UNIVERSITY OF CALGARY

Tradable Quotas within the University of Calgary's Open Scholarship Competition

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF ARTS

DEPARTMENT OF ECONOMICS

CALGARY, ALBERTA

APRIL, 2006

UNIVERSITY OF CALGARY

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend the Faculty of Graduate Studies for acceptance, a thesis entitled "Tradable Quotas within the University of Calgary's Open Scholarship Competition" submitted by Nicole LeBlanc in partial fulfillment of the requirements for the degree of Master of Arts.

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April 18, 2006

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ABSTRACT

This thesis investigates the implementation of tradable quotas in the University of Calgary's open scholarship competition. The Faculty of Graduate Studies places a quota on the number of applications each department can enter into the open scholarship competition, a competition which distributes approximately $2.5 million in graduate funding annually. The quotas are a mechanism used to limit the number of applications while still recognizing the quality students. There is, however, a lack of information and the allocation of quotas does not recognize all the best students. By allowing departments to trade application quotas for units of GRS, an efficient solution can be reached and the University can recognize the highest quality students through the competition. A deadweight loss of $95,526 of ex ante funding is found in the present system. In other words, tradable application quotas enable students with higher probabilities of success to enter the competition through purchased application quotas.

ACKNOWLEDGMENTS

I would like to sincerely thank Dr. Elizabeth Wilman and Dr. Herbert Emery for all the guidance, assistance, and support they provided me throughout this research. I would also like to thank Dr. Robert Barclay for his suggestions and comments. Finally, I would like to thank the Faculty of Graduate Studies, mainly Connie Baines and Robin Slot, for the information and data they provided, allowing me to undertake this research.

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CHAPTER 1

INTRODUCTION

The current application quota system of the University of Calgary's open scholarship competition conflicts with the university's strategic direction set out by the *Raising our Sights* 2002-2006 academic plan. The major drawback of the present system is the slow evolution of quota allocations within the competition. Quotas do not immediately flow to the highest quality students, failing to promote the 'core principle' of recruiting excellent students. The implementation of an application quota trading system in the open scholarship competition could be beneficial, increasing the system's efficiency in rewarding the most deserving students.

The University's core principles and priorities are set out in its quadrennial academic plan. *Raising our Sights*, the 2002-2006 academic plan, lays out the clear path the University of Calgary is to follow in becoming an upper echelon University. The academic plan is centred around four core principles; these principles are to guide all activities, priorities, and spending within the University. One of these core principles is to focus on recruiting excellent students. The academic plan also outlines five action items to be undertaken to attain these core principles. The first action item is to enlarge high-quality graduate programs. This action item aims at having 20% of the overall student population at the graduate level by 2006. It also aspires to develop competitive recruitment, retention, and funding strategies.

As with any institution, the University's ability to move in the desired direction is constrained by a budget, and therefore every dollar needs to be directed to its most efficient use. An important tool in attracting graduate students is funding.[1] With the aim of enlarging high-quality graduate programs, it seems evident that funding should be used to reward quality students, providing departments with the incentive to attract these high quality students through continual advancement and growth of their programs. The open scholarship competition and its quota design are a potential 2.5 million dollar policy the

[1] As found by the Faculty of Graduate Studies in a departmental questionnaire discussed June 29, 2004.

University could better use to attract high quality students and promote departmental improvements at the graduate level.

The current quota allocation system reflects historic student and program quality. It fails to immediately recognize the calibre of students attracted by a specific department. It fails to provide the proper incentives to departments to maintain or improve their academic status. This slow, inadequate evolution of quotas is a characteristic the Faculty of Graduate Studies must eliminate from the open scholarship competition. The new system must be able to immediately recognize the quality of students attracted by a department, therefore rewarding the improvements made to the department's graduate program. The new system must not allow program quotas to be carried forward by past success. The new system must direct quotas to the most deserving students and departments. The new system must attract the maximum student quality for its 2.5 million dollar budget.

The present system of quota allocations is historic; each department's quota of applications which it can submit into the open scholarship competition is determined by a moving average based upon the department's success in previous years of competition. Multiplying the average number of a department's applicants in the top 125 applications over the last three years by a set factor determines a department's new quota. This implies that a department must have three years of highly successful candidates before any substantial change can be made to their quota. So, a high quality student attracted to a program will not be fully recognized by the quota allocation method. This implies that the improvements within a department, enabling them to attract these high quality students, are not fully recognized by the quota system. Likewise, any deterioration of a department may go disregarded or unrealized for several years. These unresponsive, uncompetitive qualities of the allocation are not in step with the University's objective. The University wants to improve its graduate program at the least possible cost, that is, increase enrollment as well as the quality of students with the present budget. This implies providing departments with the incentives to take initiative and improve the quality of their graduate program. The present system fails to fully provide these incentives.

The implementation of a tradable quota system to the open scholarship competition could increase the efficiency of the system. By making quota positions more readily available to departments who attract good students, it would reward them immediately for their success. It would increase the flexibility of the competition, allowing it to adapt to departmental changes each year. Under a tradable quota system, each department would be allocated application quotas over which they would have complete authority. The department would be able to submit an application into the competition or trade the application place with another department for another form of funding. This would ensure that departments only submit applications for students whom they feel have a strong chance of winning a scholarship. Otherwise, if their chances of winning were low, the department would sell off the quota for a guaranteed amount of funding. The tradable system allows the market for quotas to ensure that the quotas are flowing to students who are most deserving. This corresponds to the University's goal by rewarding the high-quality students by providing them with immediate funding, as well as rewarding the program that attracted the student. Of course, methods for the initial allocation of quota and transferability rules must be defined. These preliminaries will be included in the model to be expanded below.

This thesis investigates the implementation of tradable quotas to the University of Calgary's open scholarship competition. This first chapter consists of introductory remarks. The second chapter explains the competition's current process. The third chapter consists of tradable permit theory and its relevance to this problem. A theoretical model explaining the design of a tradable system in the open scholarship competition is developed in chapter four. In chapter five, department expectations of success in the open scholarship competition are calculated using a Poisson regression model. Chapter six develops both the University's and each department's funding maximization problems and solves them for optimal choices using 2003 data as the representative year. Simulations using these optimal choices are run to illustrate the efficiency gains from changing the quota system. The results of these simulations along with further benefits are discussed in chapter seven. Discussion of the results, possible extension and concluding remarks make up the last chapter.

CHAPTER 2

OPEN SCHOLARSHIP COMPETITION

To consider the likely impact of tradable quotas in the open scholarship competition, it is important to take into account the structure of the funding system and the open scholarship competition as it currently stands. The information provided in this chapter was obtained from the University of Calgary's Graduate Studies webpage and personal communication with several individuals from the Faculty of Graduate Studies and the Graduate Scholarship Committee.[2]

A department's ability to attract graduate students depends mainly on its status and available funding. Department status is determined by things such as the prominence of the University, the reputation of the department, the reputation of the faculty, their research, and recent or distinguished graduates. Program status is influenced by the department, but not directly controlled. Funding, the other major tool in enticing attractive graduate students, is investigated in this thesis. Funding for graduate students comes from many different sources, some within the University and others externally.

Departments have several forms of funding they are able to provide graduate students. There are graduate assistantships, graduate research scholarships, bursaries, awards, and other scholarships.

Graduate assistantships can take on four forms: teaching assistant, research assistant, teaching fellowship, or trust. Each of the positions entails a determined amount of work for its duration. All of the assistantships are awarded based on merit by the respective department. The number of assistantships available in each department is determined mainly by the amount of research or teaching required.

A graduate research scholarship (GRS) is a stipend of $4100 paid out over four months. Its purpose is to finance research that is directly related to the recipient's thesis. No duties are required from its holder. The Faculty of Graduate Studies funds these scholarships and in 2003 distributed 2.5 million dollars in graduate research scholarships.

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[2] These individual include, but are not limited to, Dr. Herb Emery, Dr. Robert Barclay, Connie Baines, and Robin Slot.

They are allocated to each department and then awarded to students by the department. The success of a department in the open scholarship competition (i.e. the ranking of their students in the competition) determines the number of graduate research scholarships it receives from the Faculty of Graduate Studies.[3]

There is roughly nine million dollars worth of internal and external scholarships and awards available each year for students within the Faculty of Graduate Studies. These scholarships vary in value and in duration. The application process for each also varies. The Faculty of Graduate Studies or the appropriate departments choose the recipients. Some awards are available to all students, whereas others are more restricted, allowing only certain areas of research to qualify. The internal awards, which account for about one third of the 9 million dollars, are awarded through the open scholarship competition.

The open scholarship competition is a University-wide competition with which the Faculty of Graduate Studies' distributes a large number of their awards and scholarships. The value of the awards and scholarships varies, averaging around $10,000 per year. Each department within the University has a quota on the number of applications it can submit into the open scholarship competition. Currently the Faculty of Graduate Studies receives about 450 applications for the competition, 250 from Master's students and 200 from Doctoral students. The Graduate Scholarship Committee assesses these applications.[4] Every March, five committee members rank the academic record, scholarship portfolio, research proposal, letters of reference, and scholarly contributions of each application. The averaged scores are ordered and the top students are sent scholarship offers in early May. Often a second round of offers needs to be sent out. Many of the first offers are rejected and the next in rank are chosen. After all offers have been accepted, over a hundred applicants in each of the Master's and PhD categories are successful in the competition.

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[3] The exact mechanisms of the relationship were not disclosed in communications with Connie Baines in June 2004.

[4] The Graduate Scholarship Committee consists of over 20 elected faculty members. The Faculty of Graduate Studies Council elects each member for a three-year term.

Presently, each department's application quota, for either the PhD or Masters level, is based upon success in previous open scholarship competitions. The current quota system was implemented in 1995. A department's quota, for either the PhD or Master's level, is calculated by multiplying their average number of ranked applicants, that is those within the top 125 applications, over the past three years by a common factor. This moving average was chosen to reward innovative programs, which were able to attract exceptional students, while keeping quotas relatively consistent, as well as limit the total amount of applications.

In 1995, the first year of the system, the common factor was two. In 1996, it went down to 1.75 and then from 1997 onwards it was 1.5. If a department or program had little success in the past they obtained the minimum quota of three. The initial multiplicative factor was set at two for implementation ease.

After nine years of implementation, the Faculty of Graduate Studies should be questioning the appropriateness of the competition's quota system. With a three-year average determining new quotas, the system is historical. Being based on an average of past numbers generates quotas which are slow to evolve and incapable of immediately recognizing all exceptional students. The system does not allow present information to make a full impact on quotas, failing to accomplish the goal of compensating growing departments for attracting new exceptional students and penalizing declining departments for their diminishing position. Instead, department quotas change gradually. This slow evolution of quotas should be an issue concerning the Faculty of Graduate Studies, as it hinders the ability of the open scholarship competition to promote the academic plan's objectives of improving the quality of students and increasing graduate level attendance.

A related problem is the excessive amount of time spent by the Graduate Scholarship Committee reviewing applications. Approximately 450 applications are entered into the competition each year, each of which is assessed by five different committee members. It takes, on average, about twenty minutes for a committee member to review one application.[5] So in total, 750 hours, or 19 weeks, of a full-time faculty position are spent reviewing applications.

The current quota system is similar to the command-and-control approach of controlling or protecting a common good. Command and control regulation is the dominant form of regulation in the world today (Kolstad, 2000). The basic course for the regulator in a command and control system is to assess each user's situation and then specify standards to which these users must comply. Often these standards take the form of limits on inputs or outputs in the consumption or production process. This approach is similar to the open scholarship competition. Applications provide information to the Faculty of Graduate Studies which they use to decide which students deserve scholarships and similarly which departments deserve future application positions.

The centralization of control decisions in a command-and-control system allows regulators to easily determine limits, aggregate and specific. However, the information required to efficiently set such limits is enormous, making this type of regulation costly. Furthermore, there is a level of uncertainty recognized with information acquired by the regulator (Grafton, 1996). These circumstances are present in the open scholarship competition. An excessive amount of time is spent reviewing applications and still the system does not sufficiently represent departmental quality due to the lack of complete information.

Command-and-control regulation often lacks in providing incentives for innovation, depending on the timeframe between standard settings and rewards for improvement (Tietenberg, 2001). In this case, the slow evolution of quotas weakens the department's incentive for improvement.

Although in theory it is possible for a regulator to set command-and-control standards consistent with the efficient allocation of quota, in reality, the information necessary for such efficient usage in a command-and-control method is rarely obtained and the set standards do not satisfy the efficient equi-marginal condition (i.e. all firms valuing quota at the same marginal benefit) (Tietenberg, 2001). The command-and-control method restricts the possible measures a user can take, disenabling the

[5] As disclosed by Dr. Herb Emery, a former Graduate Scholarship Committee member.

mechanisms that equalize the marginal costs of all users. Regulators have attempted to improve programs by altering the economic incentives of those involved (Grafton, 1996). The idea is to align public and private objectives. These new incentives motivate users to do what is perceived to be in the public interest. One such possible economic incentive is tradable permits.

CHAPTER 3

TRADABLE PERMIT THEORY

Tradable permits are a fairly new instrument used in coping with the inefficient use of common goods. They have been applied to a number of environmental problems, proving successful in air, fish, and water applications (Grafton, 1996; Joskow, 1998). Tradable permits may be a suitable system for the open scholarship competition.

Under open access conditions, when using a common or public resource, firms do not consider the social costs of their actions. Therefore, in general, use will exceed the level that maximizes the net benefits to society. That is, firms continue to consume the common good until their marginal benefit equals their marginal cost (Tietenberg, 2004). However, the firm's marginal cost fails to account for any social cost. The level of consumption is at a point where total marginal costs exceed total marginal benefits and society's benefits are not maximized. Tradable permits designate ownership rights to their holder, changing the holder's incentives (Grafton, 1996). The permits increase the net benefits to society by forcing firms to internalize social costs. Under the right conditions, permits flow to their highest valued use, minimizing the costs of controlling the good.

