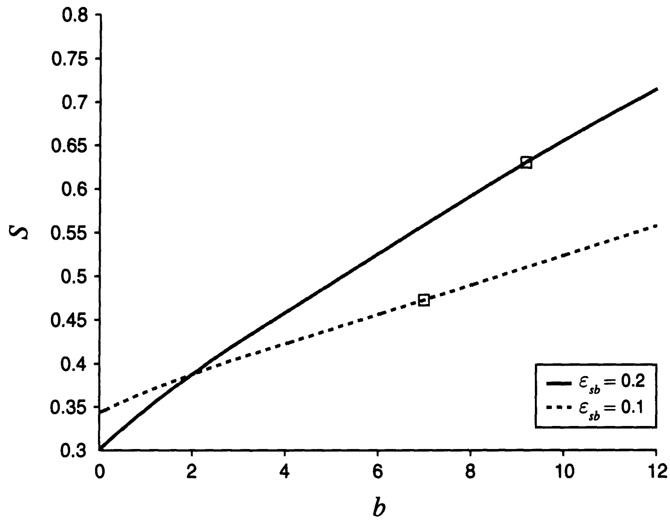

FIGURE 1. ENROLLMENT RATE AS FUNCTION OF b FOR $\frac{\partial \hat{S}}{\partial a_1} = 0$

Note: The squares in the figure represent the optimal value of the tuition subsidy b.

that raising the tuition subsidy above the value of median public tuition remains the optimal policy in each case.

The impact of liquidity constraints is again small, and actually negative this time; when liquidity constraints are weak, the responsiveness of enrollment to subsidies must be driven to a larger extent by the compactness of the distribution of η, rather than by liquidity constraints that diminish quickly as b increases. In fact, liquidity constraints cease to bind once b rises above \$4,300 (or less in some cases), and so even substantial variation in $\partial S/\partial a_1$ does not alter my conclusion; even if students are currently constrained, raising the subsidy significantly will effectively eliminate whatever constraints exist.

Figure 1 displays the enrollment rate S over the relevant range for $\partial \hat{S}/\partial a_1 = 0$ (the results are almost identical for positive $\partial S/\partial a_1$). In both cases, the optimal policy

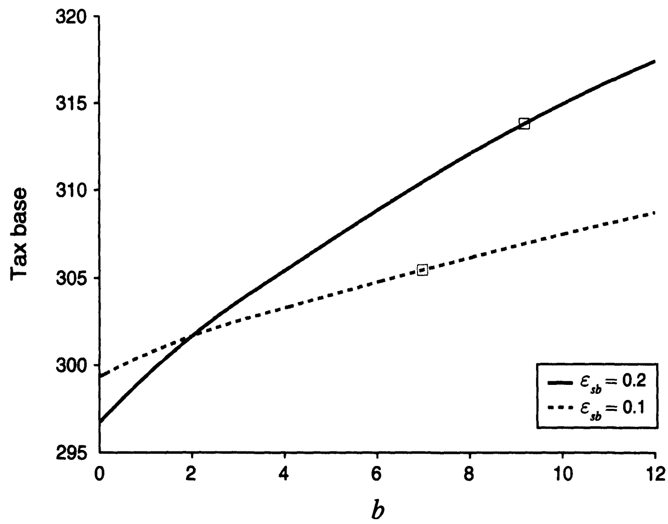

FIGURE 2. TAX BASE $\bar{Y}$ AS FUNCTION OF b FOR $\frac{\partial \hat{S}}{\partial a_1} = 0$

Note: The squares in the figure represent the optimal value of the tuition subsidy b.

