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The Real Deal? Information Asymmetries and Tuition Discounting in Higher Education

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Most theoretical studies explain tuition discounting for high ability students through competition between colleges. This paper highlights an important and previously unrecognized avenue for tuition discounting – asymmetric information about student attributes, such as academic ability and willingness to pay. In our model, a college with incomplete information uses a tuition screen to infer student attributes from a costly signal, such as standardized test scores, elective coursework, community service record, extracurricular activities, etc. We find that the presence of information asymmetry can have profound effects on equilibrium behavior. Specifically, it can lead to some high ability students earning tuition discounts that they would otherwise not receive, other high ability students earning deeper discounts than they would otherwise enjoy, and, more generally, forms of tuition discounting that are inconsistent with symmetric information environments. Moreover, information asymmetry can sometimes be the sole reason that tuition discounting for high ability students manifests itself in any shape or form, even if the college faces no competitive pressure and high ability students may have a relative lack of financial need.

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1 Introduction

Tuition discounting is a prevalent feature of the higher education marketplace (Lapovsky and Hubbell, 2003). According to Davis (2003), the average "tuition discount rate" (institutional financial aid as a percent of total tuition and fee revenue) is nearly 40 percent at private

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institutions with nearly 80 percent of students receiving some kind of discount. Much of this discounting is targeted to students who display academic merit. Heller (2008) reports that over 90 percent of both public and private institutions offer merit aid programs to their students and that merit aid comprises over 40 percent of all institutional grant aid at these institutions. The dollar amounts involved in these awards are substantial considering that the average institutional grant aid is about $10,000 at private institutions and $4,000 at public institutions according to the National Postsecondary Student Aid Survey (NPSAS, 2008).

Prior work has explained the phenomenon of tuition discounts for students with high academic ability or with other characteristics that colleges value (such as contributions to racial or income diversity) primarily on the basis of competition between colleges in a setting of perfect information (Ehrenberg and Sherman, 1984; Rothschild and White, 1995; Epple, Romano, and Sieg, 2002 and 2006). In contrast, studies that assume asymmetric information tend to focus not on tuition outcomes but on providing a rationale for early admissions programs (Avery, Fairbanks, and Zeckhauser, 2003; Lee, 2009; Avery and Levin, 2010) or on exploring the efficiency implications of informational imperfections (Dill and Soo, 2004).

Our purpose in this paper is to complement these studies by showing that asymmetric information can play an important role in the emergence of tuition discounts for students with high academic ability. This is true even in the complete absence of competition among colleges and a relative lack of financial need on the part of these students. In our model, a college with incomplete information about student characteristics may use a tuition screen to infer academic ability from a costly signal such as reported test scores. We show that despite the fact that high ability students may or may not have financial need, tuition discounting to high ability students is an integral equilibrium feature of a large class of tuition games. Specifically, there are high ability students who earn tuition discounts if and only if information asymmetry is present, there are other high ability students who see their tuition discounts deepened under asymmetric information, and forms of tuition discounting that cannot occur under symmetric information are commonplace when information is asymmetric. Perhaps most strikingly, equilibrium behavior under asymmetric information can require the college to charge the lowest tuition to students that are both the most desirable and the most willing to pay high tuition. Intuitively, this result is induced by the college's conflicting desires to maximize rent extraction and to maintain incentive compatibility. In particular, maximal rent extraction may mandate significant signaling effort on the part of high ability students, but making these signaling efforts incentive compatible may mandate the offering of what amounts to tuition scholarships for high ability students. Finally, we show that information asymmetry can be the sole reason that tuition discounting manifests itself in any shape or form.

Before proceeding we point out that our intent is not to imply that in practice, "ability" is the only attribute on which colleges screen students, or that standardized test scores are the only metric with which colleges assess ability. Indeed, a number of programs offered by particular colleges are consistent with screening or signaling behavior that leads to tuition discounts. Camps or competitions that yield scholarships for top performers are examples of this behavior, as are programs in which high school students can take courses for college credit and apply for scholarships subsequently, programs focused on developing student interest in specific subjects and career fields such as science and engineering, and the summer college prep camps operated by many institutions in which students can attend application, aid, and test-taking workshops, receive advice from college admissions and financial aid staff, and in some cases even interact with and receive performance evaluations from faculty members. Such camps, programs, and competitions allow students to signal interest in particular subjects or attributes such as leadership with the potential reward of financial aid. Scholarships that reward students for engaging in community service and extra-curricular activities accomplish this purpose as well, as pursuit of these activities can be indicative of students with low signaling costs in these areas, a strong work ethic, and good time management skills, all of which may be predictors of a prospective student's academic success.

The remainder of this paper is organized as follows. The next section examines the related literature in greater detail. Section III provides some background on the relevance of asymmetric information concerning student ability and the role of standardized testing in higher education. Section IV presents the model, derives some general results describing the subgame perfect Bayesian equilibria of the model, and considers some variations in the assumptions about the market structure and the informational environment. Section V concludes.

2 Related Literature

Tuition discounting is generally explained in the higher education literature with models that assume perfect information. Rothschild and White (1995) develop a model in which profit-maximizing higher education institutions utilize a "customer-input technology," where the quality of the human capital they produce depends, in part, on the quality of students they enroll. The equilibrium tuitions are such that each student pays the marginal cost of education net of his or her marginal productivity as an input to the institution's production function. Thus, students who have high marginal productivity as inputs because they enhance the educational experience for their peers (e.g., those with high ability, those who contribute to racial or income diversity, student athletes, etc.) are predicted to receive tuition discounts. Furthermore, since the equilibrium tuitions internalize the externalities associated with the peer effects that students generate, they result in an efficient allocation of resources. Since the model assumes colleges and students are perfectly informed, the source of tuition discounting is the price-taking competition among colleges with high demand for students who generate large peer effects.

Epple, Romano and Sieg (2002, 2006) extend the customer-input model to the case of quality-maximizing colleges that are differentiated by exogenous endowment earnings and their ability to use their endowments and tuition revenues to invest in instructional inputs. The model incorporates peer effects in ability and race, characteristics about which colleges and students are assumed to be perfectly informed. In equilibrium, tuition decreases with student ability and is lower for members of under-represented races, since competition between colleges for students who generate positive peer effects leads to such students receiving a price discount.