In reality, however, the circumstances are far from perfect and the actual benefits are disputable. Transaction costs, implementation ease and governing limitations are several of the possible obstacles that may hinder efficiency gains (Colby, 2000).

The controlling of a public good begins by setting an aggregate access limit to the use of the resource of concern. Economically speaking, the efficient level of consumption, where marginal benefit of the last unit consumed equals its marginal cost, is much too difficult to determine. It involves acquiring a lot of information, as well as giving monetary values to the effects of resource use. Both of these tasks are subject to uncertainty. To overcome these difficulties a sustainability approach is taken (Tietenberg, 2001). The aggregate limit chosen is one that can sustain the future of the good.

Access rights are then allocated to the users, giving them complete authority over their goods. Under the command-and-control approach, as described in the previous chapter, the only option is to consume the goods. With tradable permits, depending on the specific program, these access rights can be exercised, transferred to another user for a price, or banked for future use. Under perfect conditions, the permits are exercised at their highest valued use (Tietenberg, 2001). Those who value their permit less than its price have an incentive to trade with someone who values it more highly. The trade benefits both parties. If all such trades are made, the maximum value is extracted from the consumed good and a cost-effective solution to meeting the sustainable limit is found (Baumol and Oates, 1988). As discussed previously, the cost-effective solution could hypothetically be reached through the initial allocation of access rights, but the trading of permits allows the solution to arise without the regulator having to acquire the costly information necessary to make such an allocation.

A cost effective solution to controlling a good is one that controls the common resource at a minimum cost to users, or equivalently at a maximum total benefit. Assuming the costs of reducing use of the resource are convex, that is increasing marginal cost, the necessary and sufficient conditions of total cost minimization imply that each user's marginal cost of reduction must be equal. So, under perfect conditions permits will be traded until the price of a permit equals each user's marginal cost of reduction. This condition is proven below.

Consider the system under which the governing agency allocates Q permits, with q_{io} to each firm, where there are i=1,2,...N firms. Firms are free to trade these permits among themselves as long as they retain enough to cover their use and obey all transferability rules. Let $c_i(r_i)$ be the reduction cost function of the firm i, where r_i is the reduction in use of the common good, measured in the same units as the permits. Let u_i represent the profit maximizing level of resource usage for firm i and let p be the equilibrium price of permits., So the quantity of permits traded for firm i will be

$$t_i = (u_i - r_i - q_{io})$$

and denoted by t_i. This term will be negative if the firm is a net seller of permits and positive if the firm is a net buyer of permits. Assuming each firm is profit maximizing, they will be faced with the problem of minimizing their reduction costs, which is written as

$$\min_{\{r_i\}}(c_i(r_i) + p(u_i - r_i - q_{io}))$$
$$\text{subject to } r_i \geq 0$$

Again, assuming the reduction costs are convex, the minimizing solution is

$$\partial c_i(r_i) \big/ \partial r_i = p \quad \forall i$$

which implies that the costs of controlling the resource are minimized when the marginal reduction cost of each firm is equal to the price of the permits. This is assuming the perfect conditions of a fully functional market with no transaction costs, adequate enforcement, monitoring and complete information. This profit maximizing solution follows economic intuition. A firm would continue to choose the least costly method of reducing usage until all methods cost the same amount.

Under these perfect conditions, a cost-effective outcome will occur for all initial allocations of the permits (Montgomery, 1972). Trade will continue until each firm's marginal control costs equal the price of permits, giving a cost minimizing solution each time.

The common issues of setting a cap or baseline limit, allocating permits, defining transferability rules, enforcing these rules, monitoring behaviour and adapting to change are all crucial in designing a tradable permits program, no matter what the resource. I consider the importance and challenges of each of these design issues below.

A possible baseline system for tradable permit programs is the cap-and-trade system. In a cap-and-trade system, the aggregate limit is defined and tradable permits summing to this limit are allocated to users. This established limit must be firm enough to provide permit holders with the security needed to alter their incentives but also adaptive to changes. Within the open scholarship competition, new departments and changes in the number of awards will affect the aggregate level of quota. These changes can be handled by setting initial guidelines in the system, such as a given number of new quotas for each new department or award. These guidelines must be set so they do not excessively disrupt the existing system and must always be followed to maintain the integrity of the trading system.

The initial allocation of permits to users is the most controversial aspect of tradable permits and is often faced with opposition from the various stakeholders (Tietenberg, 2001). It determines how wealth is distributed to the users. There are four common methods of allocating permits: lotteries, first-come first-served, historical use and auctions (Tietenberg, 2001).

Lottery allocations are determined through a draw. This method is not acceptable for the open scholarship competition since quotas are to reward students and departments, not to be distributed randomly. First-come first-served summarizes this manner of distribution. This is also unacceptable for the open scholarship competition as it fails to use quotas as a reward policy.

Under historical use allocation, permits are distributed to firms depending on their historic market share, recognizing their investments in the industry. Allocating permits in this fashion is the most common distribution method; this is likely true for two reasons (Tietenberg, 2001). First, it eases the adoption of the program by minimizing opposition from the direct and indirect users. Secondly, allocating permits to historic users causes the least disruption to the market. The governing agency must clearly define the eligibility of firms and their specific allocations. These decisions can be faced with opposition as they determine how wealth is allocated.

Historical use allocates permits for free, no rents are captured by the governing agency. Firms are responsible only for their abatement costs and need not pay any social costs. This means that the public is not compensated for the use of the good. One way to capture rent without auctioning permits is to apply a profit charge, an output charge, an input charge, or a permit rental charge. Of these policies, the choice must appropriately favour efficient users over less efficient users (Grafton and Devlin, 1996). Even with these charges, the user still does not pay the full price of their actions. This affects the efficiency of the tradable permit program. An auction, under perfect conditions, is more efficient in maximizing total benefits than a historically based distribution (Goulder, et al., 1999).

Auctioning permits ensures that the user pays. That is, each permit to use the public good a firm uses must be purchased and the social costs of the user's actions are internalized. This benefits society as a whole. Consumption of the good will occur at a point closer to that which maximizes social benefits. However, this system does place a large financial burden on firms and can be seen as a barrier to entry. As such, auctions are rarely used due to heavy opposition.

I will not consider auctions for the open scholarship competition. The Faculty of Graduate Studies allocates each department their GRS units and application quota; therefore, they control each department's budget. As such, an auction in which departments use GRS dollars, which are supplied by the Faculty of Graduate Studies, to purchase units of quota is equivalent to the free allocation of quota.

Determining the allocation method for the open scholarship competition which appropriately represents student quality is a difficult task, this difficulty is the motivations behind this thesis.

The choice of allocation method depends mainly on the regulator's objectives. If maximizing efficiency, at any cost, is the objective, then auctions are the method of choice. The auction system will force firms to expose their willingness to pay for a permit and extract the maximum amount of revenue from the resource. If the goal is environmental protection or improvement at the minimum cost to users, a permit program based on free initial distribution is best (Lyon, 1982).

Once rights have been allocated, the rules of transferability must be decided. Unconstrained transferability increases the efficiency of the system by allowing permits to flow freely to their highest valued use (Tietenberg, 2001). However, restrictions are often placed on trade to protect external interests or avoid social costs. The areas of concern with transferability are the concentration of rights, destruction of communities, and other violations of public interest. Unavoidable restrictions also occur when there is a conflict of power between the governing agency and previously set policies. This was a major problem in the South-Western United States water permits implementation; federal policy limited the transferability of many users' permits (Colby, 2000). Most of these concerns would not be present in the open scholarship system; the system's design prevents these problems from arising.

One final concern with transferability is the actual availability of tradable permits; often during implementation the governing agency must step in and force users to make permits accessible for trade (Hausker, 1990). The ease of implementing tradable quota into the open scholarship competition could be an issue. It is likely that departments will be reluctant to participate in the trading system for several reasons. It will be difficult for a department to accurately predict an applicant's probability of winning and deduce the expected value of scholarship revenue, or ex ante funding, any given unit of quota will receive to any degree of certainty. Also, departments will likely be risk averse, placing a higher value on guaranteed GRS revenue than the equivalent amount of expected scholarship revenue.

The last issue in tradable permits is the monitoring and enforcement of the program. Like any regulation, the success of tradable permits depends on monitoring and enforcement by the regulator.

Two types of monitoring are necessary for a tradable permits program. First, regulators need to monitor the impact of use and evaluate the effectiveness of the program and its set limits. Secondly, regulators need data to monitor the compliance of users. Assuring limits are met requires information on the identity of all users, the amount of permits they each hold, and permit transfers. To promote the success of the program these data should be made available to all affected so that the market can be easily analyzed and cheating avoided. A set of sanctions for non-compliance needs to be determined to enforce the rules of the program. The severity of the penalties must match the degree of non-compliance in order for users to consider them credible. If the penalties are too lax, users will ignore them; if the penalties are too harsh, regulators will be reluctant to impose them. Penalties can take the form of fines, forfeiting future permits, revoking transfer rights, or complete removal from the program.

The Faculty of Graduate Studies will not have compliance issues, but assessing the overall effectiveness of the tradable quota program may be difficult. Program enrollment, independent studies and national statistics would give some insight into the success of the program in attracting more graduate students but quantifying the relative quality of the students rewarded by the competition would be difficult.

The feasibility and success of implementing tradable permits has been studied extensively to estimate the potential gains from such programs (Colby, 2000; Barrow, 2003). Tradable permits are often the last resort taken by regulators. In theory, they are extremely attractive, but in practice fail to bring about the predicted gains calculated under perfect market conditions .

Under tradable permits, the proposed savings are often exaggerated (Tietenberg, 1985; Hausker, 1994; Stavins, 1995). The frictionless markets used to calculate these savings are abstractions from reality, overlooking implementation complications. In effect, upon implementation, it is likely that the permit market is imperfect. Constraints, uncertainty, transaction costs, and distrust all obstruct market development (Stavins, 1995; Joskow et al., 1998). The efficiency gains of the program are not fully realized due to lack of trade and information within the market initially. Air, fish, and water programs have all faced such obstacles (Joskow et al., 1998; Colby, 2000). Regulators try to foster competitiveness and efficiency through intervention (Hausker, 1990). The evolution of the program and any intervention by the governing agency reduces the expected gains of such programs (Tietenberg, 2001).

Implementation of tradable quotas within the open scholarship competition will likely face similar obstacles. Easy monitoring and low transaction costs will be outweighed by unwillingness to trade due to risk aversity and lack of certainty in the expected scholarship revenue. Educating graduate coordinators on the mechanisms of the system, their options and how to quantify student quality would aid implementation. There would still, however, be opposition from departments reluctant to change, particularly those departments with high levels of quota in the current system. These market imperfections and issues with the system will reduce the expected gains of tradable quotas calculated here.

CHAPTER 4

TRADEABLE QUOTA MODEL

With a system of annual tradable quotas for the open scholarship competition, a unit of quota would give a department the opportunity to submit one application into the annual competition or sell the unit of quota for a guaranteed amount of GRS funding. The Faculty of Graduate Studies would determine the total aggregate quota issued. This total quota could remain constant through time unless additional scholarships or departments were added to the competition. Quota units will be distributed each year, and for simplicity, I assume that departments cannot save or borrow units of quota. I consider three methods of initial allocation of departmental quota, the current allocation method, distribution based on enrollment numbers, and equal distribution. The current allocation will be investigated to characterize the potential gains from trade. Enrollment based quotas and equal quotas are included to illustrate allocation issues.

Units of quota will be tradable, implying that a department can either reduce its number of applications submitted and sell low valued units of quota or increase its submissions by purchasing units of quota from other departments, allowing a relaxation of the quota constraint. Although the department's constraint would be relaxed, this would not be true in aggregate, as the University-wide total aggregate quota is fixed. Units of quota would be exchanged for dollars that are used as graduate research scholarships (GRS). The price of a unit of quota depends on the levels of supply and demand for quota. The Faculty of Graduate Studies would keep track of all such trades to ensure constraints are met. Such information would be made available to departments in order for them to evaluate their standing.

CHAPTER 5

POISSON REGRESSION MODEL & ESTIMATION

The desirability of a tradable quota system versus the status quo depends on the expected gains of the new system. Before entering the competition, each department forms expectations of the success of their students in the competition. Therefore, with some degree of certainty, each department places an ex ante value on each unit of quota. This value is equal to the funding the department expects to receive from the unit of quota, which is the particular student's probability of success in the competition multiplied by the monetary value of the award they would receive if successful. This ex ante value, or expected value of funding, for the unit of quota represents, to the University, the level of student quality recognized by this unit of quota. The tradable system would allow units of quota to go to their highest valued use, or to the departments with the highest ex ante value of them. Implying that departments would trade quotas based on the ex ante value they place on them, or similarly, the quality of student using the unit of quota. Therefore the expected gains of implementing such a tradable system in recognizing student quality are quantified by the change in overall ex ante funding.[6] To estimate ex ante funding for a department in any specific year, the expected success, or probability of success, of applicants within the open scholarship competition is required. Estimating these expectations is undertaken in this section using a Poisson regression model.

5.1 Data

The Faculty of Graduate Studies provided the data used in this study. Data were available for both the PhD and Masters programs, but here only the PhD case is investigated. Each of the thirty-five departments' annual application quotas, units of graduate research scholarship (GRS), and number of ranked applicants over the past six academic years were obtained. A ranked applicant is one who falls within the top 125

[6] Expected funding being Graduate Research Scholarships and expected Open Scholarships.

applicants and is very likely to receive an award. Below the summary statistics of these data are listed.