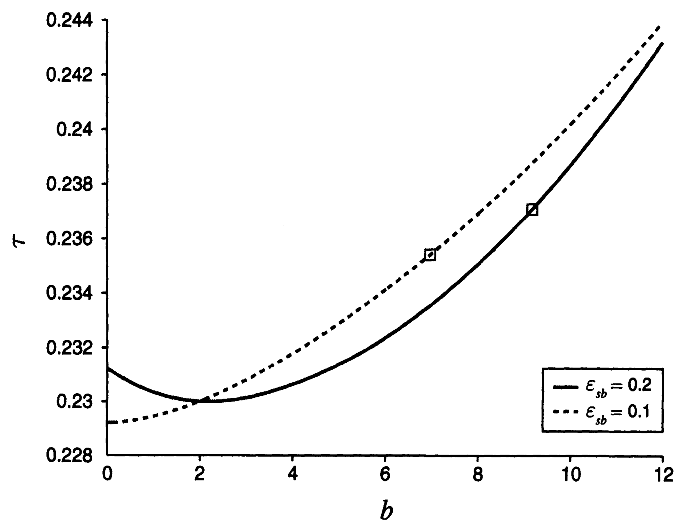

FIGURE 3. BUDGET-BALANCING TAX RATE AS FUNCTION OF b FOR $\frac{\partial \hat{S}}{\partial a_1} = 0$

Note: The squares in the figure represent the optimal value of the tuition subsidy b.

(indicated by the squares) involves inducing significant increases in the fraction of the population that attends college, up to 0.630 in the baseline case. As a result, Figure 2 shows that the tax base $\bar{Y}$ increases significantly with b. Figure 3 displays the budget-balancing tax rates, and remarkably, when $\varepsilon_{Sb} = 0.2$, a small increase in b from the current level leads to a lower tax rate because average income increases enough that the increased grants more than pay for themselves. This quickly ceases to be true as grants increase further, but if this standard estimate of the responsiveness of enrollment to tuition is correct, then at present we are slightly on the wrong side of a "financial aid Laffer curve," and there are Pareto improvements available from a small increase in tuition subsidies: taxes do not have to rise above 0.23 until the grant level reaches about \$2,380. Beyond that, τ does rise, which means that there is socially costly redistribution away from high school graduates, but their losses are more than offset by the considerable gains of college graduates until b is over \$9,000.

D. *Robustness of Results*

To further test the robustness of my results, I consider several alterations to the model in online Appendix E. In Appendix E.1, I prove that the welfare derivative is unchanged if G is not exogenous, and that the optimal value of b in the calibrated model is slightly larger in that case. Online Appendix E.2 shows that a higher degree of risk aversion lowers optimal grants, as does an alternative specification of government spending in online Appendix E.3, though without altering the main qualitative findings. Online Appendix E.4 demonstrates that optimal subsidies are either nearly identical or considerably larger if part of the government's tax revenues is used to finance a lump-sum transfer, depending on who is eligible for the transfer.

Online Appendices E.5, E.6, and E.7, meanwhile, consider additional dimensions of heterogeneity in the population. First, in online Appendix E.5, ex post heterogeneity in the form of uncertainty about future income raises optimal subsidies because young individuals are hesitant to attend college if the returns are uncertain. Online Appendix E.6 shows that heterogeneity in liquidity constraints has very small effects on the results, because a significant increase in subsidies should eliminate them even for a more severely-constrained group. Finally, a simple analysis of heterogeneous returns to education in online Appendix E.7 leads to somewhat lower optimal subsidies in the baseline case but considerably larger welfare gains, because the marginal returns to education found by Carneiro, Heckman, and Vytlacil (2011) are large at baseline but gradually decrease as lower-return individuals obtain an education. The qualitative conclusions, however, are very similar across all analyses: the optimal subsidy should at least offset median public tuition in the baseline case, and liquidity constraints have small and often negative effects.

Throughout my analysis, I focus on a simple uniform tuition subsidy, except in online Appendix E.6, where I find that there is no welfare role for two-tier grants with larger amounts for more constrained individuals. An important literature including Abbott et al. (2013) considers education policy in more comprehensive overlapping-generation models incorporating multiple dimensions of heterogeneity; additional studies include Restuccia and Urrutia (2004) and Garriga and Keightley (2007), although the latter papers exclude fiscal externalities from noneducation spending and do not perform a welfare analysis. These papers are able to consider more complex policies, including providing grants more selectively to certain groups within the population, but at the cost of additional complexity that makes it more difficult to interpret the results.[26]

[26] For example, Abbott et al. (2013) state that their finding that increasing grants would raise welfare is evidence that liquidity constraints must be significant, even though raising borrowing limits would have little impact; they do not attribute their finding to the substantial fiscal externalities present in their analysis.