Ehrenberg and Sherman (1984) model the behavior of a selective, utility-maximizing monopoly university. The model predicts that the institution will offer price discounts to groups of applicants that yield high marginal utility to the institution, have low propensities to enroll, have high enrollment elasticities with respect to financial aid, or have high elasticities of average quality with respect to the number admitted. Since high ability students meet virtually all of these criteria, they receive a discount in equilibrium. For similar reasons students with low income, racial diversity, or special extracurricular talents would be expected to receive discounts. Discounting in this context arises not from competitive pressures or peer effects, but from the fact that the college is willing to trade off tuition revenue from enrolling a given type of student with the attractiveness of the profile of attributes the student has to offer.

The higher education literature has only very recently developed models of asymmetric information, but the focus of these studies tends to be not on explaining tuition differentials but on providing a rationale for and articulating the enrollment and welfare implications of early admissions programs. Avery, Fairbanks, and Zeckhauser (2003) consider early admissions programs as a response to uncertainty in the admissions process and document several important stylized facts concerning these programs, such as the admissions advantage for students who apply early and the tendency for students to engage in strategic application behavior. Dill and Soo (2004) show that competitive higher education equilibria are not necessarily efficient when students are imperfectly informed about institutional quality but do not explore tuition discounting as an attempt to overcome information deficiencies. Avery and Levin (2010) show that in a setting where students are uncertain about their chances of admission and colleges are uncertain about students' enthusiasm to attend, early admissions programs raise the welfare of colleges and the average utility of students (although some students ex-post regret their early application decisions). The model predicts the aforementioned stylized facts on early admissions programs (in particular, students who apply early are more likely to be admitted because they have signaled a better fit with the college), but does not consider the role of tuition in shaping the enrollment decisions of students who are admitted through early and conventional routes.

Lee (2009) shows that early decision policies can benefit colleges by protecting them from the “winner’s curse” (of accepting students who are not ultimately admitted elsewhere) when they are imperfectly informed about student ability. As in our model students signal their true types by submitting academic records along with their applications, but the paper only considers the admissions outcome rather how tuitions vary with ability or the signal actually sent. Kim (2010) considers a setting in which there is asymmetric information about both student ability and willingness to pay (WTP) for college. He shows that colleges can use early admissions programs to effectively screen applicants according to WTP while nominally adhering to a need-blind admissions policy. Students who apply early are more likely to be admitted than later applicants of comparable quality because they are more likely to have high WTP, so the college can use the tuition revenue earned from them to compete for high ability low income students who apply through regular admission. The paper assumes schools do not award merit-based aid or aid for other desired characteristics but only need based aid; thus it does not share our focus on how asymmetric information about student ability affects the relationship between tuition and ability. In addition, the paper considers strategic competition among schools in admissions policies and price setting, so does not illustrate how asymmetric information alone can be a source of tuition differentials even in the absence of competition among schools.

3 Background: Asymmetric Information and Standardized Testing in Higher Education

Although competition among colleges, the focus of most prior papers that examine the phenomenon of tuition discounting, is certainly an important feature of the higher education landscape, uncertainty is also prevalent in the college application and admissions process. Students face uncertainty about whether they will be admitted to an institution, their chances for success if admitted, and the quality of the education they will ultimately receive. Colleges face uncertainty about how much a student is willing to pay to attend, whether an admitted applicant will actually enroll, and the chances of retaining enrollees over time.

The true academic ability of a student is another potential source of uncertainty in the higher education market. While it is possible to simply look at a student’s high school GPA and the courses they took in high school to get some idea of their true innate ability, high schools vary widely in quality and grading standards, making these measures imperfect reflections of how “good” or “smart” the student actually is. Thus, when applying to college, students submit a large body of materials in addition to their high school transcripts (e.g., application forms, essays, letters of recommendation, and standardized test scores) whose purpose is ostensibly to help institutions arrive at an accurate assessment of the student’s innate intellectual giftedness, work ethic, time management skills, level of preparation for ongoing study, etc. These are important attributes for college admissions and financial aid officers to discern because the recruitment of talented students who are likely to be academically successful can enhance both the college's academic reputation and the quality of the educational experience of other students who enroll. This provides a straightforward explanation for the fact that colleges try to entice highly able students with attractive financial aid awards (Pappano, 2009).

Given the abundance of other materials in an application package, the important role of standardized tests such as the SAT and the ACT in the admissions process is notable. Virtually all colleges require applicants to submit scores and a significant minority even admits to applying minimum score cutoffs for admission (Briggs, 2009; Steinberg, 2009). About three-quarters of institutions that offer merit aid awards report using SAT or ACT scores as criteria for these awards (Heller, 2008). The existence and influence of standardized tests, which are items of considerable anticipation and stress for high school juniors and seniors each year (Rimer, 2008), suggests that there is uncertainty about a student's true ability that persists even after transcripts and recommendations are considered. The value of the tests may then lie in their purported ability to measure scholastic ability in an objective, uniform way that is immune to the effects of grade inflation at a particular high school, bias on the part of letter writers, or embellishment of one's accomplishments on an application.

The importance placed on standardized test scores naturally induces students to expend time and effort to enhance their performance on these tests. Formal test preparation is a multibillion-dollar industry, in which firms such as *Kaplan* and *The Princeton Review* offer classroom-based courses and tutoring programs that provide students with content instruction and test-taking strategies. The underlying premise is that with enough effort and coaching, a student can achieve a score that will improve his or her admissions and financial aid outcomes (Briggs, 2009). Although the gains to test preparation are thought to be relatively small (about 30 points on the SAT on average), they can still significantly increase an applicant's chances of admission to college (Briggs, 2009). These findings, along with the guarantees of improved scores offered by some test preparation services, raise the possibility that students who invest sufficient resources in preparation can "overachieve" by scoring better than students of equal or higher ability who do not. This may help explain why prior work finds large variation in college grades even accounting for test scores (e.g., Betts and Morrell, 1999; Cohn, Cohn, Balch and Bradley, 2004; Rothstein, 2004) and why unequal ability to pay for test-preparation services is a concern for those interested in promoting access to higher education (Briggs, 2009).