Table 5.1 Data summary

Variable	Mean	Minimum	Maximum	Standard Deviation	Number of Observations
Units of Quota	5.457	3	19	3.612	210
Number of Ranked	3.271	0	12	2.846	210
Units of GRS	14.014	2.5	40	7.516	210

There are 210 observations in total: six years of data from the 35 departments. The average quota size for a department over the six year period is 5.457, the maximum quota is 19 and the minimum is 3. The average number of students ranked, or successful in the competition, from a department is 3.27, with a standard deviation of 2.846, a minimum of 0, and a maximum of 12. The average number of GRS units distributed to each department is 14.014, with a standard deviation of 7.516, a minimum of 2.5, and a maximum of 40.

In the case of discrepancies between a departmental quota and the number of applications actually submitted, the quota is taken as reached. Graduate research scholarships are distributed solely to the departments, not specifically to either their Masters or Doctoral program. Therefore, the GRS units attributed to PhD students is taken as proportional to their enrolment within the department.

Using this information, the expected value of each unit of quota to specific departments, before and after trading, is determined.

5.2 Poisson regression models

To approximate the ex ante amount of funding for any specific department, expectations on the outcome of the open scholarship competition must be made. The probability of a successful outcome (an award) will depend upon the quality of the nominee. A typical department will have a range of potential nominees, and will put forward its best nominees first. As its quota is increased, it will nominate individuals for whom the probability of a successful outcome is less. Hence, it is expected that the marginal value of quota declines due to diminishing probability of success.

The measure of success within the competition is the number of open scholarships awarded to a department, or equivalently the number of students ranked in the competition.[7] This variable takes on a positive integer value. Such data are referred to as count data. Poisson regression models have been widely used to analyze count data (Cameron and Trivedi, 1990).

The Poisson regression model requires that r_i, the number of students ranked, or scholarships awarded, in department i, is drawn from a Poisson distribution with parameter λ_i, where λ_i is related to the regressors, x_i. This Poisson distribution is represented by the following equation

$$\Pr ob(R_i = r_i | x_i) = \frac{e^{-\lambda_i} \lambda_i^{x_i}}{r_i!} \qquad r_i = 0,1,2,\ldots$$

The chosen form for λ_i will be the log-linear form

$$\ln \lambda_i = \beta^T x_i$$

where β is a vector of unknown coefficients.

Given this distribution, the expected number of ranked students or the expected count will be

$$E(r_i | x_i) = Var(r_i | x_i) = \lambda_i = e^{\beta^T x_i}$$

The condition of the mean being equal to the variance is the main criticism of the Poisson model (Wooldridge, 2002; Greene, 2003). This restrictive shortcoming is avoided by several alternative models, the most common of which being the negative binomial model. This aforementioned model relaxes the equi-dispersion assumption by introducing an individual, unobserved effect into the conditional mean. Most often, this specification error is assumed to follow a gamma distribution with unit mean, implying equal conditional means for both the Poisson regression model and the Negative Binomial Model, but different variances. As an aside, no matter what the distribution of

[7] The number of scholarships awarded to a department through the competition is approximated by the number of students from department i ranked within the top 125 applicants, as it is, on average, the number of offers sent out.

the data, the Poisson Regression model gives consistent, asymptotically normal estimates. Nonetheless, the data are tested to ensure they satisfy the Poisson variance assumption.

The department and its respective quota are considered to affect the outcome of the annual open scholarship competition and are included as regressors in the distribution parameter.[8] The departmental dummy variables are expected to capture any systematic differences in success attributed to the departments that would be otherwise unexplained; these variables could reflect quality differences and other factors such as grade inflation that may influence the open scholarship competition outcome. The respective quota, to the first and second power, are both included in the Poisson parameter. The department's quota to the second power allows for the appropriate quality of diminishing marginal probabilities of success with respect to quota size. Therefore, the distribution parameter is given by

$$\ln \lambda_i = \beta_0 + \beta_1 q_i + \beta_2 q_i^2 + \sum_{j=1}^{35} \theta_i D_i^j \qquad i = 1,2,\ldots,35$$

q_i being the quota of department i and D_i^j representing the departmental dummy variables.

The coefficients of this nonlinear regression are estimated using maximum likelihood techniques. The log-likelihood function for the Poisson regression model is written as

$$\ln L = \sum_{i=1}^{210} (-\lambda_i + r_i \cdot [\beta, \theta]^T \cdot x_i - \ln r_i!)$$

Two different Poisson regression models will be estimated. The first, Model 1, is simplified by limiting the number of department coefficients estimated whereas the second model, Model 2, will include the full set of 35 departmental dummy variables.

[8] Years were initially included as variables but then removed when estimated coefficients failed to differ significantly.

5.3 Poisson probability estimation

Using Stata 8.0, the vector of coefficients β and θ is estimated for both models, giving the Poisson expectations of the number of scholarships a given department expects to receive with their quota. The restriction of the mean being equal to the variance, or equivalently the appropriateness of the Poisson distribution needs to be tested. Following the regression-based procedure described in Greene (2003, pp. 743-744), the null hypothesis of

$$H_o : Var[r_i|x_i] = E[r_i|x_i]$$

versus the alternative,

$$H_a : Var[r_i|x_i] = E[r_i|x_i] + \alpha \cdot g(E[r_i|x_i])$$

is tested by regressing

$$z_i = \frac{(r_i - \hat{\lambda}_i)^2 - r_i}{\hat{\lambda}_i\sqrt{2}}$$

on $\hat{\lambda}_i$ without a constant term and testing the significance of the coefficient, where $\hat{\lambda}_i$ is the predicted value from the Poisson regressions. T-tests for both the models find the estimated coefficients to be significantly different from zero with p-values less than 0.001 in both cases. However, the estimated values of the coefficients are small, -0.116 and –0.141 for Model 1 and Model 2, respectively. Alternative models, such as Ordinary Least Squares and Negative Binomial have similar shortcomings. Estimations of the aforementioned models were carried out. The results were consistent with those of the Poisson estimation. This provides support to presume that the Poisson distribution is a reasonable approximation for investigating the outcome of the open scholarship competition.

The results of the Poisson regressions are given below. The first model is presented in Table 5.2; in this case each department was categorized as a high, medium or low quota department. This classification was based upon the department's average assigned quota over the six year period. Three, the minimum quota, is the low quota category, four to ten is medium and over ten is the high quota designation.[9] The regressors are jointly significant, rejecting the null hypothesis with a p-value of 0.0001 ($\chi^2(4)$=351.00), They are successful in explaining a third of the variation in scholarship assignment (Pseudo R^2=0.33[10]).

Table 5.2 Estimated Poisson parameters of Model 1.

Coefficient	Estimated Values	Standard Errors
β_0	-0.431	0.169
β_1	0.215	0.0532
β_2	-0.00605	0.00247
θ_{med}	0.762	0.152
θ_{high}	0.847	0.283

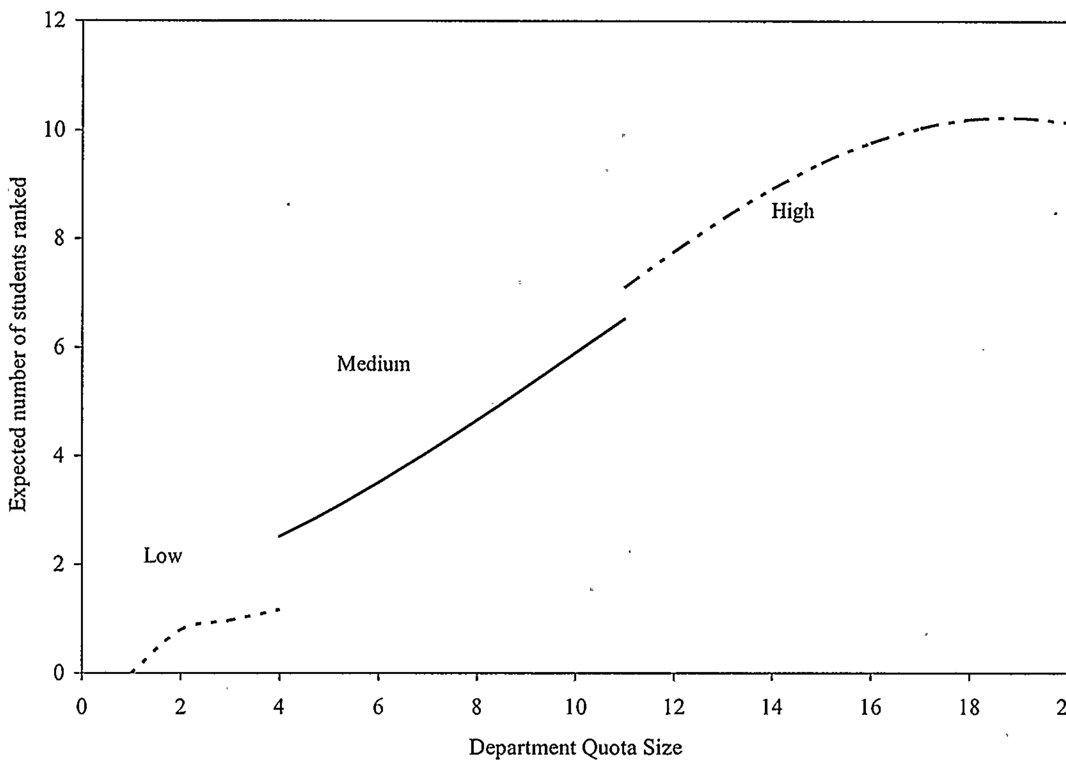
Comments can be made concerning the estimated coefficients. Coefficients on q and q^2 indicate that the expected number of scholarships increases with q but at a decreasing rate. The ascending values of the θ_{med} and θ_{high} dummy coefficients implies an increased probability of receiving a scholarship when moving from the medium to high category.

The expected number of ranked applicants for each type of department is plotted against various quota sizes in Figure 5.1. This graph presents how many awards a department can expect to receive given this quota size. The levels of success are different across low, medium and high departments. The number of ranked student (i.e. scholarships awarded) increases with quota size.

[9] The limitations of categorizing departments by quota size in a system where quota allocation is under revision for being an ineffective measure of department quality are noted. The existing quota sizes are, however, a reflection of program size and program quality, influencing the level of success in past Open Scholarship Competitions.

[10] Alternative measurements of fit have been suggested for the Poisson model as it does not have an equivalent R^2 from linear regression models. The Pseudo R^2 presented here is a likelihood ratio index (Greene 2003).

Figure 5.1 Expected number of students ranked in high, medium and low departments under various quota sizes



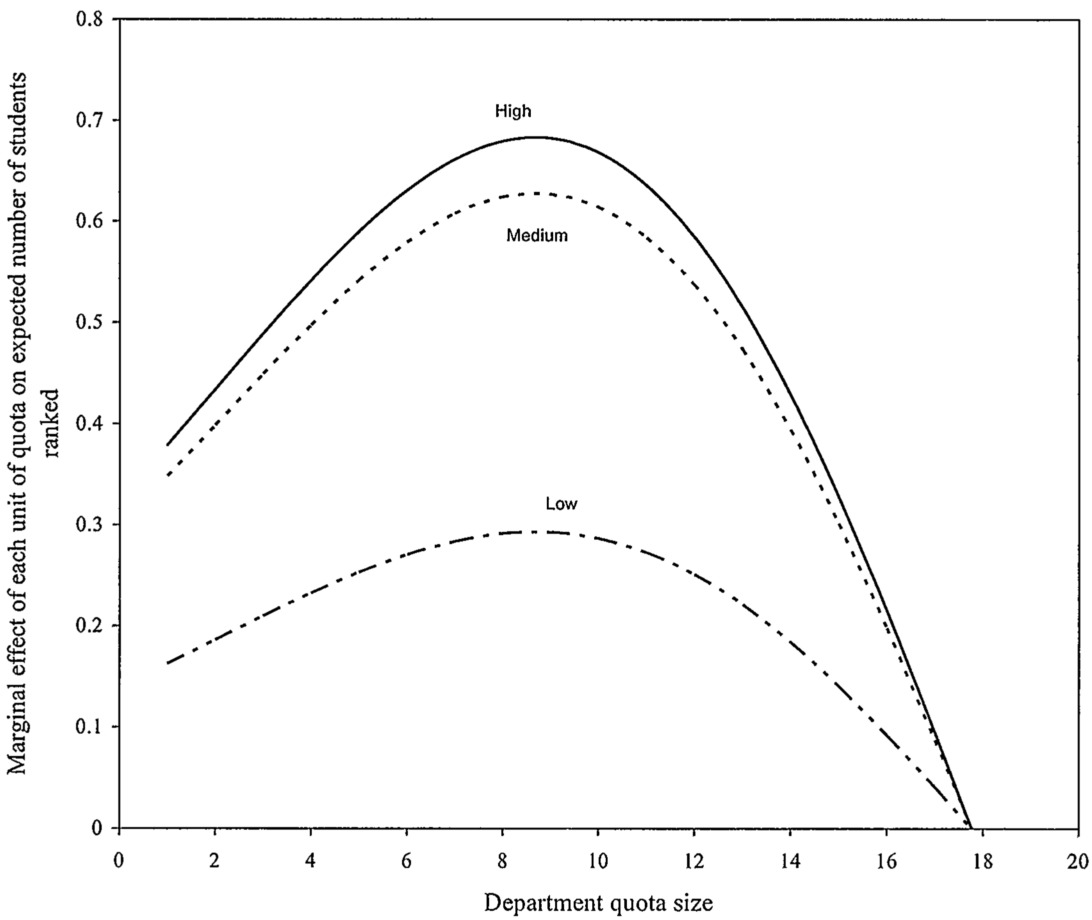
The plateau at the end of the estimated curve is caused by quota size being censored at 19 in the data. In reality a maximum should never be reached. Each additional unit of quota should increase the expected number of ranked students by a diminishing but positive amount.