As such, this literature is complementary to the research approach pursued in the current paper: whereas I provide simple and robust results about the optimal magnitude of subsidies, papers such as Abbott et al. (2013) provide valuable information about the impact of a range of policies targeted at different groups in the population. While the analysis in online Appendix E finds that my results for the optimal uniform subsidy are robust to numerous forms of heterogeneity, it is likely that the globally optimal financial aid policy would feature subsidies that are differentiated by observable characteristics, and my analysis suggests that subsidies should be highest for groups with high returns to education who are close to indifference about college enrollment. Based on evidence in Abbott et al. (2013) that students from lower-wealth families face higher psychic costs of education on average, as well as the likelihood that they would face the most binding liquidity constraints, my analysis suggests that financial aid should be most heavily targeted at lower-income, high-ability groups whenever possible; this matches the finding in Abbott et al. (2013) that the grant increase with the largest welfare gain is one aimed at lower-income families. It is also likely that subsidies should be targeted at groups facing risky returns from college, if fields of study with that characteristic can be identified. However, one robust finding of the current paper is that impressive welfare gains are possible even with a very simple policy instrument.

III. The Relative Importance of Liquidity Constraints and Fiscal Externalities

In this section, I evaluate the relative importance of liquidity constraints and fiscal externalities, as I perform the experiment of "switching off" liquidity constraints and fiscal externalities one at a time. As suggested by the results so far, liquidity constraints have a relatively small impact on optimal subsidies, and eliminating all liquidity constraints does not greatly alter the results; in fact, the optimal subsidy actually increases. However, eliminating the fiscal externalities leads to a large reduction in optimal subsidies.

A. *No Liquidity Constraints*

I begin by assuming away liquidity constraints. There is no simple way to impose a zero-liquidity-constraint condition in the sufficient statistics approach; $L = 0$ does not actually correspond to an absence of liquidity constraints, because $L = 0$ implies that $u'(c_u) = v_c^0(c_v^0, l_0)$, but an absence of liquidity constraints actually requires $u'(c_u) = v'(c_v^1, l_1)$, which implies a negative effect of income on enrollment.[27] In order to impose the theoretical condition of no liquidity constraints, I would need to know what empirical value of L this would correspond to, and we

[27] I expect that $v_c^0(c_v^0, l_0) > v_c^1(c_v^1, l_1)$, and so $u'(c_u) > v_c^1(c_v^1, l_1)$ if $L = 0$. Thus, a precisely-estimated zero effect of income on enrollment is in fact evidence in favor of liquidity constraints. If individuals were unconstrained, income should have a negative effect on enrollment, because a dollar of income would be more valuable to those who do not attend college, as argued by Belley and Lochner (2007). In the structural analysis without liquidity constraints in the current subsection, I find that the model implies that each additional \$1,000 of initial assets should reduce enrollment by 0.1 to 0.2 percentage points.

TABLE 4—RESULTS FROM CALIBRATION AND SIMULATION WITH NO LIQUIDITY CONSTRAINTS

ε_{Sb}	
Panel A. Numerical estimate of $\frac{dW}{db}$ at $b = 2$	
0.1	0.1302
0.2	0.3464
Panel B. Optimal student grants	
0.1	\$7,691
0.2	\$9,446
Panel C. Welfare gains from moving to optimum	
0.1	\$1,520 (49.0%)
0.2	\$5,379 (173.3%)

cannot be sure that any existing estimate actually measures $\partial S/\partial a_1$ in a no-liquidity-constraint world.

Therefore, I focus on the structural analysis. I begin by using $\hat{c}_v^1 = 1.26\hat{c}_v^0$ to solve for values of consumption, and then I use $v'(c_v^1) = u'(c_u)$, the no-liquidity-constraint condition, to solve for θ. The rest of the calibration procedure continues as before, and the results are displayed in Table 4. The results are similar to before: the values of dW/db are somewhat smaller than in Table 3, but the optimal benefit levels and welfare gains are actually higher than in the $\partial\hat{S}/\partial a_1 = 0$ case, as the responsiveness of enrollment to subsidies is now driven entirely by the compactness of the distribution of η, rather than by liquidity constraints that diminish quickly as b increases. This supports the evidence from the results in the previous section, demonstrating that my results are not sensitive to the existence of liquidity constraints.