An interesting recent development is the decision by the College Board, the organization that designs and administers the SAT, to adopt a program called "Score Choice" (Rimer, 2008), which allows students to choose which scores they wish to report to colleges. This announcement has sparked opposition from some colleges, who claim that it will increase students' stress and anxiety in the application process and provide an advantage to affluent students who can afford to take the test multiple times (Rimer, 2008). However, these objections may also arise from concerns that selective reporting will decrease the signal-to-noise ratio in the score, making it more difficult for colleges to infer true student ability. In other words, colleges perceive an asymmetry in available information about student ability that will be exacerbated by a selective reporting option.

Although the scores students post on standardized tests are clearly of direct value to colleges (Ehrenberg, 2002) even without a tight connection to true ability, so are the underlying qualities that the tests try to measure. Prior work contends that the quality of an institution is enhanced by students whose exceptional skills and achievements promote a richer learning experience for their peers (Rothschild and White, 1995; Epple, Romano and Sieg, 2002). The ability to generate these peer effects is arguably more a function of innate intellectual gifts rather than the test scores that are to some extent a function of these gifts.

Of course standardized test scores are not the only way in which students can signal that their admittance would be of high value to the college. As previously noted, transcripts, extracurricular activities, enrollment in academic camps, contests, etc., may all be factors over which the student has some control and may effectively serve as signals. Even letters of recommendation can be managed to a degree as students can expend effort to bring themselves to the attention (through camps, contests, etc.) of letter writers whose opinion may be particularly influential (university faculty, for instance).

Many colleges offer formal programs that are consistent with the notion that they have an interest in screening students along various dimensions and following up with tuition discounts. Camps or competitions that yield scholarship opportunities are examples of this behavior, a small sample of which include the following. Monroe College in the Bronx, NY offers a program for high school seniors called JumpStart, where students can take classes for college credit and become eligible for grants and scholarships if accepted to the college (monroecollege.edu, 2013). Knox College in Galesburg, IL hosted a sectional round of a 2013 science and engineering competition for high school students and awarded scholarships to top finishers that could be used toward tuition at Knox (knox.edu, 2013). Kendall College in Chicago, IL offers $1000 scholarships to all students who participate in their summer culinary camps (kendall.edu, 2013). College of the Atlantic in Bar Harbor, ME offers $10,000 per year scholarships to alumni of Camp Rising Sun, an invitation-only leadership summer program for 14-16 year olds operated by the Louis August Jonas Foundation (coa.edu).

Programs that operate less explicitly as a screening device include the summer college prep camps operated by top institutions such as UC-Berkeley, Yale, Harvard, Chicago, Michigan, Brown, and Columbia. These programs provide students with useful information and strategies for their college search, and an opportunity for college officials and even faculty to become acquainted with these students (collegexpress.com). While scholarships are not explicitly advertised as possible outcomes of these camps, strong performances may aid the student in securing strong recommendations from influential faculty supervisors.

In light of the market's asymmetric information on student ability, it is useful to examine the higher education market with an approach similar to the classic screening models of Rothschild and Stiglitz (1976) and Wilson (1977) and the education signaling game of Spence (1973). We describe our model in detail in the next section.

4 Theoretical Model

Before introducing our formal model and analysis, we would like to highlight three important points. First, although this paper's focus is on the effects that asymmetric information may have on tuition discounting, this should not be interpreted as suggesting that other potential explanatory factors are unimportant. For instance, the market effects of asymmetric information are often highlighted in a Spence (1973) signaling game by assuming that education is nonproductive, but this assumption is certainly not intended to suggest that education is generally expected to have no impact on worker productivity. Similarly, our study focuses on settings where asymmetric information is the driving force of tuition discounting so as to highlight this causal factor. We hope it is clear to the reader that, more generally, the effects of various contributing factors to tuition discounting may well be superimposed on each other.

Secondly, much of our discussion has focused on standardized test scores as representing a primary mechanism by which students signal ability. This focus is largely an expository convenience as there are many different signals that may be used in the actual higher education market. One obvious one is a student's academic record. Both GPA and difficulty of courses taken represent costly signals in terms of time, effort, and money. Less obvious examples include summer camps or academic contests. Performance in such activities may even be directly linked to scholarship funds, but even if they are not, they may have an indirect link. For instance, if university faculty run a summer camp it is not uncommon for them to write letters of recommendation for high performing camp students, which can in turn lead to scholarship awards. Even less obvious examples are scholarships that may be based on community service or extracurricular activities, which may be interpreted as proxies for a student's drive/determination, work ethic, and time management skills. It is common to see students deliberately take on such activities in hopes of building a record that will make them more competitive for various scholarship opportunities.

Thirdly, the fact that various features of a student's record have the potential to serve as a signal of his/her underlying attributes does not necessarily mean that such potential has always been exploited in practice. Even so, as state and federal governments provide less and less support while health care and other costs rise ever higher, one may expect that colleges will respond by increasingly attempting to exploit every advantage at their disposal.

Let us now turn to the formulation of our model. We consider a game of ability screening in the college application and admissions process that parallels the Spence (1973) education signaling game, though does so with one important difference. Students in our model have multiple private information attributes, rather than just one. In particular, we model students as differing both in terms of their academic ability and their willingness to pay for a college education, with only the first attribute being correlated with differences in signaling cost. We find that the presence of asymmetric information regarding student attributes has a variety of potentially profound effects on equilibrium market behavior. First, we find that information asymmetry has a universal impact in that it shapes the level of tuition discounts received in virtually every possible tuition game. Second, we find that in a large set of environments, equilibrium behavior leads the market to strictly inverted tuition discounting, a situation in which those students with the greatest willingness to pay are in fact asked to pay the least. Moreover, a driving force of this behavior is the presence of information asymmetry. Lastly, we show that information asymmetry can sometimes be the sole reason that tuition discounting manifests itself in any shape or form.

So as to model individual students as being "small" relative to the overall market, we characterize the set of students with a finite measure space N and measure μ, where $\mu(M)$ represents the "size" of any given measurable set of students $M \subseteq N$. As the precise form of N plays no special role, we simply assume $N=[0,n]$ for some finite $n>0$ and that μ is the Lebesgue measure. Students differ along two dimensions: academic ability and willingness to pay (reservation price) to enroll at college A, the college receiving focus in our model, which we will at times simply refer to as "the college." Willingness to pay of course depends on tuition/financial aid offered at alternative universities, long run career objectives, social and business contacts, initial wealth endowments, discount rates, etc.