The increase in expected number of ranked applicants from each additional unit of quota gives insight into a department's value of each unit of quota. The marginal effect of each additional unit of quota on the expected number of ranked applicants is given by,

$$\partial r_i / \partial q_i = (\hat{\beta}_1 + 2\hat{\beta}_2 q_i)e^{\lambda_i}$$

This marginal effect is plotted below in Figure 5.2 for each type of department. These curves represent the increase each specific unit of quota has on the total expected number of students ranked within each department. The marginal effect of each unit of quota increases until the tenth unit of quota. From the tenth unit onwards the marginal effect of each unit of quota diminishes. At a quota size of 18 the marginal effect becomes zero. Again, this is because of data censorship. In reality each unit of quota should have a positive marginal effect, although diminishing with quota size. The differences in these curves, across the high, medium, and low departments, are due to the different probabilities of success across departments as a reflection of the program quality.

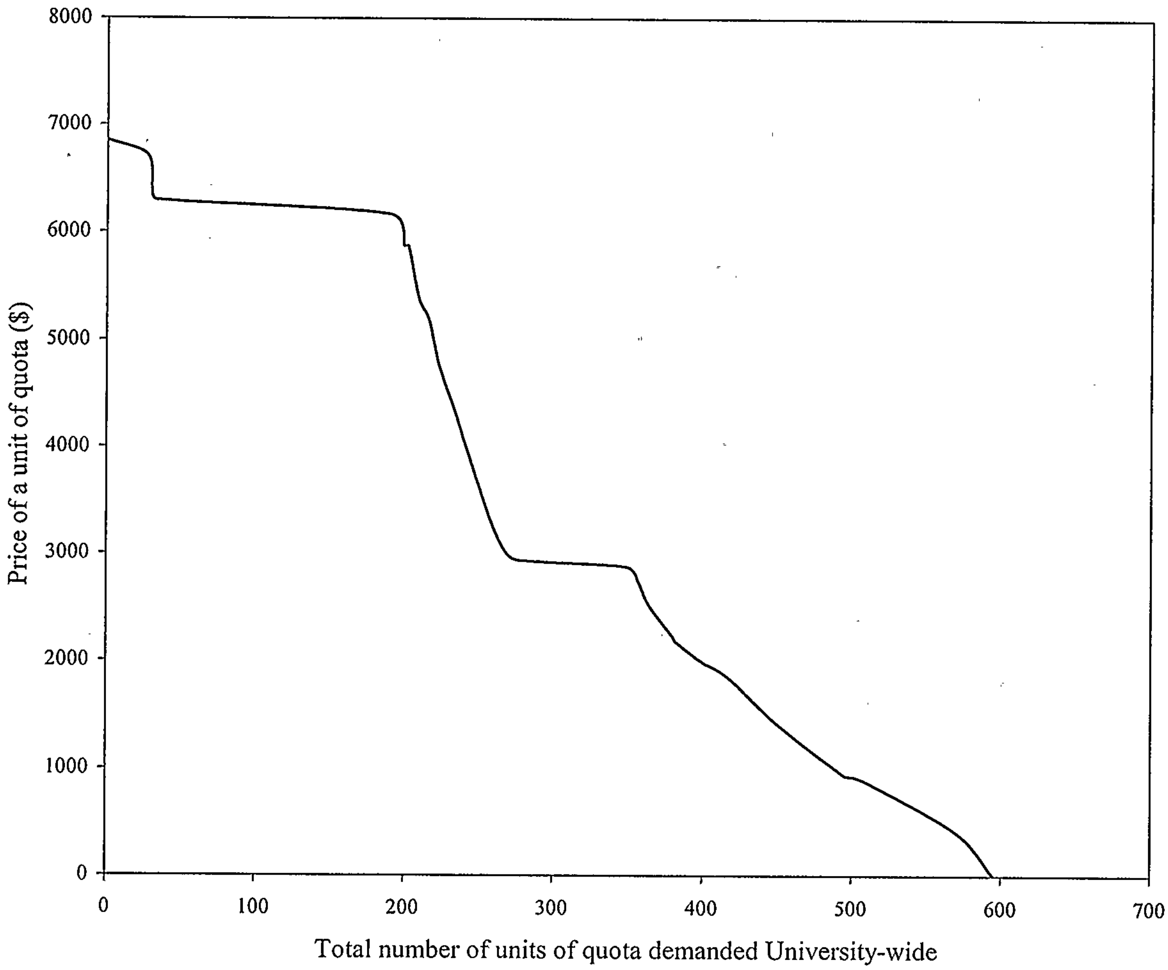
Figure 5.2 Marginal effect of each unit of quota on expected number of students ranked in Model 1



From this graph, each department's willingness to pay for a particular unit of quota can be determined. Assuming the average value of an award is $10,000, multiplying the marginal effect of each unit of quota by $10,000 gives the expected dollar value to be earned from each unit of quota, the ex ante value. This ex ante value represents the amount a department would be willing to pay for that specific unit of quota as it represents the dollar value they expect to earn from it.

Using these ex ante values along with departmental budget constraints, each department's demand curve for quota is obtained. Aggregating these curves appropriately gives the aggregate University-wide demand for quota, which is shown in Figure 5.3. Integer-constrained quotas and the broad department categorization cause the predicted University-wide demand curve to be discontinuous. Since department's expectations are continuous they have continuous demand. But quota size is discontinuous as it is constrained to integer values. Therefore certain price ranges exist for which demand remains unchanged. Within these ranges there are vertical discontinuities in the total demand curve. Also, departments are broadly categorized in this model. The demand schedules for each department within a particular categorization are the same. So, at the limits of these price ranges, demand for quota can change by a substantial amount, since numerous departments lie in each categorization and follow the same demand schedule. This categorization causes the horizontal gaps in the aggregate demand curve. As well, at a price of zero demand should be infinite, but due to data censorship the estimated marginal effect of a unit of quota reaches zero for high quotas and University-wide demand is satiated at 600 units of quota.

Figure 5.3 Total University-wide demand for quota in Model 1 given 2003 allocation



A second model containing a full set of dummy variables for the 35 departments represented in the data was estimated. Many of the estimated coefficients of the departmental dummy variables were found to be statistically equivalent.[11] So, the departments were grouped accordingly into five statistically significant classifications and the model was re-estimated with five department dummy variables. The results of this estimation are shown in Table 5.3.

[11] At first glance it was obvious that many of the estimated departmental dummy variable coefficients were equivalent, as they were very close in numeral value. Departments were grouped according to their similar coefficients. The likely combinations were tested iteratively and a five group combination was chosen as it produced the best test statistics for coefficient equivalency.

The department classifications, D1, D2, D3, D4 and D5, which are based on the equivalence of department coefficients, have the following characteristics. The first group, D1, is made up of low quota departments with little success in winning awards. D2 departments have a medium level of quota with little success in winning awards. The D3 departments have medium quota levels and moderate success at winning awards. D4 is made up of departments with high levels of quota and moderate success at winning awards. The last classification, D5, contains departments with high quota levels and nearly complete success in winning awards[12].

This second set of regressors is found to be jointly significant, and the null hypothesis is rejected with a p-value less than 0.0001 ($\chi^2(6)$=404.11). They are also more successful in explaining the variation in scholarship assignment than the original model (Pseudo R^2=0.378[13]).

Table 5.3 Estimated Poisson parameter of Model 2

Coefficient	Estimated Value	Standard Error
β_0	-0.862	0.233
β_1	0.124	0.062
β_2	-0.002	0.002
θ_{D2}	1.38	0.187
θ_{D3}	1.68	0.223
θ_{D4}	1.78	0.284
θ_{D5}	1.85	0.273

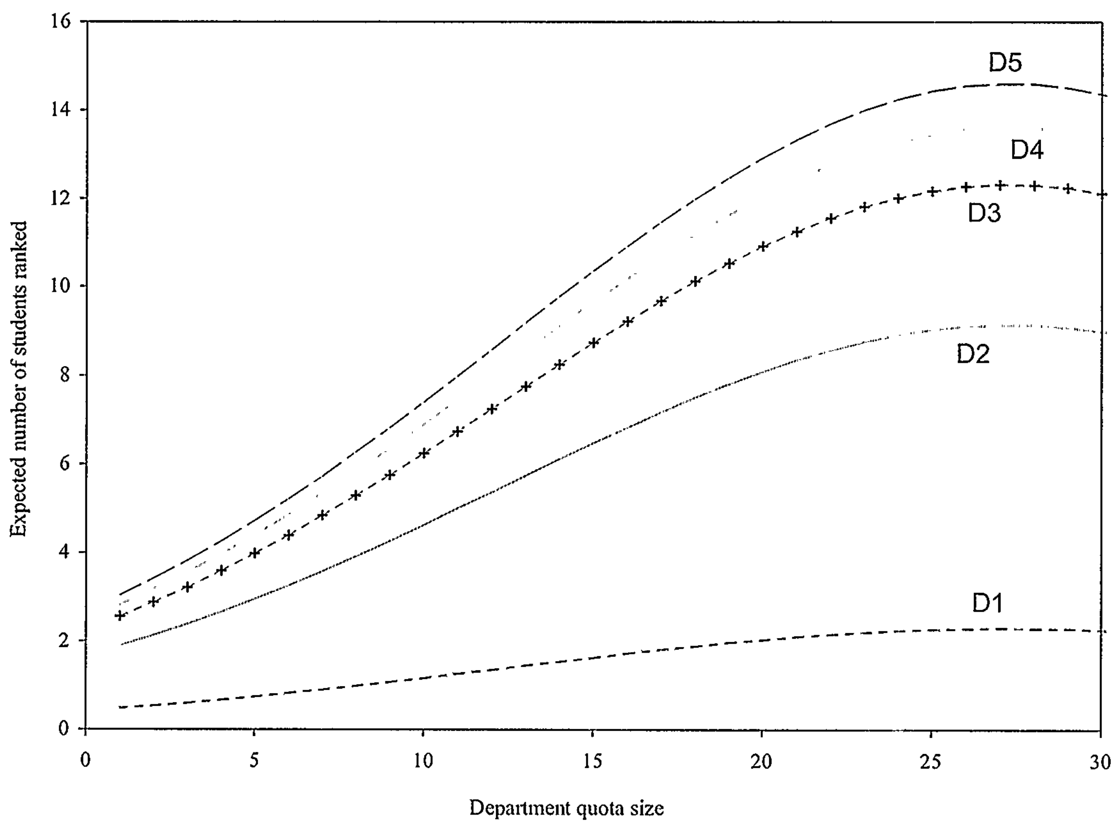
Comments and comparisons can be made concerning these estimated coefficients. The signs of β_0, β_1 and β_2 all correspond to those of the estimates from the previous model.

[12] COMS, DRAM, ECON, FISL, MDGI, MDMI, MGMT, MTST, MUSI, and SOWK are included in D1 and their coefficients are equal with a p-value of 0.9054. CPSC, ENCI, ENCP, GLGP, MDCH, MDCV, MDNS, MDSC, NURS, PHAS, POLI, RELS, and SOCI are included in D2 and their coefficients are equal with a p-value of 0.9687. ANTH, CPSY, ENEC, GEOG, MDBC, PHIL, and PSYC are included in D3 with ENGL and their coefficients are equal with a p-value of 0.9739. D4 consists of ARKY and CHEM and their coefficients are equal with a p-value of 0.8868. BISI and HIST make up D5 and have equal coefficients with a p-value of 0.8334. The classifications were chosen by maximizing the five different p-values. The departments with coefficients on the limits of the classification ranges were tested in both neighboring classifications, with the highest p-value determining its classification. This simple process was carried out instead of testing every possible combination as some combinations were obviously inaccurate.
[13] Again, the Pesudo R^2 is a measurement of fit, an equivalent to the R^2 from linear regression models. The Pesudo R^2 presented here is a likelihood ratio index (Greene, 2003).

The quota coefficient, β_1, is greater than zero but smaller than that of Model 1, implying that the new department coefficients explain a larger portion of the department's success in the competition. This comment is confirmed upon comparison of the specific department coefficients with the high, medium and low coefficients, the former being larger.