B. *No Fiscal Externalities*

Next, I instead shut off the fiscal externality, in the sense that I ignore G and assume that τ_t is a lump-sum tax imposed on employed workers to pay for tuition subsidies, growing at rate g per period, so $\tau_t = (1+g)^{t-1}\tau$. Redoing my initial analysis in this context is straightforward, and the resulting equation for the welfare gain from increasing b is

$$\frac{dW}{db} \simeq S\left(L - \frac{\gamma_1}{\gamma_1 - S}\,\varepsilon_{Sb}\right).$$

The numerical results can be found in Table 5. The values of dW/db are much smaller, as are the optimal values of b; if $\partial S/\partial a_1 = 0$, then there is no reason to subsidize education (I set $b = 0$ as a lower bound).

The structural analysis follows in the usual way, with results in Table 6 that are similar to those in Table 5. Values for dW/db are slightly larger, as are optimal grants in most cases, though still small in the absence of fiscal externalities. Therefore, using both approaches, I find that fiscal externalities are important to establishing

TABLE 5—RESULTS FROM SUFFICIENT STATISTICS AND EXTRAPOLATION WITH NO FISCAL EXTERNALITIES

	$\frac{\partial \hat{S}}{\partial a_1}$	
ε_{Sb}	0	0.0021
Panel A. Estimate of $\frac{dW}{db}$ at $b = 2$		
0.1	−0.0407	0.0064
0.2	−0.0814	−0.0592
Panel B. Optimal student grants		
0.1	\$0	\$3,251
0.2	\$0	\$0
Panel C. Welfare gains from moving to optimum		
0.1	\$295 (9.5%)	\$30 (1.0%)
0.2	\$539 (17.4%)	\$335 (10.8%)

TABLE 6—RESULTS FROM CALIBRATION AND SIMULATION WITH NO FISCAL EXTERNALITIES

	$\frac{\partial \hat{S}}{\partial a_1}$	
ε_{Sb}	0	0.0021
Panel A. Numerical estimate of $\frac{dW}{db}$ at $b = 2$		
0.1	−0.0151	0.0319
0.2	−0.0536	−0.0314
Panel B. Optimal student grants		
0.1	\$1,730	\$2,612
0.2	\$1,254	\$1,562
Panel C. Welfare gains from moving to optimum		
0.1	\$8 (0.3%)	\$39 (1.3%)
0.2	\$79 (2.5%)	\$27 (0.9%)

beneficial effects of significantly increased subsidies; even large liquidity constraints on their own might not be enough to support significant grant increases, and in the baseline case, the optimal policy would involve significant reductions in tuition subsidies in the absence of fiscal externalities.

C. *Liquidity Constraints Are Second-Order for Welfare Analysis*

It was already apparent from the results in Section II that varying the magnitude of liquidity constraints had little impact on the optimal subsidy. In the baseline case with $\varepsilon_{Sb} = 0.2$, switching from a zero effect of income on enrollment to the estimate that Acemoglu and Pischke (2001) called a "large effect" raised optimal subsidies by less than \$300 per year. Section IIIA further proves this point: eliminating liquidity constraints altogether has little impact on the result, and actually raises the optimal subsidy.

However, the same cannot be said for fiscal externalities; the fiscal motive for subsidizing students is strong, and if it were somehow eliminated, the case for more generous support for students would almost certainly go with it. The existence of a substantial distortionary income tax negatively impacts investment in education, implying a strong external fiscal benefit from education and an important role for tuition subsidies that can offset the underinvestment in education. As discussed earlier, this can be understood as an example of the Theory of the Second Best: income taxes represent a preexisting distortion in the economy, and thus an education subsidy, which in a non-distorted world would serve no purpose, may increase efficiency.[28]

The logic behind the relative unimportance of liquidity constraints for policy is that, while liquidity constraints may well be a reasonable motivation for some form of financial aid, fiscal externalities on their own can justify completely offsetting tuition and possibly providing additional stipends in most cases, by which point any liquidity constraints will have ceased to be a major concern. Therefore, liquidity constraints are of second-order importance when designing college tuition subsidy policy.