As a stylized simplification, we assume there are two ability types and two reservation price types within each ability type. (It should be clear that our results readily extend to larger sets of types.) Letting *H* and *L* denote "high" and "low" ability and 1 and 2 denote "high" and "low" reservation price, we have the four student types *H*1, *H*2, *L*1, and *L*2, with the corresponding reservation prices δ_{H1}, δ_{H2}, δ_{L1}, and δ_{L2}; where $\delta_{H1} > \delta_{H2} > 0$ and $\delta_{L1} > \delta_{L2} > 0$. Thus *H*1 and *L*1 correspond to the high reservation price individuals of the respective ability type. Both ability and reservation price are private information of the respective student, so the law of large numbers dictates that college *A*'s prior beliefs on an arbitrarily selected strictly positive mass of students reflect the distribution of student types in the population as a whole.

Although academic ability and willingness to pay are private information, students do have access to a costly signal, such as a standardized exam, where higher signal values require effort and training that is less costly for *H* students than for *L* students. (As noted at the start of this section, many other "ability signals" also exist in practice. We focus on the standardized exam metaphor in order to streamline exposition.) Such signals in turn enable the college to select students for admission in a nonarbitrary fashion, provided there are systematic differences in the signal selections made of students across student type. We let $\eta_L > \eta_H > 0$ denote the (constant) marginal signaling costs of *L* and *H* students, respectively. That is, signal costs depend only on ability type. (This assumption is adopted so as to avoid a superfluous proliferation of parameters; it is not essential for our conclusions.)

We also introduce a zero cost signal component that can be thought of as an elementary form of cheap talk. Basically one can interpret this as a mechanism for students to signal, if they wish, that they do not place the lowest possible value on college education. While it does capture an element of realism, we introduce this zero cost signal as a technical convenience that simplifies our discussion of equilibrium existence. A full description of a student's signal thus includes both a costly component $s_+ \geq 0$ and a zero cost component $s_z \in \{0, 1\}$. The utility cost of sending the signal $s = (s_+, s_z) \in S = \Re_+ \times \{0,1\}$ is equal to $\eta_H s_+$ for *H* students and equal to $\eta_L s_+$ for *L* students. Each student's objective is to select a strategy that maximizes the difference between the benefits received, whether they be from attending college *A* or pursuing the next best option, and the costs incurred.

College *A* is the sole "active" college in our model and is assumed to be a nonprofit organization in the sense that profits matter only to the extent that they enable the institution to remain solvent, retain access to credit markets, etc. The utility the college realizes from enrolling a student body known to have a mass of e_L type *L* students and e_H type *H* students is of the form $u(e_L, e_H) = \beta_L e_L + \beta_H e_H$, provided that profits are nonnegative; where $0 < \beta_L < \beta_H$ represent the (constant) marginal utilities of enrolling type *L* and *H* students. If negative profits are realized, one can think of the resulting utility as being so low that the utility maximizing college would avoid such a choice whenever possible. Consequently, the college behaves as if its objective is to simply maximize u subject to a nonnegative profit constraint. Profits are of course defined as aggregate tuition revenue minus operating costs, where operating costs depend solely on the size of the student body and can be expressed as a continuously differentiable, convex function $c: \Re_+ \rightarrow \Re_+$. Finally, note that although our model includes a single active college, one can think of the influence of colleges outside of our model as being captured by the effects that their given tuition/financial aid offers have on student reservation prices for attending college *A*.

Sequential play in our model begins with college *A*'s selection of a tuition strategy - a mapping $t: S \rightarrow \Re_+$ where $t(s)$ is the tuition charged to any individual who is admitted to college *A* after submitting the signal $s \in S$. Students observe the tuition strategy and, knowing their actual ability and willingness to pay attributes, respond by selecting a signal and incurring the requisite signal costs. The college observes the masses of students who have sent various signals and, after formulating beliefs regarding the distribution of student types within each of these masses, selects the share of students to be admitted from each observed test score group. Finally, each student accepted for admission decides whether or not to enroll.

The solution concept of interest will be that of a subgame perfect Bayesian equilibrium, which we define to be a strategy profile such that: (1) student signal strategies are sequentially rational following every tuition screen; (2) college beliefs regarding the perceived distribution of student attributes following any profile of observed test scores are consistent with Bayes' rule and student strategies; (3) college admissions strategies are sequentially rational given beliefs and any profile of observed test scores; (4) student enrollment strategies are sequentially rational following any admissions decision; (5) if a student is indifferent between enrolling and not, their default is to enroll; and (6) for each tuition screen subgame, the continuation equilibrium on that subgame is Pareto optimal in the class of all subgame perfect Bayesian equilibria of this subgame.

Conditions 1-4 are completely standard and require no further discussion. Condition 5 is implemented so that when confronted with student indifference, college enrollment numbers are driven by the college admission decisions rather than arbitrary tiebreaking procedures on the part of students. Condition 6 captures a mild element of renegotiation proofness (see Farrell and Maskin 1989). It assumes that for any subgame stemming from tuition screen selection, the continuation equilibrium to be followed is Pareto optimal within the class of all equilibria on this subgame that satisfy conditions 1-5. In assessing sequential rationality, note that a student's expected utility, given the college's strategy, can be expressed as:

$$EU = [\textit{admission probability}]*[\textit{reservation price} - \textit{tuition}] - \textit{signal cost}$$

In expressing utility in this fashion, it should also be noted that student utility is "standardized" so that "zero" utility corresponds to the benefits realized from the next best alternative and thus the reservation price can be interpreted as the incremental benefits realized from college A admission. Further note that signal costs are incurred whether or not the student is ultimately admitted and enrolled.

So as to be crystal clear about what we mean when we refer to "tuition discounting," we introduce the following formal definition.

Definition 1 ***Tuition discounting*** is said to occur when some students pay different tuition than others. Those paying the highest tuition are said to be paying ***full tuition***, those paying less than full tuition are said to be receiving a ***tuition discount***.