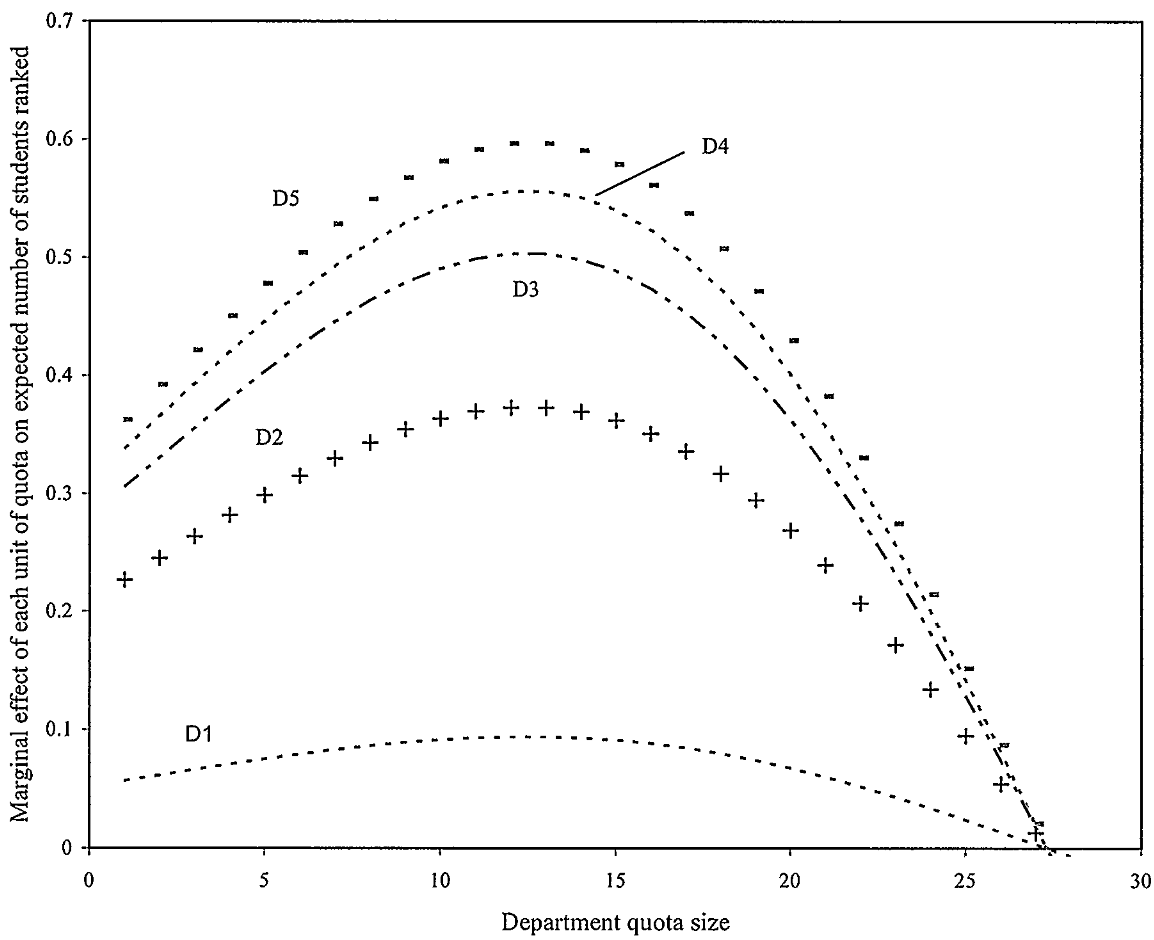
The second model gives graphs that are similar in shape to those produced by the first model's estimates (Figure 5.1, 5.2, 5.3). Below, in Figure 5.4, the expected number of ranked students for each department type is plotted against quota size. This graph presents the number of awards each department type can expect to receive given their quota size. The number of ranked students increases with quota size until it reaches twenty-seven. Again, this is due to data censorship.

Figure 5.4 Expected number of students ranked within a department under various quota sizes



The marginal effect of each unit of quota on expected number of ranked students for each department type is plotted in Figure 5.5. These curves represent the amount each unit of quota increases the expected number of ranked students.

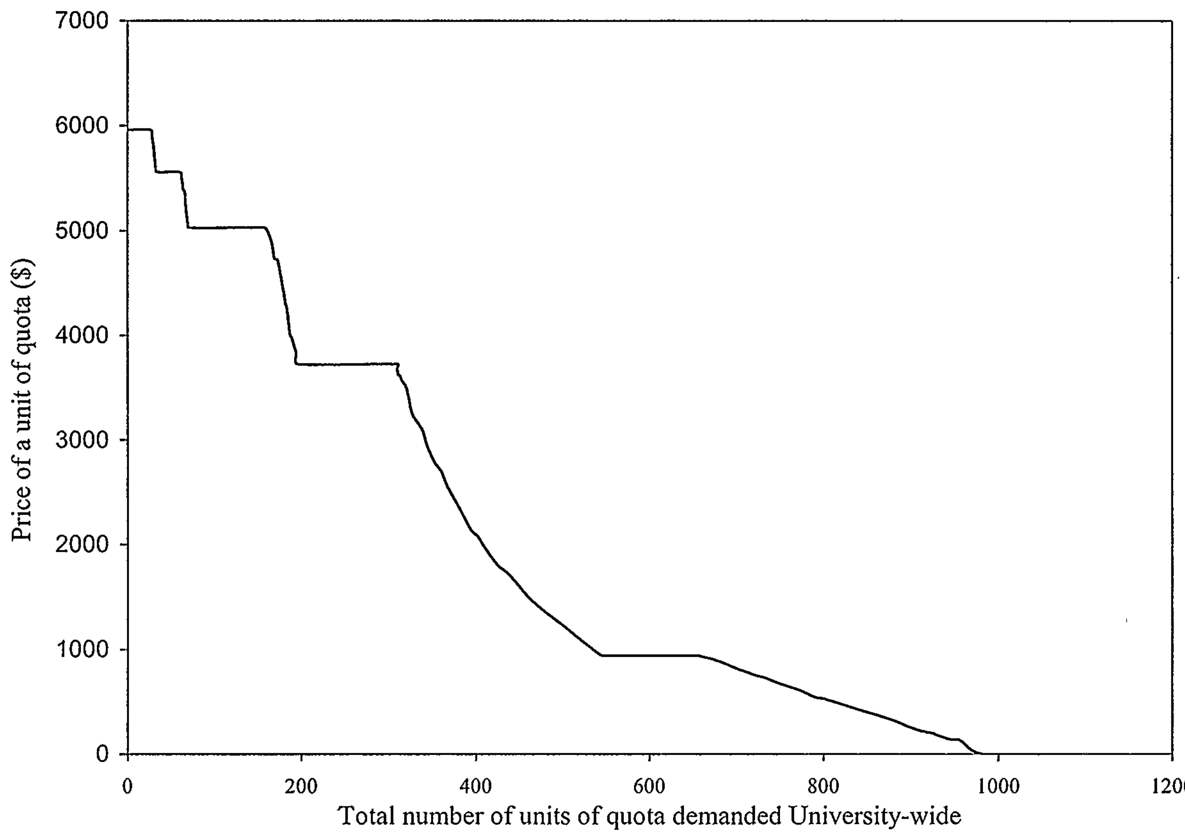
Figure 5.5 Marginal effect of each unit of quota on expected number of students ranked in Model 2



Again, these curves are transformed into demand curves by converting the marginal effect of each unit of quota on the number of students ranked into a dollar value, which in turn represents the department's willingness to pay for the additional quota. This can be done by multiplying the effect of the unit of quota by the value of a ranked student, $10,000.

Appropriately aggregating these demand curves and considering each department's budget gives the University-wide demand for quota. This aggregation is shown below in Figure 5.6. This University-wide demand curve is again discontinuous because of integer constraints and broad department categorizations, as described with Figure 5.3.

Figure 5.6 Total University-wide demand for quota in Model 2 given 2003 allocation



These estimated expectations and demands will be used to calculate the amount of funding a department expects to receive with and without tradable quotas. More importantly, I will use these expectations to determine how many units of quota each department should trade given different circumstances.

CHAPTER 6

MAXIMIZING EX ANTE FUNDING

Recognizing the maximum amount of student quality, that is maximizing the ex ante value of funding, from the open scholarship competition, is discussed in the following section. First the Faculty of Graduate Studies' maximization problem is considered. This is followed by the individual department's challenge of maximizing ex ante funding.

6.1 Maximizing the Ex Ante Value of Graduate Program Funding

All the awards within the open scholarship competition are distributed internally within the University. While the total dollar value of funding distributed through the competition is fixed, the amount of student quality assessed or rewarded through the competition is not. The students entered into the competition will be of varying qualities. It is the University's goal to have the highest quality students entered into the competition and therefore rewarded. By rewarding the application quota with the highest probability of success, in other words the highest quality applicant, the maximum quality will be awarded. This implies that by maximizing the overall ex ante value of funding from the competition, which is the sum of each applicant's probability of success multiplied by the value of the award, the quotas are going to students with the highest probability of success and the best students, University-wide, are entered into the competition. Given efficient ranking of all the applicants, the maximum amount of student quality is being rewarded by the University with the limited amount of funding in the competition.

So, from the University's perspective, to maximize the quality of students rewarded, a sensible goal would be to maximize the ex ante funding from the open scholarship competition net the cost of effort involved in assessing and ranking applications. That is, they would ensure that scholarships went to the best students by maximizing the following

$$\sum_{i=1}^{N} Ar(Q_i) - C(Z)$$

$$where\ Z = \sum_{i=1}^{N} Q_i$$

with the choice of Q_i and similarly Z. Here, $Ar(Q_i)$ represents the ex ante value of funding for department i, where $r(Q_i)$, the Poisson expectation of the number of students ranked calculated in the previous chapter, expresses each department's expected success given their level of quota, Q_i, and A is the average value of an award. C(Z) is the total cost function of assessing applications.

The first order conditions for this maximization are

$$Ar'(Q_i) = Ar'(Q_j) = C'(Z) \qquad \forall i = 1...N, j = 1...N.$$

These conditions give both the optimal level of aggregate quota, Z*, and the optimal allocation of quota across departments, Q_i*. With these optimal values, the marginal value of an additional unit of quota is equalized across departments, and that common marginal value is equal to the marginal assessment cost associated with an additional unit of quota.

While it is theoretically possible to find Z* and C(Z*), in practice it will be difficult to determine C(Z). The alternative is for the University to simply set the aggregate quota at a feasible level, Z=Ž, and then maximize the expected funding subject to the constraint Z $\leq$ Ž. The first order condition above then becomes

$$Ar'(Q_i) = Ar'(Q_j) = P$$

where P is the shadow price of the constraint on the aggregate quota.

Once the aggregate quota (Z* or Ž) has been determined, there is still the question of obtaining the optimal allocation of quota across departments. With enough information it is possible for the University to impose the optimal allocation. However, this information is extremely costly to acquire and filled with uncertainty, as mentioned previously. The efficient alternative is to allow departments to trade units of quota, using GRS funding as the currency. In a quota trading system, 'risk-neutral' departments will trade to the point

$$Ar'(Q_i) = Ar'(Q_j) = P$$

where P is the equilibrium price for a unit of quota. In a market with unrestricted trading, the optimal allocation will be achieved through trade regardless of the initial allocation of quota among departments. The only difference will be the distribution of wealth across departments.

6.2 Maximizing Department Ex Ante Expected Funding

Each department's funding of concern will be the dollar sum of expected open scholarship revenue and graduate research scholarships

$$A \cdot r(Q_i) + G \cdot N_i$$

The first term represents the ex ante open scholarship funding department i expects to receive, $r(Q_i)$ being the Poisson expectation of awards to be won by department i given their quota, Q_i, and A denoting the dollar value of these awards. The second term gives the dollar value of graduate research scholarships (GRS) department i will receive, where N_i is the number of GRS units department i obtains and G represents the dollar value of a GRS unit.

If departments are allowed to trade units of quota they will choose Q_i to maximize their expected funding, trading GRS funding for units of quota. The choice variables in this maximization problem are Q_i, quota size and N_i, the number of GRS units. This maximization is constrained by the department's endowed funding, defined by the initial allocation of units of quota, $\overline{q}_i$, the price of a unit of quota P, the allocated number of GRS units $\overline{n}_i$ and the dollar value of a unit of GRS, G. This constraint is given by

$$G \cdot N_i + P \cdot Q_i \leq P \cdot \overline{q}_i + G \cdot \overline{n}_i$$

The maximization problem can then be written as the following Lagragian equation

$$\max_{Q_i, N_i} L = (A \cdot r(Q_i) + G \cdot N_i) + \lambda_i [P \cdot \overline{q}_i + G \cdot \overline{n}_i - G \cdot N_i - P \cdot Q_i]$$

$$\textit{subject to } N_i \geq 0$$

The non-negativity of N_i is included because in this system departments are constrained by their present budget, they are not able to borrow future units of GRS from the Faculty of Graduate Studies, nor can they use funds from any other source. This constraint is relaxed in the next section to calculate the optimal level of quota for each department. There could also be a constraint to ensure the non-negativity of Q_i, however, it is assumed that departments cannot sell more units of quota than they are endowed.

The first order condition of this maximization with respect to Q_i is

$$Ar'(Q_i) - \lambda_i P = 0$$

and with respect to λ_i is the department's budget constraint

$$G \cdot N_i + P \cdot Q_i = P \cdot \overline{q}_i + G \cdot \overline{n}_i$$

which is assumed to hold with equality.

The Kuhn-Tucker maximization conditions (Kuhn and Tucker, 1951) from the non-negativity restriction include

$$\partial L / \partial N_i = G - \lambda_i G = G(1 - \lambda_i) \leq 0$$

implying that $1 - \lambda_i \leq 0$ since G >0

$$N_i \geq 0$$

$$N_i \cdot \left(\partial L / \partial N_i \right) = N_i (1 - \lambda_i) = 0$$

Together these yield the necessary first order conditions:

$$A \cdot r'(Q_i) \geq P$$

$$N_i \geq 0$$

$$N_i \cdot (A \cdot r'(Q_i) - P) = 0$$

$$G \cdot N_i + P \cdot Q_i = P \cdot \overline{q}_i + G \cdot \overline{n}_i$$

The first condition implies that at the constrained maximum, the dollar value of each department's marginal unit of quota should be larger than or equal to its price. Intuitively this follows from departments choosing the highest valued use for each of their units of quota. The second condition reiterates the fact that a department's choices are constrained by their budget. They are only allowed to buy as many units of quota as their GRS budget supports. The third condition ensures that, of the two inequalities, at least one holds with equality, guaranteeing that departments choose their quota at a point where either they are indifferent to submitting another applicant given the price of doing so or they have exhausted their GRS budget. The final constraint is the department's budget.