IV. General Equilibrium Effects

The findings of the previous section have important implications for future research, as they suggest that research aimed at better estimating the magnitude of externalities from education would be of particular value. Therefore, in this section, I will address two potential sources of variation in the strength of fiscal externalities, both coming from general equilibrium effects of education in the labor market. I begin by looking at how the wage premium may shift with the supply of college graduates, using a standard estimate of the elasticity of substitution. Then I consider the possibility of spillovers, or positive externalities of education onto the wages of other workers. I show that my two main conclusions are robust: tuition subsidies should increase from the baseline level, and the sensitivity of optimal policy to liquidity constraints is limited. However, general equilibrium effects do significantly alter the specific numerical results for optimal subsidies, indicating that future research in these areas would be of great benefit to the optimal policy literature.

A. *General Equilibrium Effects on College Wage Premium*

Analysis in papers such as Katz and Murphy (1992) suggests that changes in the supply of college graduates may have significant effects on relative wages.[29] Heckman, Lochner, and Taber (1998b) show that this has consequences for the effectiveness of tuition subsidies: if increased attendance lowers the college wage premium, then grants to students can only induce a small increase in attendance before declines in the wage premium offset the increased incentives to attend. Heckman, Lochner, and Taber (1998a) estimate an elasticity of substitution between

[28] In this case, the intuition is even simpler: the goal of the education subsidy is to offset the distortion from income taxation, which acts upon the education margin. The result is analogous to Feldstein (1997), in which inflation acted as a tax upon a savings margin already subject to income taxation: the usual Harberger deadweight loss triangles become trapezoids when the margin in question is already distorted. An education subsidy that reduces the preexisting distortion produces a large trapezoid-shaped welfare improvement.

[29] For more recent analyses, see Katz and Autor (1999), Fortin (2006), and Johnson and Keane (2013).

high school and college graduates of 1.441, and show in Heckman, Lochner, and Taber (1998b) that this means that the effect of a tuition subsidy on enrollment in general equilibrium is about one-tenth the size of the partial equilibrium effect.

However, this conclusion is sensitive to assumptions about the usage of skill in the economy, as Lee (2005) finds general equilibrium effects of tuition subsidies that are more than 90 percent as large as the partial equilibrium values. Also, it is possible that the short-run effects on relative wages of an increase in supply of college graduates may overstate the long-run effect if increased supply of skills leads to technological change to take advantage of those skills. Acemoglu (1998), Kiley (1999), and Acemoglu (2002), present models in which an increased supply of skilled workers leads to technological adjustment that creates more jobs designed for skilled workers, with the skill premium then increasing over time, possibly above the original level.

The magnitude of long-run general equilibrium effects therefore remains an unanswered question, and one that is deserving of further study; my goal is not to take a position on this issue, but simply to evaluate the possible sensitivity of my results to this effect. Therefore, I will present results corresponding to the Heckman, Lochner, and Taber (1998a) case; additional results, available upon request, demonstrate that the impact of tuition subsidies is nearly identical to baseline if the elasticities of substition from Lee (2005) are used.

I assume a constant elasticity of substitution production function over high school and college graduates:

$$Y_t = \zeta_t \left(a S_1^{\frac{\kappa-1}{\kappa}} + (1-a) S_0^{\frac{\kappa-1}{\kappa}} \right)^{\frac{\kappa}{\kappa-1}},$$

where $S_1 = S l_1$ and $S_0 = (1-S) l_0$, and κ is the elasticity of substitution. I assume that wages and the production function are specific to the generation in question, i.e., that vintage effects make the human capital of different cohorts perfectly non-substitutable, thereby producing an upper bound on general equilibrium effects.[30] Therefore, the wage of a college graduate is $w_{1t} = \partial Y_t / \partial S_1$ and the wage of a high school graduate is $w_{0t} = \partial Y_t / \partial S_0$, and a is chosen to make $w_{1t}/w_{0t} = 1.08^4$ at baseline. The value of ζ_t increases at a rate of g per period so that wages increase at the same rate. Calibration proceeds in the same way as before, since the only derivative used there is dS/db, which I assume is evaluated at constant wages. I assume, as before, that $l_0 = l_1 = 1$ at baseline, and set ζ_1 to make $w_{01} = 34$.