As a first step in our analysis, we note that if student attributes were not private information, every subgame perfect equilibrium of the corresponding model would entail every admitted student paying their full reservation price whenever the enrolled student body falls short of the entire population. Indeed, if college A knows every student's reservation price it will not charge a student less than this full amount as extra revenue earned would enable it to afford to enroll more students and lead to increased college utility. Consequently, in a regime of symmetric information, tuition discounting must move in lockstep with the distribution of student reservation prices. As our first result we show that the presence of asymmetric information limits the extent to which the college can extract surplus from students, even in the presence of full signal separation. This result reveals that the manner in which tuition discounting manifests itself differs substantially between regimes of symmetric and asymmetric information.

Proposition 1 For every subgame perfect Bayesian equilibrium of every tuition game with multiple reservation prices, there is at most one student (ability, reservation price) type that pays an equilibrium tuition equal to its reservation price.

Proof: Assume a nonzero mass of students of a particular ability Q and reservation price δ pay tuition equal to δ. First note that such a student must also pay zero signal cost else they would earn negative net utility and they could do strictly better by not pursuing admission. No student with reservation price higher than δ can pay their own reservation price in equilibrium as they would thus realize zero utility, whereas they would realize strictly positive utility by emulating the signal of Q-ability, δ- reservation price students. Moreover, no nonzero mass of students with reservation price lower than δ can pay their reservation price in equilibrium. Indeed, if this were the case, they must have zero signal cost (else they would receive negative utility), implying that Q-ability, δ- reservation price students would prefer to emulate this group rather than to pay δ, thereby contradicting the assumed equilibrium.

QED

Tuition discounting can occur in a variety of routine circumstances, one of the most obvious being when a high ability student with verifiable financial need can only be lured with a lower tuition than that charged to others (the behavior that occurs when information is symmetric). A less obvious but nonetheless important guiding force of tuition discounting is the presence of asymmetric information. The following definition serves to highlight a unique effect of this force.

Definition 2 ***Inverted tuition discounting*** occurs if the students with the lowest tuition do not have the lowest reservation price of all admitted students. ***Strictly inverted tuition***

discounting occurs if, moreover, students with the lowest tuition have the highest reservation price.

Inverted tuition discounting cannot arise in a world of symmetric information. Indeed, as previously discussed, such fully symmetric information leads students with higher reservation prices to pay higher tuition irrespective of their academic ability and thus the existence of equilibria that exhibit inverted tuition discounting is itself evidence that asymmetric information directly impacts the equilibrium tuitions. Moreover, student types that cannot experience discounted tuition when information is symmetric can very well enjoy such discounts when information is asymmetric. As such, information asymmetry can be a distinct and independent cause of tuition discounting.

There is also an empirical basis for detecting the presence of asymmetric information-induced tuition discounting, since tuition discounting under symmetric information must move in lock step with the distribution of student reservation prices, whereas tuition discounting that is caused by asymmetric information does not. Even if one is unable to directly observe individual student reservation prices, which would admittedly be a challenging task in any empirical application, just knowing the population distribution of reservation prices will suffice to ascertain that asymmetric information is playing an important role in tuition discounting if the observed tuition distribution is inconsistent with the population distribution of reservation prices. The following result establishes that there is a large class of tuition games in which strictly inverted tuition discounting is necessarily realized in every possible subgame perfect Bayesian equilibrium, further confirming asymmetric information's potentially pivotal role in tuition discounting.

Proposition 2 Strictly inverted tuition discounting is realized in every subgame perfect Bayesian equilibrium in an unboundedly large subset of the space of all tuition games.

Before presenting a formal proof of Proposition 2, we first offer some basic intuition for why equilibrium behavior can lead the college to charge the lowest tuition to students with the greatest willingness to pay (i.e., strictly inverted tuition discounting). The rationale is that the college seeks to both accumulate tuition revenue <u>and</u> enroll a talented student body. These competing desires can lead to compromises. Loosely speaking, if the lure of high ability students is sufficiently strong, there is pressure for the college to use low tuition to induce such students to invest in a costly signal that low ability students do not wish to replicate, thereby revealing the identities of high ability students. This pressure can be compounded by variation in student reservation prices and the incentive compatibility concerns that arise in separating equilibrium. Our formal proof of Proposition 2 will parameterize an unboundedly large set of tuition games where this downward pressure on tuition is sufficient to spur the college into adopting a tuition screen that results in strictly inverted tuition discounting.

Proof of Proposition 2: Our proof proceeds as follows. In step 1 we construct a particular class of tuition games, which we denote by K, and we confirm that K is large in the sense that it contains an unbounded open set of tuition games. In step 2 we construct an optimization problem from tuition game parameters and establish properties shared by solutions to this optimization problem when the parameters come from games in K. In step 3 we show that a solution from this optimization problem can be used to construct a subgame perfect Bayesian equilibrium whenever the underlying game is an element of K. We conclude with step 4 by proving that every subgame perfect Bayesian equilibrium of an element of K will induce strictly inverted tuition discounting.

Step 1 We characterize a tuition game by its student reservation price parameters δ_{H1}, δ_{H2}, δ_{L1}, and δ_{L2}; its marginal signal cost parameters η_H and η_L; its population size parameters N_{H1}, N_{H2}, N_{L1}, and N_{L2}; its marginal enrollment benefit parameters β_L and β_H, and its student enrollment cost function $c(\bullet)$. Throughout we shall maintain the previously stated assumptions that $\eta_L > \eta_H$ and that c is a continuously differentiable, convex function $c: \Re_+ \rightarrow \Re_+$. In order to express the conditions listed below more compactly, we also let $N_H = N_{H1} + N_{H2}$.

$$\delta_{H1} > \delta_{L1} > \delta_{H2} > \delta_{L2} > 0 \tag{2.0}$$

$$N_H\left(\delta_{H2} - \frac{\eta_H\left(\delta_{L1} - \delta_{H2}\right)}{\eta_L - \eta_H}\right) + N_{L1}\delta_{L1} > c\left(N_H + N_{L1}\right) \tag{2.1}$$

$$\frac{\delta_{L1} - \delta_{H2}}{\delta_{H2} - \delta_{L2}} > \frac{\eta_L - \eta_H}{\eta_H} > \frac{N_H}{N_{L1}} \tag{2.2}$$

$$\delta_{L2} < c'(0) \tag{2.3}$$

$$\frac{\beta_H}{c'(N_H + N_{L1})} > \frac{\beta_L}{c'(N_H + N_{L1}) - \delta_{L2}} \tag{2.4}$$