Given these conditions, two cases need to be considered for each department in order to find their optimum quota. In the first case, the department is able to purchase as many units of quota as they choose, without exhausting their GRS budget. In this situation the following two first order conditions hold:

$$Ar'(Q_i) = P$$
$$G \cdot N_i + P \cdot Q_i = P \cdot \overline{q}_i + G \cdot \overline{n}_i$$

Solving

$$Ar'(Q_i) = P$$

for Q_i gives the department's demand function for quota which maximizes expected funding for any specified A and P, $Q_i^*(A,P)$. For an assumed A and P the optimal quota, $Q_i^*(A, P)$, can be inserted into the budget constraint to determine the corresponding optimal number of GRS units, $N_i^*(A,P)$. These two values, Q_i^* and N_i^*, represent the optimal choices for department i given a scholarship is worth A and a unit of quota trades at price P. Putting these optimal values into the objective function gives the department's maximum expected funding for the specified P and A:

$$A \cdot r(Q^*_i) + G \cdot \overline{n}_i - P(Q^*_i - \overline{q}_i)$$

The difference $(Q^*_i - \overline{q}_i)$ indicates the number of quota units a department desires to trade. If this difference is negative, then units of quota are traded for GRS funding and the department is a net supplier of units of quota to the competition. If the term is positive, then units of quota are purchased and the department is a net consumer of units of quota.

Now, in the second case, the department is constrained by its budget, limiting the number of units of quota they can purchase, giving the following three first order conditions:

$$N_i = 0$$
$$Ar'(Q_i) > P \text{ and}$$
$$G \cdot N_i + P \cdot Q_i = P \cdot \overline{q}_i + G \cdot \overline{n}_i$$

Here, the budget constraint can be used to solve for the constrained optimal level of quota, $\overline{Q}_i(P, \overline{q}_i, \overline{n}_i)$. This serves as the department's demand for quota as a function of P. Using this value in the objective function, the department's constrained maximum expected funding for a specified A and P is

$$Ar(\overline{Q}_i) + G\overline{n}_i - P(\overline{Q}_i - \overline{q}_i)$$

The difference $(\overline{Q}_i - \overline{q}_i)$ indicates the number of desired trades which are affordable to the department.

6.3 Equilibrium prices and optimal quotas

By combining the two maximization problems presented in the two previous sections, the equilibrium price at which quotas are traded and the constrained optimal level of quota for each department can be determined. The problem is characterized by the following conditions:

$$A \cdot r'(Q_i) \geq P$$
$$N_i \geq 0$$
$$N_i \cdot (A \cdot r'(Q_i) - P) = 0$$
$$G \cdot N_i + P \cdot Q_i = P \cdot \overline{q}_i + G \cdot \overline{n}_i$$
$$\sum_{i=1}^{n} Q_i = \breve{Z} \qquad \text{for i=1...n departments}$$

The first four conditions represent the first order conditions from each department's constrained maximization problem. The last equation ensures that total quota remains at the chosen level, $\breve{Z}$, bringing the University's maximization problem into consideration.

Using 2003 data and simultaneously solving these equations, the outcome of the hypothetical tradable quota system is estimated. These results are used to illustrate the efficiency gains of a tradable system.

The task of simultaneously solving the equations is not as straightforward as it may seem. The optimization condition

$$A \cdot r'(Q_i) = A(\beta_1 + 2 \cdot \beta_2 \cdot Q_i)e^{\beta_0+\beta_1 \cdot Q_i+\beta_2 \cdot Q_i^2+\sum \theta_i D_i^j} \geq P$$

is a normalized quadratic and has only non-algebraic solutions. This implies that solving this system of equations using conventional matrix algebra is impossible and numerical methods must be used. Each variable, P and Q_i, are found by iteratively solving the set of equations until an acceptable solution is reached. The pre-determined demand curves (Figures 5.3 and 5.6) give insight into worthy starting points. As each quota is constrained to an integer value and departments are categorized together, demand for quota is discontinuous and the aggregate quota for which there is an equilibrium price is restricted to certain values[14].

In this iterative calculation, A, the dollar value of an award won in the open scholarship competition, is taken to be \$10,000, G, the dollar value of a unit of GRS in 2003 is \$4000 and $\breve{Z}$, the aggregate quota in 2003, is 203.

Model 1, with the high, medium and low department classification, is considered first. Using the estimated marginal Poisson expectations, the 2003 quota allocations, and the 2003 aggregate quota of 203, \$5870 (\$5865.76-\$5875.33) is the equilibrium price for a unit of quota. The constrained optimal quota for each department at this equilibrium price is given in Table 6.1.

At this price, low quota departments choose to sell all three of their units of quota. They are in a position to receive more funding through the sale of their quota than they expect to receive by submitting applications into the competition. From Figure 5.1, three units of quota for the low quota departments is expected to yield only one ranked applicant, or \$10,000 in funding for the successful students.[15] In contrast selling the three units of quota generates \$17,620, which can be allocated to one or more students. Medium departments wish to acquire ten units of quota, but can purchase only as many as they can afford. High departments wish to enter 12 applications. Initially the high quota

[14] As explained in Section 5.3 with Figure 5.3.

[15] It may turn out that in a given year the department will actually generate zero, two or even three ranked (i.e funded) applicants, but ex ante, history predicts that the department can expect to receive one award.

departments were allocated more than 12 units of quota, so the high quota departments, ARKY, CHEM and ENGL, will choose to sell off excess units of quota. With only so many high quality students within the department, as application numbers increase the quality of the marginal applicant decreases. Overall high and low quota departments are sellers and medium quota departments are buyers.

At this price, the system allows the low valued units of quota to be sold to departments who have a higher valuation of them, implying that purchased units of quota are used to enter high quality students into the competition that otherwise would not have been selected. This is an overall Pareto improvement; a department gains expected funding without making any other department worse off. Low quality departments are guaranteed an amount of funding higher than their initial expectation, departments purchasing units of quota are able to increase their expected funding and additional student 'quality' is assessed and rewarded through the system. These improvements will be investigated further in the next chapter.

If it is assumed that departments are able to borrow future GRS units, or use another source of funding, to purchase units of quota, allowing the budget constraint to be relaxed, the unconstrained optimal level of quota for each department can be reached. This optimal quota for each department, at an equilibrium price of $5870, is presented in Table 6.2. These optimal quotas will be used to calculate the optimal level of expected funding that can be reached, which can then be used to determine the cost of the budget constraint on trading efficiency.

Table 6.1 Constrained optimal quota in Model 1 given the 2003 quota allocation and quota price of $5870

Department	2003 Allocated Quota	Department Classification	Constrained Optimal Quota
ANTH	6	Medium	7
ARKY	14	High	12
BISI	10	Medium	10
CHEM	13	High	13*
COMS	3	Low	0
CPSC	6	Medium	8
CPSY	7	Medium	10
DRAM	3	Low	0
ECON	3	Low	0
ENCI	6	Medium	10
ENCP	5	Medium	7
ENEC	5	Medium	8
ENGL	18	High	12
FISL	3	Low	0
GEOG	8	Medium	9
GLGP	3	Low	0
HIST	10	Medium	10
MDBC	8	Medium	10
MDCH	3	Low	0
MDCV	5	Medium	6
MDGI	3	Low	0
MDMI	3	Low	0
MDNS	5	Medium	7
MDSC	4	Medium	7
MGMT	3	Low	0
MTST	3	Low	0
MUSI	3	Low	0
NURS	5	Medium	6
PHAS	4	Medium	6
PHIL	7	Medium	10
POLI	4	Medium	7
PSYC	7	Medium	10
RELS	5	Medium	10
SOCI	5	Medium	8
SOWK	3	Low	0
TOTAL	203		203

* CHEM's trades were restricted to ensure the system cleared

Table 6.2 Optimal quota in Model 1 given the 2003 quota allocation and quota price of $5870

Department	2003 Allocated Quota	Department Classification	Optimal Quota
ANTH	6	Medium	10
ARKY	14	High	11*
BISI	10	Medium	10
CHEM	13	High	11*
COMS	3	Low	0
CPSC	6	Medium	10
CPSY	7	Medium	10
DRAM	3	Low	0
ECON	3	Low	0
ENCI	6	Medium	10
ENCP	5	Medium	10
ENEC	5	Medium	10
ENGL	18	High	11*
FISL	3	Low	0
GEOG	8	Medium	10
GLGP	3	Low	0
HIST	10	Medium	1*
MDBC	8	Medium	1*
MDCH	3	Low	0
MDCV	5	Medium	1*
MDGI	3	Low	0
MDMI	3	Low	0
MDNS	5	Medium	7*
MDSC	4	Medium	10
MGMT	3	Low	0
MTST	3	Low	0
MUSI	3	Low	0
NURS	5	Medium	10
PHAS	4	Medium	10
PHIL	7	Medium	10
POLI	4	Medium	10
PSYC	7	Medium	10
RELS	5	Medium	10
SOCI	5	Medium	10
SOWK	3	Low	0
TOTAL	203		203

* Trades were restricted to ensure the system cleared

Determining the equilibrium price and the optimal quotas of the second model is not as straight forward. There is a large discontinuity in demand near the aggregate limit of 203 (See Figure 5.6). At a price of $3726 ($3725.79- $3726.85) overall demand is 310 units of quota. However, if price increases marginally (above $3726.85) all D2 departments choose not to enter the competition and instead sell their assigned quota, decreasing aggregate demand to 196 units. Therefore, 196 units is the aggregate demand closest to 203 units for which there is an equilibrium price. At a price of $3827, D1 and D2 departments sell all their units of quota; again they are in a position to receive more guaranteed funding through the sale of their units of quota than they expect to obtain from the competition. D3 departments demand 20 units of quota, D4 demands 21, and D5 departments demand 22 units of quota. The constrained optimal quota for each department, at the equilibrium price of $3827, is given in Table 6.3. Seven trades were restricted to rectify the surplus of units of quota that would remain in the system otherwise. The restrictions were placed on departments who had the highest value for the marginal unit of quota they wished to sell. The impacts of all trades on the efficiency of the open scholarship competition will be discussed in the following chapter.

The unconstrained optimal quotas will not be reported for Model 2. The different equilibrium prices for the various allocation methods make comparing the results difficult.

The equilibrium prices determined here are specific to the information used to calculate them. Because fractional units of quota were not allocated or allowed to be traded, different initial allocation rules resulted in some variation in the aggregate quota. This change in the supply of quotas for trade resulted in different equilibrium prices. The equilibrium prices for each of the allocation methods under consideration have been calculated individually; they are not discussed but are given in the corresponding expected funding table in the Appendices.

The Faculty of Graduate Studies has control over total quota. Determining the optimal level of aggregate quota is a complicated task.[16] The price of a unit of quota is a dynamic value dependent upon the quota market; given that the Faculty of Graduate Studies controls both the aggregate number of quota units and the allocation of quota units, they will have some power to influence the price. However, expectations made by each department will be fairly unknown to the Faculty of Graduate system. As discussed earlier with the command and control approach, the information required to set such a price optimally is complex and most likely unattainable.

[16] The optimal level of aggregate quota being the value at which the marginal assessment cost associated with the additional unit of quota is equal to each department's marginal value of an additional unit of quota once all ex ante funding maximizing trades have been made.

Table 6.3 Constrained optimal quota in Model 2 given the 2003 allocation and quota price of $3827

Department	2003 Allocated Quota	Department Classification	Constrained Optimal Quota
ANTH	6	D3	8
ARKY	14	D4	21
BISI	10	D5	22
CHEM	13	D4	21
COMS	3	D1	0
CPSC	6	D2	2*
CPSY	7	D3	20
DRAM	3	D1	0
ECON	3	D1	0
ENCI	6	D2	2*
ENCP	5	D2	1*
ENEC	5	D3	10
ENGL	18	D3	20
FISL	3	D1	0
GEOG	8	D3	9
GLGP	3	D2	0
HIST	10	D5	20
MDBC	8	D3	13
MDCH	3	D2	0
MDCV	5	D2	1*
MDGI	3	D1	0
MDMI	3	D1	0
MDNS	5	D2	1*
MDSC	4	D2	0
MGMT	3	D1	0
MTST	3	D1	0
MUSI	3	D1	0
NURS	5	D2	0
PHAS	4	D2	0
PHIL	7	D3	14
POLI	4	D2	0
PSYC	7	D3	18
RELS	5	D2	0
SOCI	5	D2	0
SOWK	3	D1	0
TOTAL	203		203

* These trades were restricted in order to clear the market.

CHAPTER 7

ESTIMATED IMPACTS OF TRADABLE QUOTAS

Using the constrained optimal quotas and equilibrium prices calculated in Chapter 6, the potential changes in ex ante funding due to the implementation of tradable quotas into the open scholarship competition are estimated. Three alternative allocations of quota are considered. I discuss the numerical results in the first section of this chapter and further implications of these results in the second section.

7.2 Estimated impacts to expected funding

The estimated ex ante funding for each allocation method is given in Appendix A or B, with each Appendix corresponding to one of the two Poisson regression models. The current quota allocation system is considered along with quotas proportional to enrollment numbers, an allocation method which is somewhat reflective of departmental quality and equal quotas, an allocation that is in no way reflective of department quality. There are several central results present throughout the scenarios.

First, under all three allocation methods there is a positive increase in the University's total ex ante or expected funding given the implementation of tradable quotas. Recall that all the funding in the open scholarship competition is distributed internally, so this positive change in the overall value of ex ante funding represents the increased probability of the applicants entered into the competition with purchased quotas. This implies that, overall, application quotas are going from students with low probability of success to students with a higher probability of success, or equivalently higher quality. A department will choose to sell a unit of quota if the ex ante funding from the unit of quota is lower then the equilibrium price.

The overall increase in ex ante funding in Model 1, due to tradable quotas, ranges from \$92,526 with the current allocation to \$219,264 with equal quotas. The range of these values reflects the volume of trades. Each department's change in expected funding represents units of quota flowing from low probability or low quality applicants to higher probability applicants. The price of the unit of quota is the benchmark by which the department bases trading decisions.