Table 7 presents results when the elasticity of substitution $\kappa = 1.441$ as in Heckman, Lochner, and Taber (1998a), which is a typical value in the literature. My findings confirm that the role of tuition subsidies in increasing enrollment is minimal if high- and low-education workers are not good substitutes for each other: raising b from \$2,000 to \$3,000 only raises enrollment by 0.17 to 0.19 percentage

[30] That is, I assume that the population share of college graduates adjusts immediately to that of the current generation, rather than allowing for gradual adjustment to a new long-run equilibrium. In this, I follow the approach of Heckman, Lochner, and Taber (1998b), who state that short-run general equilibrium effects on enrollment with rational expectations in their model are also very small. Card and Lemieux (2001) document that increases in the college wage premium have primarily affected younger workers, i.e., recent graduates.

TABLE 7—RESULTS FROM CALIBRATION AND SIMULATION WITH ELASTICITY OF SUBSTITUTION = 1.441

	$\frac{\partial \hat{S}}{\partial a_1}$	
ε_{Sb}	0	0.0021
Panel A. Numerical estimate of $\frac{dW}{db}$ at $b = 2$		
0.1	0.0833	0.1417
0.2	0.0885	0.1166
Panel B. Optimal student grants		
0.1	\$3,207	\$4,071
0.2	\$3,844	\$3,742
Panel C. Welfare gains from moving to optimum		
0.1	\$194 (6.2%)	\$547 (17.6%)
0.2	\$218 (7.0%)	\$371 (11.9%)

points. However, that minimal effect on enrollment induces redistribution toward high school workers, which would be valued by a utilitarian social planner; in the baseline case, the same \$1,000 increase in b raises wages of high school workers by 0.2 percent, while decreasing college wages by about the same amount. Therefore, even though the subsidy is ineffective in significantly increasing enrollment, there is still a welfare case for increased subsidies; the optimal subsidies, however, are lower than before, and the welfare gains are considerably smaller.

The magnitude of these general equilibrium effects, therefore, is of considerable importance, clearly demonstrating the value of future work that can shed more light onto this phenomenon, while it remains true that the effect of liquidity constraints on optimal policy is modest.

B. *Wage Spillovers*

A number of papers have sought evidence of positive wage spillovers from college education, i.e., a positive externality of education manifesting itself in higher wages for other workers, resulting from off-the-job interactions or some form of social capital. This is not entirely a fiscal externality, as the spillovers have important direct effects on other individuals, but they will also lead to increased tax revenues with important fiscal benefits.

Moretti (2004a,b) finds evidence of substantial positive spillovers, whereas Ciccone and Peri (2006) do not. The survey by Lange and Topel (2006, 488) argues that "the data do not provide a strong reason to believe in the importance of productive externalities from schooling," but their own estimates are positive, and marginally significant in most cases, implying that each year of education raises total factor productivity by about 3–5 percent. Iranzo and Peri (2009) aims to reconcile the literature's contradictory results with their finding that each additional year of high school generates minimal spillovers, whereas each year of college per worker raises productivity by 6–9 percent.

As in the previous subsection, I do not intend to make any claim about the magnitude or existence of spillovers. Instead, I will present results for a central

TABLE 8—RESULTS FROM CALIBRATION AND SIMULATION WITH SPILLOVERS

	$\frac{\partial \hat{S}}{\partial a_1}$	
ε_{Sb}	0	0.0021
Panel A. Numerical estimate of $\frac{dW}{db}$ at $b = 2$		
0.1	1.4115	1.4601
0.2	2.8135	2.8389
Panel B. Optimal student grants		
0.1	\$22,808	\$23,196
0.2	\$19,349	\$19,572
Panel C. Welfare gains from moving to optimum		
0.1	\$44,289 (1,426.8%)	\$42,102 (1,356.4%)
0.2	\$67,814 (2,184.7%)	\$66,767 (2,151.0%)

estimate,[31] and I follow Damon and Glewwe (2011) in using the point estimates from Lange and Topel (2006), which on average imply that a 1 percentage point increase in the population with a bachelor's degree increases average wages by 0.2 percent within education groups. Many estimates, including those by Moretti (2004b) and Iranzo and Peri (2009), are considerably larger, and so Damon and Glewwe (2011, 1248) refer to this as a "very conservative" estimate. I proceed with the original baseline calibration (assuming that ε_{Sb} is evaluated in a partial equilibrium setting).