Every subgame perfect Bayesian equilibrium is ability separating (2.5)

The set of all tuition games satisfying conditions 2.0-2.5 will be denoted by K. As we will confirm, the set of parameters satisfying 2.0-2.5 is “large” in the sense that it is open and unbounded in the space of all possible model parameters (where the cost function parameter is an element of the set of continuously differentiable convex cost functions endowed with the well-known L^1 topology). To see this, note that by selecting parameters so that the left hand side and middle of 2.2 are arbitrarily close, the left hand side of 2.1 can be made arbitrarily close to $N_H\delta_{L2}+N_{L1}\delta_{L1}$. Moreover, c can be selected so that $c(N_H+N_{L1})$ is arbitrarily close to $(N_H+N_{L1})\delta_{L2}$. As $\delta_{L1}>\delta_{L2}$ and 2.0-2.3 entail no restrictions on β_H and β_L beyond $\beta_H>\beta_L$, it follows that the intersection of 2.0-2.3 is a nonempty and, by construction, open and unbounded set. That the intersection of 2.0-2.4 must also be open and unbounded follows immediately from the fact that $c'(N_H+N_{L1})-\delta_{L2} > 0$ (this latter inequality being a consequence of 2.3).

Before continuing on to the next step of our proof, we point out that we have not yet identified parametric conditions that will lead to the satisfaction of 2.5 nor have we determined whether or not such restrictions can be combined with conditions 2.0-2.4 to yield an open and unbounded class of games. Resolving this issue is simplified by waiting until we have carried out additional equilibrium analysis. For the moment, we take as given that the intersection of conditions 2.0-2.5 contains an open and unbounded set of games and we confirm that this is indeed the case in "Step 1 Addendum" at the end of our proof.

Step 2 Consider the following optimization problem for an arbitrarily given $\Gamma\in K$.

$$\max_{\gamma,T,s,\tau} \gamma \text{ s.t.}$$

$$\delta_{H2}-\tau-\eta_H s \geq \gamma[\delta_{H2}-\delta_{L2}] \tag{2.6}$$

$$\delta_{L1}-T \geq \delta_{L1}-\tau-\eta_L s \tag{2.7}$$

$$\delta_{L1}-T \geq \gamma(\delta_{L1}-\delta_{L2}) \tag{2.8}$$

$$\tau N_H+TN_{L1}+\delta_{L2}\gamma N_{L2}=c(N_H+N_{L1}+\gamma N_{L2}) \tag{2.9}$$

$$\gamma\in[0,1],\ T\geq 0,\ s\geq 0,\ \tau\geq 0 \tag{2.10}$$

Note that if $\gamma=0$, $T=\delta_{L1}$, $s=\dfrac{\delta_{L1}-\delta_{H2}}{\eta_L-\eta_H}$, and $\tau=\delta_{H2}-s$ then constraints 2.6-2.8, 2.10 are each satisfied, and $\tau N_H+TN_{L1}+\delta_{L2}\gamma N_{L2} > c(N_H+N_{L1}+\gamma N_{L2})$, thereby ensuring that the set of parameters satisfying constraints is nonempty and a solution $(\gamma^*,T^*,s^*,\tau^*)$ must exist. Note also that 2.3 further ensures that $\gamma^*\in(0,1)$. We next establish three additional properties of solutions to this optimization problem.

Claim *1 A solution must satisfy* 2.6 *with equality.* Suppose 2.6 is slack for a solution $(\gamma^*,T^*,s^*,\tau^*)$. Consider the arguments γ^*,T,s^*,τ, where $\tau>\tau^*$ and $T<T^*$ such that $\tau N_H+TN_{L1}=\tau^*N_H+T^*N_{L1}$. For these arguments and τ sufficiently close to τ^*, it follows that 2.6-2.8 are each slack, in turn implying that γ^* cannot be optimal (as can be seen by noting that a further change in arguments that is sufficiently slight, but revenue enhancing enables an increase to γ

in equation 2.9 without eliminating all slack from 2.6-2.8.) This contradiction implies 2.6 cannot be slack and proves Claim 1.

***Claim** 2 A solution must satisfy* 2.7 *with equality.* Suppose 2.7 is slack for a solution (γ^*,T^*,s^*,τ^*). Consider the arguments γ^*,T^*,s,τ^*; where $s<s^*$. For these arguments and s sufficiently close to s^* it follows that 2.6 is slack and 2.7-2.10 remain satisfied. Thus (γ^*,T^*,s,τ^*) must also represent a solution. However, Claim 1 implies that a solution must satisfy 2.6 with equality. This contradiction implies 2.7 cannot be slack and proves Claim 2.

***Claim** 3 A solution must satisfy* 2.8 *with equality.* Suppose 2.8 is slack for a solution (γ^*,T^*,s^*,τ^*). Consider the arguments γ^*,T,s,τ such that $\Delta s=s-s^*$, $\Delta\tau=\tau-\tau^*=-\eta_H\Delta s$, and $\Delta T=T-T^*=(\eta_L-\eta_H)\Delta s$. As is readily confirmed by the reader, (γ^*,T,s,τ) satisfies 2.6-2.8 for Δs sufficiently small. But $\Delta\tau N_H+\Delta TN_{L1}=-\eta_H\Delta sN_H+(\eta_L-\eta_H)\Delta sN_{L1}>0$, a consequence of $\dfrac{\eta_L-\eta_H}{\eta_H}>\dfrac{N_H}{N_{L1}}$ (K-property 2.2). This implies that 2.9 is not satisfied for (γ^*,T,s,τ). However, for s and τ as chosen above, T' can be selected in the interval ($T^*,T^*+(\eta_L-\eta_H)\Delta s$) so that $\Delta\tau N_H+(T'-T^*)N_{L1}=0$, in which case the change from (γ^*,T^*,s^*,τ^*) to (γ^*,T',s,τ) is revenue neutral. This implies that (γ^*,T',s,τ) is a solution for which 2.7 is slack. This contradiction of Claim 2 implies that 2.8 cannot be slack and proves Claim 3.