As mentioned previously, under perfect conditions, no matter what the initial allocation, trade should allow for the efficient outcome to be reached. Therefore, for each quota allocation method the same total ex ante funding should be reached through trade. Model 1 delivers this result. Initially, the total expected funding with the current allocation in Model 1 is estimated at $1,975,606 and the total expected funding with quotas proportional to enrollment in the same model is $1,933,851. If quotas are traded, total expected funding in these cases increase to the similar values of $2,068,132 and $2,065,113, respectively. The third allocation of equal quotas in Model 1 has a higher overall ex ante funding since 210, instead of 203, units of quota are allocated through this method[17]. If the additional seven quotas are assumed to be valued on the margin at $5,870, subtracting their value from the overall ex ante funding after trade results in $2,068,082 of expected funding. This value is comparable to those of the other two allocation methods. This result is not apparent in the Model 2 results. The varying aggregate quotas and the different equilibrium prices make the overall ex ante funding incomparable.

The impact of trade, or the difference between the initial overall ex ante funding and the overall ex ante funding reached through trade, gives a measure as to the distance of the initial allocation from the constrained optimal allocation. The figure below presents these values for each allocation. Recall that the absolute amount of funding distributed through the open scholarship competition remains unchanged. What is represented here is the aggregation of each department's expected funding, before and after trade. The positive change in overall expected funding represents higher quality applicants displacing lower probability applicants with purchased application quotas in the competition.

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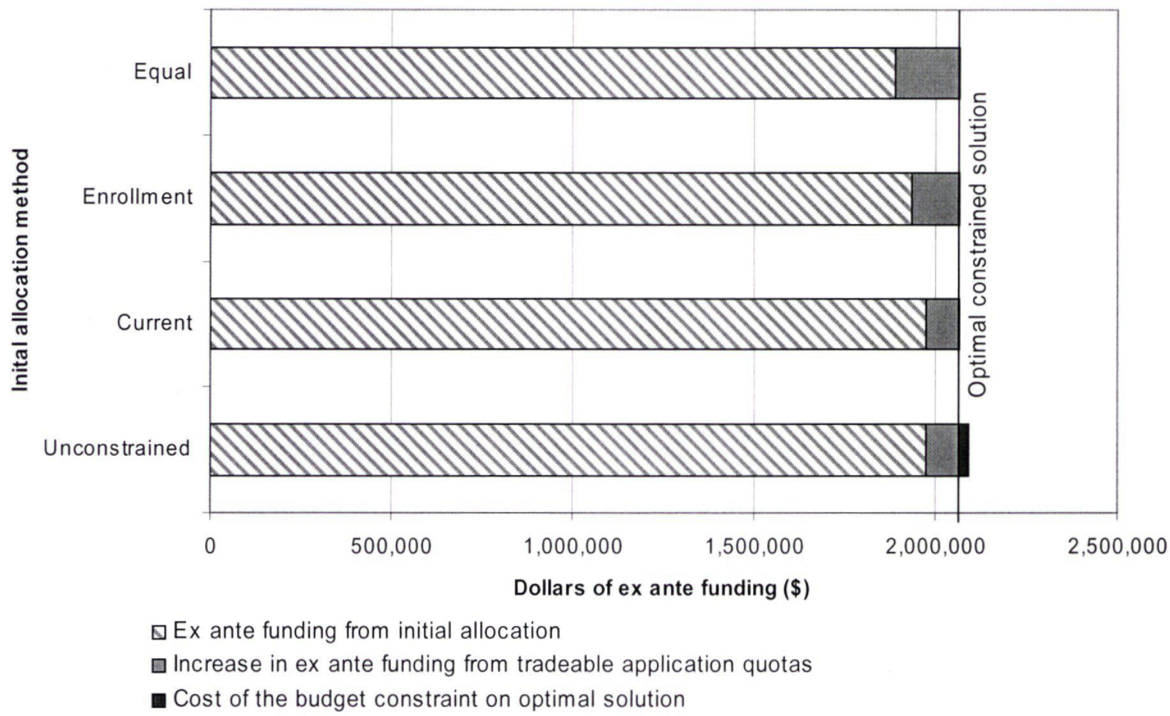
[17] Quotas are constrained to integer values, so aggregate quota for the equal allocation method must be divisible by 35, the number of departments.

Figure 7.1 Impacts of tradable quotas on total ex ante funding under each method of allocation for Model 1



The optimal constrained solution is reached through trading application quotas and represents around $2,068,000 of ex ante funding. The growing distance of the initial ex ante funding from the optimal as we move from the current allocation system, to enrollment based allocation and then to equal allocation depicts the growing impact of trade on expected funding. Implying that of the three allocations the current method is closest to the optimal and therefore recognizes student quality better than an enrollment based allocation or an equal allocation. This is expected; however, the increase of $92,526 in Model 1 and $77,184 in Model 2 to ex ante funding with the current allocation given trade implies that the current allocation system is not the constrained optimum.

Comparing the impact of trade on total ex ante funding given the budget constrained current allocation (Current) and the unconstrained current allocation (Unconstrained) implies that departmental budgets restrict trading from reaching the true optimum of $2,092,134 in Model 1. This cost of the budget constraint is shown in Figure 7.1.

The robust increase in ex ante funding given the implementation of a tradable system implies that there are benefits to trading quotas; the overall quality assessed by the competition is increased by trade. However, other issues remain within the system. The method of allocating the initial quotas and similarly GRS units, which can be used to purchase quota, determine the distribution of wealth across departments. The allocation therefore impacts the competition's success in rewarding departmental improvements.

7.3 Further implications and benefits

The tradable quota system within the open scholarship competition reduces the difficulty of the task that the competition faces in discriminating between applicants of varying quality. Given the current allocation method, tradable quotas allow for departments to communicate their improvements to the Faculty of Graduate Studies quicker through purchasing quotas for their high quality students.

The lesser issue of time being spent reviewing applications is not resolved through allowing departments to trade quotas. This depends on the aggregate limit set by the Faculty of Graduate Studies. The time spent by faculty reviewing applications is a function of the aggregate quota. The limit set by the Faculty of Graduate Studies needs to be high enough to retain competition among entrants, but low enough to control the costs of the competition.

There are several further benefits not represented in the overall change of ex ante expected funding. A department altering from their expected behaviour, by perhaps retaining a unit of quota instead of selling them all, gives a credible signal to the open scholarship committee of the applicant's quality. This is an efficiency gain to the system, allowing the tradable system to supply additional information into the competition.

A tradable system would, however, add an additional step to the open scholarship process. Departments would have to assess their students prior to the competition to determine how many applications they wish to enter into the competition and adjust their quota accordingly, by informing the Faculty of Graduate Studies how many units of quota they wish to buy or sell.

CHAPTER 8

DISCUSSION AND CONCLUSIONS

This thesis proposes a method to improve the effectiveness of the open scholarship competition in rewarding student quality and similarly rewarding departmental improvements. By enabling departments to trade application quotas for units of GRS an efficient solution to rewarding quality can be obtained, assuming perfect market conditions and risk neutral departments. In principle, quotas will flow to the highest quality students, implying an equalized marginal value of quota across all departments.

A dead weight loss of $92,526 in ex ante funding was found in the present system. This value is the difference between the amount of funding expected by departments in the current system through the initial allocation and that which would be expected if quotas were tradable. This implies that if unit of quotas were tradable, quality student, who otherwise could not be entered, would be entered into the competition through purchased application quotas, increasing the ex ante funding from the competition.

Such a tradable system would enable departments to purchase or sell quotas as they saw fit given their eligible students, and reduce their need to rely on the Faculty of Graduate Studies' allocation decisions. A tradable system will allow more information concerning department quality to be communicated to the Faculty of Graduate Studies at no extra cost. Departments would have more flexibility in attracting high quality students by knowing they can purchase a unit of quota if necessary.

Simulating the results of a tradable quota system in the open scholarship competition brings about a Pareto improvement in all cases. The magnitude of the improvement brought about through trade increases with the initial allocation's distance from the efficient solution. The calculated deadweight loss could be as high as $116,528 in ex ante funding if departmental budget constraints were removed.

A remedy to increase the efficiency of the system was presented. By allowing departments to trade quotas, additional student quality is rewarded and departments have more incentive to promote internal improvements. Implementing tradable quotas alone will not, however, solve all of the issues with the open scholarship competition. An improved method of allocating initial quotas will need to be determined. The cap on the total aggregate quota distributed to departments may also need to be reconsidered to reduce any excessive time spent reviewing applications.

Tradable permits have proven successful in emissions (Joskow, et al., 1998) and fisheries (Grafton, 1996) settings. While tradable quotas show promise for achieving higher quality graduate programs with limited funding, future research could assess their feasibility in the open scholarship competition by developing an experimental market and testing it in the University of Calgary's Behavioural and Experimental Economics Laboratory.

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APPENDIX A

MODEL 1 FUNDING RESULTS

Table A.1 Expected funding given the 2003 quota allocation and equilibrium price of $5870

Department	Existing Quota (q_i)	Expected Funding with Given Quota (EF_0)	Constrained Optimal Quota (Q_i)	Number of Trades (Q_i-q_i)	Expected Funding with Constrained Optimal Quota (EF_1)	Change in Expected Funding (EF_1-EF_0)
ANTH	6	$49,992	7	1	$50,082	$91
ARKY	14	$127,985	12	-2	$129,421	$1,436
BISI	10	$113,218	10	0	$113,218	$0
CHEM	13	$124,231	13	0*	$124,231	$0
COMS	3	$15,453	0	-3	$21,324	$5,871
CPSC	6	$53,211	8	2	$53,621	$410
CPSY	7	$127,776	10	3	$128,884	$1,108
DRAM	3	$14,850	0	-3	$20,721	$5,871
ECON	3	$18,489	0	-3	$24,360	$5,871
ENCI	6	$69,208	10	4	$70,408	$1,199
ENCP	5	$49,551	7	2	$49,399	-$152
ENEC	5	$54,366	8	3	$54,533	$167
ENGL	18	$137,294	12	-6	$153,711	$16,417
FISL	3	$20,508	0	-3	$26,379	$5,871
GEOG	8	$58,928	9	1	$59,347	$419
GLGP	3	$40,623	0	-3	$46,494	$5,871
HIST	10	$105,846	10	0	$105,845	$0
MDBC	8	$72,463	10	2	$73,252	$789
MDCH	3	$16,311	0	-3	$22,181	$5,871
MDCV	5	$42,573	6	1	$42,330	-$243
MDGI	3	$17,295	0	-3	$23,166	$5,871
MDMI	3	$24,489	0	-3	$30,360	$5,871
MDNS	5	$49,106	7	2	$48,955	-$152
MDSC	4	$49,457	7	3	$48,649	-$808
MGMT	3	$19,779	0	-3	$25,650	$5,871
MTST	3	$28,709	0	-3	$34,580	$5,871
MUSI	3	$23,739	0	-3	$29,610	$5,871
NURS	5	$43,414	6	1	$43,171	-$243
PHAS	4	$43,226	6	2	$42,327	-$899
PHIL	7	$73,967	10	3	$75,076	$1,108
POLI	4	$48,781	7	3	$47,973	-$808
PSYC	7	$87,718	10	3	$88,826	$1,108
RELS	5	$66,981	10	5	$67,938	$957
SOCI	5	$56,187	8	3	$56,355	$167
SOWK	3	$29,885	0	-3	$35,756	$5,871
TOTAL	203	$1,975,606	203	0	$2,068,132	$92,526

* CHEM's trades were restricted to ensure the system cleared

Table A.2 Expected funding given quotas proportional to enrollment and equilibrium price of $5870

Department	Existing Quota (q_i)	Expected Funding with Given Quota (EF_o)	Constrained Optimal Quota (Q_i)	Number of Trades (Q_i-q_i)	Expected Funding with Constrained Optimal Quota (EF_1)	Change in Expected Funding (EF_1-EF_0)
ANTH	2	$30,157	3	1	$28,534	-$1,623
ARKY	5	$71,973	10	5	$75,620	$3,647
BISI	15	$137,865	13	-2*	$141,723	$3,858
CHEM	9	$99,184	12	3	$101,078	$1,895
COMS	0	$3,714	0	0	$3,714	$0
CPSC	6	$53,211	8	2	$53,621	$410
CPSY	8	$133,965	10	2	$134,754	$789
DRAM	1	$11,122	0	-1	$8,981	-$2,141
ECON	3	$18,489	0	-3	$24,360	$5,871
ENCI	12	$105,561	12	0*	$105,561	$0
ENCP	6	$55,178	8	2	$55,588	$410
ENEC	9	$78,432	10	1	$78,802	$370
ENGL	5	$72,783	10	5	$76,430	$3,647
FISL	1	$16,781	0	-1	$14,639	-$2,141
GEOG	3	$31,190	4	1	$30,066	-$1,124
GLGP	8	$53,572	0	-8	$75,844	$22,272
HIST	5	$75,539	10	5	$76,495	$957
MDBC	9	$78,752	10	1	$79,122	$370
MDCH	5	$20,960	0	-5	$33,921	$12,961
MDCV	4	$37,359	5	1	$36,703	-$656
MDGI	2	$15,312	0	-2	$17,296	$1,983
MDMI	5	$29,139	0	-5	$42,100	$12,961
MDNS	8	$66,884	10	2	$67,673	$789
MDSC	12	$96,651	12	0*	$96,651	$0
MGMT	13	$46,403	0	-13	$84,350	$37,947
MTST	4	$30,924	0	-4	$40,450	$9,525
MUSI.	2	$21,757	0	-2	$23,740	$1,983
NURS	8	$61,191	9	1	$61,610	$419
PHAS	3	$38,480	5	2	$36,700	-$1,780
PHIL	3	$52,419	7	4	$50,487	-$1,932
POLI	3	$44,035	6	3	$42,013	-$2,023
PSYC	6	$81,757	10	4	$82,956	$1,199
RELS	5	$66,981	10	5	$67,938	$957
SOCI	5	$56,187	8	3	$56,355	$167
SOWK	7	$39,945	0	-7	$59,236	$19,292
TOTAL	202	$1,933,851	202	0	$2,065,113	$131,262