This effect can easily be incorporated into the simulation to find a numerical estimate of dW/db, but moving away from $\hat{b} = 2$, it does not seem plausible that this spillover would remain at the same level as S increases. Therefore, in Table 8 I present results where the effect declines with S, so that the wage increase per percentage point of attendance is χ/S^2, where $\chi = 0.002(0.388^2)$.[32]

Even with this "very conservative" assumption about wage spillovers, the welfare gain from increasing student grants is now enormous: a 1 percent increase in b to \$2,020 generates an annual economy-wide gain of \$1.58 billion in the baseline case. Furthermore, even with spillovers that diminish at the rate of S^2, the optimal grants are very large, substantially higher than the median value of tuition, room, and board at public universities of \$13,035 in 2007–2008. With such a large grant, wages increase by about 4.2 percent, and thus the welfare gains are also very large, with a value of \$474.8 billion in the baseline case, or 3.2 percent of GDP. Given the increased spending of \$254.5 billion per year that such a policy change would imply, the average return to investment is 187 percent. Also, because of the spillovers to

[31] Trostel (2002) also provides a welfare analysis of education subsidies with both fiscal externalities and productivity spillovers, using a linearized calibrated model in which the external benefit of education is 9 percent of the private benefit. He finds an optimal education subsidy of 53 percent, greater than the marginal tax rate of 40 percent, but the main focus of his paper is on the relative distortions on time and goods invested in education, and the use of public policy to correct the mix of investments. This issue is beyond the scope of the current paper, as I assume that time and goods are required in fixed proportions for a unitary college investment.

[32] This implies a spillover that declines from 0.2 percent at $S = 0.388$, to 0.12 percent at $S = 0.5$, and to 0.06 percent at $S = 0.7$.

uneducated individuals, there is considerable scope for Pareto improvements; in all cases, Pareto gains can be obtained from marginal increases in b up to at least \$10,000, and at the optimum for $\varepsilon_{Sb} = 0.2$, both high school and college graduates are better off than when $b = 2$. Finally, optimal subsidies are almost totally insensitive to the strength of liquidity constraints.

The results for the optimum can only be a rough approximation, given the lack of evidence on how spillovers would change with S, but they indicate that even wage spillovers that are a relatively small component of the total return to education could have a large impact on policy, because individuals take the private returns into account, but do not account for the social gains from spillovers when making education decisions. Even the magnitude of the welfare derivative alone indicates that wage spillovers that might have been considered small in previous work would actually be extremely important, indicating a need for further work in this area.

V. Conclusion

In this paper, I have presented a simple model of college education, and performed an analysis of optimal tuition subsidies in the presence of fiscal externalities and liquidity constraints using both a sufficient statistics method and a simple calibration.

My results indicate that fiscal externalities on their own justify increased government support for students. The intuition is similar to that from my companion paper (Lawson 2017a), though the direction of the impact on policy is reversed: in the presence of a distortionary income tax, a tuition subsidy leads to an increased tax base resulting from increased college enrollment, with significant fiscal benefits that are not accounted for by individuals making education decisions. The estimated optimal tuition subsidies are relatively large, several thousand dollars per year greater than median public university tuition. Liquidity constraints, however, are of second-order importance for optimal tuition subsidy policy, and the results are robust even to an elimination of liquidity constraints. Both of these main results are robust to a wide variety of extensions to the model, as demonstrated in online Appendix E.

In contrast, my results indicate that the optimal level of the tuition subsidy is sensitive to the existence of significant general equilibrium effects of tuition subsidies on wages. If effects on relative wages are as severe as those estimated by Heckman, Lochner, and Taber (1998a), then the increase in subsidies should be considerably smaller. On the other hand, even modest wage spillovers could provide a case for stipends that are much larger than median public tuition. Thus, further work that models and estimates wage formation in general equilibrium would be especially relevant for the purposes of welfare analysis.

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