<u>Step 3</u> Given a solution (γ^*,T^*,s^*,τ^*), consider the tuition screen t^* defined by $t^*(s^*,0)=\tau^*$, $t^*(0,1)=T^*$, $t^*(0,0)=\delta_{L2}$, and $t^*(s,x)=\delta_{H1}+1$ for all $(s,x)\notin\{(s^*,0),(0,1),(0,0)\}$; where $\delta_{H1}+1$ is simply a tuition sufficiently high to deter any student from selecting the signal (s,x). Claims 1-3 imply that if (γ^*,T^*,s^*,τ^*) is a solution, then

$$\tau^*=\left((1-\gamma^*)\delta_{H2}+\gamma^*\delta_{L2}-\frac{\eta_H(\delta_{L1}-\delta_{H2})(1-\gamma^*)}{\eta_L-\eta_H}\right) \tag{2.11}$$

The fact that 2.8 is an equality, $\gamma^*<1$, and $\delta_{L1}>\delta_{H2}$ implies that $\gamma^*[\delta_{H2}-\delta_{L2}]>\delta_{H2}-T^*$. Thus, the equality of 2.6 in turn implies

$$\delta_{H2}-\tau^*-\eta_H s^*>\delta_{H2}-T^* \tag{2.12}$$

By construction, 2.12, and 2.4, if the college selects the tuition screen t^* then one continuation equilibrium of t^* results in all H students selecting signal (s^*,0), all $L1$ students selecting (0,1), all $L2$ students selecting (0,0), the college admitting all students that have selected either (s^*,0) or (0,1), and admitting γ^*N_{L2} of the students selecting signal (0,0). To see this, observe that if students anticipate that masses of size N_H, N_{L1}, and N_{L2} respectively select signals (s^*,0), (0,1), and (0,0) and that the college will respond as stated, then a best response for individual *H, L*1, and *L*2 students is to respectively make the selections stated, a consequence of 2.6-2.8, and 2.12 (each effectively being an incentive constraint) being satisfied. 2.4 and 2.9 ensure that the college's sequential best reply to these signals and the college's Bayesian beliefs is, in effect, to first admit all students selecting signals (s^*,0) and (0,1) and then admit the proportion γ^* of those selecting signal (0,0).

Finally, note that if there were a continuation equilibrium emanating from t^* in which the share of students selecting signal (0,0) that are admitted exceeded γ^*, it would follow that in this supposed continuation equilibrium, all *L*1 students would strictly prefer to select signal (0,0) over any other signal, particularly (0,1). However, 2.3 and convexity of *c* imply that there can be no continuation equilibrium in which the proportion of (0,0) selecting students that are admitted exceeds γ^*. Lastly, note that if there were sequentially rational responses to t^* in which the share of students selecting (0,0) is strictly less than γ^*, it would follow that each student is no better off (and possibly worse off) than they would be in the continuation equilibrium described in the previous paragraph. As the college is strictly worse off, it follows that for every subgame perfect Bayesian equilibrium, the subgame that stems from t^* necessarily results in all *H*1 students (as well as all *H*2 students) paying a tuition of τ^* and all *L*2 students paying a tuition of δ_{L2}.

Step 4 By construction, any tuition screen that induces ability separation but does not induce a solution yields a college payoff that is strictly worse than the tuition screen constructed in step 3. In equilibrium, the college will of course select a tuition screen that leads to its most preferred continuation equilibrium outcome. 2.5 implies that such a continuation equilibrium must be an ability separating equilibrium. Let ($\gamma^*, T^*, s^*, \tau^*$) again denote a solution. Notice that 2.0, the first half of 2.2, and 2.11 imply that $\tau^* < \delta_{L2}$. As such, any equilibrium in which *H* students pay tuition of τ^* while *L*2 students pay δ_{L2} will exhibit strictly inverted tuition discounting. Given that we have already established that no ability separating continuation equilibrium can do better for the college than one that induces a solution and there is a tuition screen that necessarily induces a solution, it follows that every subgame perfect Bayesian equilibrium of every game in K exhibits inverted tuition discounting.

Step 1 Addendum To confirm that the intersection of 2.0-2.5 contains an open and unbounded set, we need only establish that for games in K, the ability to separate ability types is so beneficial to the college they are unwilling to sacrifice this for the increased income that may result. Identifying every possible game for which this is the case is rather involved. Fortunately, we need only identify conditions such that when combined with 2.0-2.4 the result is an unbounded and open set. One such example is defined by the following conditions:

$$\delta_{H1}(N_{H1}+N_{L1})+\delta_{L2}(2N_{H2}) < c(N_{H1}+N_{L1}+2N_{H2}) \tag{2.13}$$

$$\left(\frac{N_{H2}}{N_{H2}+N_{L2}}\beta_H+\frac{N_{L2}}{N_{H2}+N_{L2}}\beta_L\right)2N_{H2} < N_{H2}\beta_H \tag{2.14}$$

Inequality 2.13 indicates that even if the college was somehow able to charge a tuition of δ_{H1} (the highest reservation price of any student) to all N_{H1} and N_{L1} students and charge δ_{L2} to all students pooling with *L*2 students (the highest tuition that *L*2 students would ever accept), the college would be unable to affordably enroll more than $N_{H1}+N_{L1}+2N_{H2}$ students. Inequality 2.14 states that if *H*2 students were to pool with *L*2 students, then the expected utility that the college would realize from enrolling $2N_{H2}$ students from this pool would be strictly less than the utility realized from enrolling N_{H2} students known to be of type *H*2. 2.13 and 2.14 thus imply that there is no scenario in which pooling *H*2 students with *L*2 students can lead to a result which is preferred from the college perspective to the college enrolling all *H*2 students with certainty (along with all *H*1 and *L*1 students). Note that these conditions are ensured if $c(N_{H1}+N_{L1}+2N_{H2})$ is sufficiently large (for the case of 2.13) and if N_{L2} is sufficiently large (for the case of 2.14). It follows by construction that the intersection of 2.0-2.4, 2.13, and 2.14 is an open and unbounded set of tuition games, i.e., K contains an open and unbounded class of games over which every subgame perfect Bayesian equilibrium leads to strictly inverted tuition discounting.