* BISI, ENCI and MDSC's trades were restricted to ensure the system cleared

Table A.3 Expected funding given equal quotas and equilibrium price of $5870

Department	Existing Quota (q_i)	Expected Funding with Given Quota (EF_o)	Constrained Optimal Quota (Q_i)	Number of Trades (Q_i-q_i)	Expected Funding with Constrained Optimal Quota (EF_1)	Change in Expected Funding (EF_1-EF_0)
ANTH	6	$49,991	7	1	$50,082	$91
ARKY	6	$78,100	11	5	$82,184	$4,084
BISI	6	$88,539	10	4	$89,738	$1,199
CHEM	6	$79,108	11	5	$83,192	$4,084
COMS	6	$22,730	0	-6	$38,934	$16,204
CPSC	6	$53,211	8	2	$53,621	$410
CPSY	6	$121,815	10	4	$123,014	$1,199
DRAM	6	$22,127	0	-6	$38,331	$16,204
ECON	6	$25,766	0	-6	$41,970	$16,204
ENCI	6	$69,208	10	4	$70,408	$1,199
ENCP	6	$55,178	8	2	$55,588	$410
ENEC	6	$59,993	9	3	$60,822	$829
ENGL	6	$78,910	11	5	$82,994	$4,084
FISL	6	$27,785	0	-6	$43,989	$16,204
GEOG	6	$46,778	7	1	$46,868	$91
GLGP	6	$47,900	0	-6	$64,104	$16,204
HIST	6	$81,166	10	4	$82,365	$1,199
MDBC	6	$60,313	9	3	$61,142	$829
MDCH	6	$23,587	0	-6	$39,791	$16,204
MDCV	6	$48,200	7	1	$48,291	$91
MDGI	6	$24,571	0	-6	$40,776	$16,204
MDMI	6	$31,766	0	-6	$47,970	$16,204
MDNS	6	$54,734	8	2	$55,144	$410
MDSC	6	$60,298	9	3	$61,127	$829
MGMT	6	$27,055	0	-6	$43,260	$16,204
MTST	6	$35,985	0	-6	$52,190	$16,204
MUSI	6	$31,016	0	-6	$47,220	$16,204
NURS	6	$49,041	7	1	$49,132	$91
PHAS	6	$54,067	8	2	$54,477	$410
PHIL	6	$68,006	10	4	$69,206	$1,199
POLI	6	$59,623	9	3	$60,452	$829
PSYC	6	$81,757	10	4	$82,956	$1,199
RELS	6	$72,609	10	4	$73,808	$1,199
SOCI	6	$61,815	9	3	$62,644	$829
SOWK	6	$37,162	2	-4*	$51,383	$14,221
TOTAL	210	$1,889,908	210	0	$2,109,172	$219,264

*SOWK's trades were restricted in order to clear the market.

Table A.4 Expected funding given optimal quotas under the 2003 allocation and an equilibrium price of $5870

Department	Existing Quota (q_i)	Expected Funding with Given Quota (EF_o)	Optimal Quota (Q_i)	Number of Trades (Q_i-q_i)	Expected Funding with Constrained Optimal Quota (EF_1)	Change in Expected Funding (EF_1-EF_0)
ANTH	6	$49,991	10	4	$51,190	$1,199
ARKY	14	$127,985	11*	-3	$129,144	$1,159
BISI	10	$113,218	1*	-9	$117,796	$4,578
CHEM	13	$124,231	11*	-2	$124,282	$51
COMS	3	$15,453	0	-3	$21,324	$5,871
CPSC	6	$53,211	10	4	$54,410	$1,199
CPSY	7	$127,776	10	3	$128,884	$1,108
DRAM	3	$14,850	0	-3	$20,721	$5,871
ECON	3	$18,489	0	-3	$24,360	$5,871
ENCI	6	$69,208	10	4	$70,408	$1,199
ENCP	5	$49,551	10	5	$50,507	$957
ENEC	5	$54,366	10	5	$55,322	$957
ENGL	18	$137,294	11*	-7	$153,434	$16,141
FISL	3	$20,508	0	-3	$26,379	$5,871
GEOG	8	$58,928	10	2	$59,717	$789
GLGP	3	$40,623	0	-3	$46,494	$5,871
HIST	10	$105,845	1*	-9	$110,423	$4,578
MDBC	8	$72,463	1*	-7	$77,830	$5,367
MDCH	3	$16,311	0	-3	$22,181	$5,871
MDCV	5	$42,573	10	5	$43,530	$957
MDGI	3	$17,295	0	-3	$23,166	$5,871
MDMI	3	$24,489	0	-3	$30,360	$5,871
MDNS	5	$49,106	7*	2	$48,955	-$152
MDSC	4	$49,457	10	6	$49,757	$301
MGMT	3	$19,779	0	-3	$25,650	$5,871
MTST	3	$28,709	0	-3	$34,580	$5,871
MUSI	3	$23,739	0	-3	$29,610	$5,871
NURS	5	$43,414	10	5	$44,371	$957
PHAS	4	$43,226	10	6	$43,526	$301
PHIL	7	$73,967	10	3	$75,076	$1,108
POLI	4	$48,781	10	6	$49,082	$301
PSYC	7	$87,718	10	3	$88,826	$1,108
RELS	5	$66,981	10	5	$67,938	$957
SOCI	5	$56,187	10	5	$57,144	$957
SOWK	3	$29,885	0	-3	$35,756	$5,871
TOTAL	203	$1,975,606	203	0	$2,092,134	$116,528

*Trades were restricted in order to clear the market.

APPENDIX B

MODEL 2 FUNDING RESULTS

Table B.1 Expected funding given the 2003 quota allocation and equilibrium price of $3727

Department	Existing Quota (q_i)	Expected Funding with Given Quota (EF_o)	Constrained Optimal Quota (Q_i)	Number of Trades (Q_i-q_i)	Expected Funding with Constrained Optimal Quota (EF_1)	Change in Expected Funding (EF_1-EF_0)
ANTH	6	$53,199	8	2	$54,645	$1,446
ARKY	14	$124,823	21	7	$132,063	$7,239
BISI	10	$121,769	22	12	$140,070	$18,301
CHEM	13	$120,295	21	8	$129,343	$9,048
COMS	3	$9,717	0	-3	$14,895	$5,179
CPSC	6	$45,030	2	-4*	$48,702	$3,672
CPSY	7	$129,377	20	13	$141,765	$12,388
DRAM	3	$9,113	0	-3	$14,292	$5,179
ECON	3	$12,752	0	-3	$17,931	$5,179
ENCI	6	$61,027	2	-4*	$64,700	$3,672
ENCP	5	$43,928	1	-4*	$48,312	$4,384
ENEC	5	$59,058	10	5	$63,025	$3,968
ENGL	18	$135,761	20	2	$136,241	$480
FISL	3	$14,772	0	-3	$19,950	$5,179
GEOG	8	$58,886	9	1	$59,870	$985
GLGP	3	$52,743	0	-3	$40,065	-$12,678
HIST	10	$114,397	20	10	$132,521	$18,124
MDBC	8	$72,421	13	5	$78,341	$5,921
MDCH	3	$28,430	0	-3	$15,752	-$12,678
MDCV	5	$36,950	1	-4*	$41,334	$4,384
MDGI	3	$11,558	0	-3	$16,737	$5,179
MDMI	3	$18,752	0	-3	$23,931	$5,179
MDNS	5	$43,484	1	-4*	$47,868	$4,384
MDSC	4	$46,147	0	-4	$34,472	-$11,675
MGMT	3	$14,042	0	-3	$19,221	$5,179
MTST	3	$22,972	0	-3	$28,151	$5,179
MUSI	3	$18,002	0	-3	$23,181	$5,179
NURS	5	$37,791	0	-5	$26,943	-$10,849
PHAS	4	$39,916	0	-4	$28,241	-$11,675
PHIL	7	$75,569	14	7	$83,590	$8,021
POLI	4	$45,472	0	-4	$33,797	-$11,675
PSYC	7	$89,320	18	11	$101,227	$11,907
RELS	5	$61,359	0	-5	$50,510	-$10,849
SOCI	5	$50,565	0	-5	$39,716	-$10,849
SOWK	3	$24,149	0	-3	$29,327	$5,179
TOTAL	203	$1,903,547	203	0	$1,980,731	$77,184

* These trades were restricted in order to clear the market.

Table B.2 Expected funding given quotas proportional to enrollment and equilibrium price of $3824

Department	Existing Quota (q_i)	Expected Funding with Given Quota (EF_0)	Constrained Optimal Quota (Q_i)	Number of Trades (Q_i-q_i)	Expected Funding with Constrained Optimal Quota (EF_1)	Change in Expected Funding (EF_1-EF_0)
ANTH	2	$38,032	4	2	$37,686	-$346
ARKY	5	$77,734	14	9	$91,280	$13,546
BISI	15	$151,332	22	7	$158,705	$7,373
CHEM	9	$98,364	18	9	$113,059	$14,695
COMS	0	$3,714	0	0	$3,714	$0
CPSC	6	$45,030	2	-4*	$48,702	$3,672
CPSY	8	$133,923	20	12	$145,492	$11,569
DRAM	1	$7,881	0	-1	$6,838	-$1,043
ECON	3	$12,752	0	-3	$17,931	$5,179
ENCI	12	$82,083	9	-3*	$82,292	$209
ENCP	6	$46,997	2	-4*	$50,669	$3,672
ENEC	9	$76,813	14	5	$83,031	$6,218
ENGL	5	$74,359	14	9	$83,424	$9,065
FISL	1	$13,539	0	-1	$12,496	-$1,043
GEOG	3	$38,250	4	1	$38,200	-$50
GLGP	8	$68,030	4	-4*	$70,375	$2,345
HIST	5	$87,606	15	10	$106,690	$19,084
MDBC	9	$77,132	14	5	$83,351	$6,218
MDCH	5	$34,055	1	-4*	$38,439	$4,384
MDCV	4	$34,049	0	-4	$22,375	-$11,675
MDGI	2	$10,918	0	-2	$13,010	$2,091
MDMI	5	$20,167	0	-5	$31,385	$11,218
MDNS	8	$53,146	4	-4*	$55,491	$2,345
MDSC	12	$73,173	8	-4*	$73,619	$446
MGMT	13	$22,464	0	-13	$56,491	$34,026
MTST	4	$23,657	0	-4	$31,878	$8,220
MUSI	2	$17,363	0	-2	$19,454	$2,091
NURS	8	$47,454	4	-4*	$49,799	$2,345
PHAS	3	$37,192	0	-3	$24,514	-$12,678
PHIL	3	$59,479	10	7	$63,585	$4,106
POLI	3	$42,748	0	-3	$30,070	-$12,678
PSYC	6	$84,965	17	11	$96,817	$11,852
RELS	5	$61,359	1	-4*	$65,743	$4,384
SOCI	5	$50,565	1	-4*	$54,949	$4,384
SOWK	7	$27,148	0	-7	$44,235	$17,088
TOTAL	202	$1,833,476	202	0	$2,005,789	$172,312

* These department's trades were restricted in order to clear the market.

Table B.3 Expected funding given equal quotas and equilibrium price of $3727

Department	Existing Quota (q_i)	Expected Funding with Given Quota (EF_o)	Constrained Optimal Quota (Q_i)	Number of Trades (Q_i-q_i)	Expected Funding with Constrained Optimal Quota (EF_1)	Change in Expected Funding (EF_1-EF_0)
ANTH	6	$53,199	8	2	$54,645	$1,446
ARKY	6	$82,313	15	9	$96,735	$14,422
BISI	6	$99,889	18	12	$123,034	$23,145
CHEM	6	$83,321	15	9	$97,743	$14,422
COMS	6	$11,904	0	-6	$26,076	$14,172
CPSC	6	$45,030	4	-2*	$46,514	$1,484
CPSY	6	$125,023	20	14	$138,038	$13,015
DRAM	6	$11,301	0	-6	$25,473	$14,172
ECON	6	$14,940	0	-6	$29,112	$14,172
ENCI	6	$61,027	4	-2*	$62,511	$1,484
ENCP	6	$46,997	4	-2*	$48,481	$1,484
ENEC	6	$63,201	11	5	$67,975	$4,774
ENGL	6	$78,502	15	9	$88,359	$9,857
FISL	6	$16,959	0	-6	$31,131	$14,172
GEOG	6	$49,986	7	1	$50,613	$627
GLGP	6	$61,437	4	-2*	$62,921	$1,484
HIST	6	$92,517	16	10	$112,393	$19,876
MDBC	6	$63,521	11	5	$68,295	$4,774
MDCH	6	$37,124	4	-2*	$38,608	$1,484
MDCV	6	$40,020	4	-2*	$41,503	$1,483
MDGI	6	$13,745	0	-6	$27,918	$14,173
MDMI	6	$20,940	0	-6	$35,112	$14,172
MDNS	6	$46,553	0	-6	$36,362	-$10,191
MDSC	6	$52,117	0	-6	$41,926	-$10,191
MGMT	6	$16,229	0	-6	$30,402	$14,173
MTST	6	$25,159	0	-6	$39,332	$14,173
MUSI	6	$20,190	0	-6	$34,362	$14,172
NURS	6	$40,861	4	-2*	$42,345	$1,484
PHAS	6	$45,886	4	-2*	$47,370	$1,484
PHIL	6	$71,214	13	7	$78,581	$7,367
POLI	6	$51,442	4	-2*	$52,926	$1,484
PSYC	6	$84,965	17	11	$96,817	$11,852
RELS	6	$64,428	4	-2*	$65,912	$1,484
SOCI	6	$53,634	4	-2*	$55,118	$1,484
SOWK	6	$26,336	0	-6	$40,508	$14,172
TOTAL	210	$1,771,910	210	0	$2,035,151	$263,241

* These department's trades were restricted in order to clear the market.