QED

Observe that under the parameter configurations specified in inequalities 2.0, the *H*2 students would pay less than the *L*1 students even under perfect information because they have a lower reservation price. However, the *H*1 students would not. What we have shown is that under asymmetric information, not only would both the *H*1 and *H*2 students pay less than the *L*1 students, but they would pay even less than the *L*2 students! Thus, our analysis shows that there are high ability students who earn tuition discounts in subgame perfect Bayesian equilibrium if and only if information asymmetry is present. Furthermore, these discounts are “deep” in that the tuition these types pay is less than even the lowest reservation price in the student population! At the same time there are other high ability students whose discounts are deepened by the mere presence of asymmetric information, relative to what they would receive under full information. In this sense, the tuition discounting that arises under asymmetric information is much stronger than that which would arise under identical parameterizations where information is full.

Our analysis assumes asymmetric information about both student ability and student reservation prices. It is also enlightening to consider information asymmetry that involves either ability or reservation price, but not both. Suppose the college is fully informed of student ability, but is uncertain of reservation prices. It can be shown that in this setting those students with the lowest reservation price of their ability type will be charged a tuition equal to their reservation price but with their admission being less than certain (assuming that enrolling the entire population at these low prices is not feasible). The higher reservation price students of the respective ability type will, however, be charged a tuition sufficiently high to make them indifferent between being admitted with certainty and paying the lower price with less than certain admission. Consequently, inverted tuition discounting fails to emerge as a part of equilibrium behavior. Lastly, suppose that there is incomplete information regarding student ability, but full information prevails with respect to reservation prices. To make the assumption of asymmetric information on student ability meaningful when there is symmetric information regarding reservation prices it must be the case that reservation prices are insufficient to identify student ability. That is, both student ability levels have positive masses of students in each reservation price category. In this setting, it can be shown that tuition will always be set at the reservation price of the corresponding set of students. Thus, once again, we see that asymmetric information can be a key element in inducing the structure of tuition discounting.

We close this section by noting that if all students have the same reservation price and information is symmetric, then all enrolled students will necessarily be charged the same tuition. On the other hand, if information is asymmetric, then any separating equilibrium will induce tuition discounting. Indeed, students cannot be coaxed into undertaking a costly separating signal unless such a signal will be rewarded with discounted tuition. This proves our final proposition.

Proposition 3 There exist tuition games for which tuition discounting is realized in subgame perfect Bayesian equilibrium only if information on student attributes is asymmetric.

5. Conclusion

This paper develops a model of asymmetric information in which a college can effectively screen students by ability with a tuition schedule that depends on a costly signal such as standardized test scores, elective course work, or extracurricular activities. The results reveal that the presence of asymmetric information regarding student characteristics can be a significant force in inducing the phenomenon of tuition discounting to emerge as an equilibrium response to economic parameters. In particular, we show that 1) levels of tuition discounting are always affected by the presence of information asymmetry regarding student ability and willingness to pay, 2) strictly inverted tuition discounting (a phenomenon that cannot occur under full information) is pervasive across a large class of tuition games when information asymmetry is present, and 3) for some tuition games, tuition discounting can arise only if information on student attributes is asymmetric.

Perhaps the most striking feature of our analysis is that tuition discounts need not be driven by student need or competition from other colleges. Indeed, in a large set of economic environments the college's equilibrium response to the underlying information asymmetry is to charge the *lowest* tuition to students that are the most willing and able to pay high tuition, a situation that would most definitely not occur under perfect information. Intuitively, this result is induced by the conflicting desire to maximize rent extraction and to maintain incentive compatibility. In particular, maximal rent extraction may require significant signaling effort on the part of high ability students, but making these signaling efforts incentive compatible may require the offering of what amounts to tuition scholarships for high ability students.

A number of provocative questions surround the role of standardized testing, one of which concerns its true economic function. Our analysis indicates that standardized testing can be an effective way to resolve information problems regarding student ability. However, the effectiveness of this signal is reduced if noise is introduced in the form of randomness in the relationship between test-taking effort/ability and the resulting score. A noisy signal could limit the ability of institutions to distinguish between student abilities, particularly when it is hard to create a wide separation of student scores (for instance because there is a maximum attainable score and the test is either easy to prepare for or students are allowed to take the test multiple times and selectively report their scores). It follows that there may be efficiency gains to be realized from efforts to design standardized exams that induce minimal scoring "noise," e.g., ensuring that test questions are understandable to students of varying backgrounds, that testing conditions are as uniform as possible across venues, and so forth. Likewise, if there is a lot of noise in the signal it can be beneficial to design a challenging test that facilitates ample signal separation and to limit selective score reporting. Even so, the benefits of enabling colleges to more effectively separate students by ability must be weighed against the social costs of potentially limiting access to educational opportunities among less able or less affluent students.

There are also important questions surrounding the practice of tuition discounting that are yet to be fully resolved. The stated rationale for discounting is to allow institutions to maximize revenue while attracting the most desired mix of students, but concern has been raised that its enrollment management benefits are dubious, that it can create serious financial problems for institutions, and that it may reduce access and choice for low-income students (Redd, 2000; Davis, 2003; Heller, 2006). The circumstances under which these detrimental effects do and do not occur, and whether discounting itself is the culprit or the real problem lies in some underlying structural or informational feature of the market that puts pressure on colleges to engage in discounting, are interesting topics for future research. Investigating these matters will require the development of models that incorporate strategic competition among institutions in the design of admissions programs and the setting of both need-based and merit-based aid.

The literature on information problems in higher education is still new and is primarily focused on early admissions programs rather than on how tuitions vary with student attributes and how enrollments are distributed across the quality hierarchy of institutions. Furthermore, although anecdotal evidence suggests that they are important, the true severity of information deficiencies in this market is difficult to measure and, hence, has yet to be empirically diagnosed. There are also information asymmetries about student and college characteristics that await the attention of theorists, not to mention the task of incorporating these asymmetries alongside those that have already been studied and considering how the market structure of higher education shapes the results. Ongoing inquiry into these matters should help further clarify the appropriate policy responses as well as the costs and benefits of our educational system's ongoing reliance on standardized testing.

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