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PROFIT REGULATION OF DEFENSE CONTRACTORS AND PRIZES FOR INNOVATION: THEORY AND EVIDENCE* **

by

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Abstract

This paper first argues based on theoretical grounds, that informational and incentive constraints inherent in the innovation process require that regulatory institutions create prizes for innovation. Since the quality of an innovation is difficult to objectively describe or measure, the most natural method for awarding prizes is to allow firms to earn positive economic profit on production contracts. Explicit recognition of this role of profit regulation generates interesting perspectives on a number of important policy issues involving regulatory design. The value of the prizes offered on twelve major aerospace systems were calculated. The prizes are clearly large enough to support the contention that their existence is an important aspect of the current regulatory structure.

1. Introduction

The defense sector is clearly subject to a form of cost-based economic regulation just as public utilities are. A set of regulations which are as detailed, all-encompassing, and arcane as any that can be found in other regulated sectors determines the prices that defense contractors will receive for their products. These regulations are often referred to as the Department of Defense (DoD) "profit policy." Although economists have made great strides in analyzing the nature of the regulatory problem in a variety of industries, comparatively little attention has been devoted to the defense sector. The goal of this paper is to describe and empirically investigate an extremely simple theory which captures an important aspect of the nature of the regulatory problem in defense contracting.

The theory describes a critical difference between the regulatory problems in defense and public utilities and therefore suggests why different rules and institutions might be appropriate in each case. Furthermore it yields a number of implications regarding how an optimal regulatory policy should be structured and sheds light on a number of current policy debates over DoD profit policy. Finally a large part of the paper is devoted to empirically verifying that the incentives posited by the theory exist and are large.

The theory is simply that profit regulation of defense contractors is structured (and necessarily must be structured) in such a way that firms generating valuable new innovations will receive large rewards. That is profit regulation of defense contractors must establish large prizes for innovation. Innovation is a major product of defense contractors. However it is difficult to directly purchase effort directed at innovation for two separate reasons. First there is a moral hazard problem. A firm's effort level directed towards innovation is difficult to directly observe and the level of innovation produced is only stochastically related to the level of innovative effort. Second, individual firms are likely to have private information about the probable value of various potential avenues of research. An optimal R&D program should attempt to use this private information by decentralizing some R&D decisions and giving private decision makers incentives to choose the best avenues of research from government's perspective.

Any scheme which proposes to reward "good" ideas immediately faces the problem of finding an objectively verifiable measure of "good." The natural solution in this case is to use whether the idea is adopted or not. Thus the existing regulatory scheme creates prizes for innovation by guaranteeing that any firm which becomes a prime contractor on a new weapons system will earn positive economic profit on the production contracts for the weapons system. Firms which can successfully generate ideas good enough to be adopted by the government therefore receive prizes in the form of economic profit on the production phase of the system.

Note that the existence of prizes or economic profit in the latter phase of a weapon's development and production does not mean that firms necessarily earn positive profits overall. In fact if entry into the defense sector is not that difficult as, for example, Peck and Scherer [1962] have argued,[1] then one would expect firms to earn zero economic profit in the long run. A rent-seeking model captures the situation induced by the current regulatory structure. Firms compete for prizes by spending money on innovation. An increase in the level of economic profit defense contractors are allowed to earn would therefore have two effects. In the short-run, existing firms would compete more vigorously among themselves to develop ideas which would be accepted for production. Thus even in the short run an increase in allowed profit levels on production contracts would be at least partially transformed into increased expenditures on innovation. If firms were still earning economic profit, then in the long run more firms would enter the industry and compete for the prizes until the industry was restored to zero profits.

If this view is correct, the key role of profit policy may be to regulate the level of innovation within the industry. This point seems to have been totally overlooked in the current heated debate over whether profit policy should set higher or lower prices.[2] The implicit assumption which all sides in the debate seem to agree with is that the only effect of raising (lowering) allowed profit levels on production by some amount would be to raise (lower) firms' overall profit levels by the same amount. If the major function of profit policy is to regulate the pace of innovation then the current debate is simply missing the point.

This paper does not attempt to completely and exhaustively explore all the implications of this theory for regulatory policy. Rather it simply attempts to show that the idea of "prizes for innovation" is an extremely useful organizing principal when thinking about regulatory issues in defense contracting. I intend to more completely and formally exploit this idea to analyze what form an optimal regulatory structure should take in a future paper.

In this paper I instead focus on empirically measuring the size of prizes induced by the current regulatory structure. In order to do this, stock price data on firms competing for twelve major aerospace contracts is analyzed. As will be explained, government procurement is always organized in such a way that the set of all firms competing for the right to be the prime contractor on a new system can be identified. Thus the increase in the market value of the winning firm and the decrease in the market value of all the losing firms on the day the winner is announced can be measured. A theory which explains how to calculate the size of the prize based on the observed changes in contestants' market values is first developed. Then the changes in market values and the implied size of the prizes for the twelve major aerospace systems are calculated. The size of the prizes is compared to both the value of the competing firms and the acquisition cost of the programs. A reasonably conservative estimate of the size of the prize associated with the average contest considered is 67 million dollars. This is about 15% of the market value of the average competing firm. Furthermore it is 4.6% of the expected discounted revenues the average winning firm would receive from the project, which means that 4.6 cents of every dollar of revenues the winning firm receives from producing the system is pure economic profit.

This paper does not directly address the question of whether the current level of prizes is too high or low. It merely attempts to establish the theoretical link between prizes and innovation and then show that prize levels induced by current rules are large enough that a theoretical analysis of the role of these prizes is important. To answer the question of whether the prizes are too large or too small would require an assessment of the adequacy of the current level of innovation which is clearly beyond the scope of this paper. Furthermore, a prize system will also necessarily generate some less-desirable forms of rent seeking behavior such as influence-seeking behavior directed towards congressmen.[3] An over-all determination of the optimal prize level would have to consider this as well.

This paper is related to four other papers or groups of papers. First, many authors have noted that firms compete vigorously for the right to be the prime contractor of a new weapons system.[4] Second, a large number of formal principal-agent models of procurement employ the assumption that an unobservable effort choice will reduce cost and/or improve quality of the eventual output.[5] Third, Goldberg [1977] has advanced the general idea that different auction mechanisms will affect precontract information production by firms, which is related to the ideas of this paper. Fourth, Lichtenberg [1986] has proposed a signalling theory to explain why defense firms invest their own income in R&D. According to his theory, defense firms invest in R&D to signal their ability to perform R&D and thus obtain R&D contracts from the federal government. In contrast, this paper argues that firms invest in R&D to win production contracts.

Section 2 of the paper presents background information on the procurement process necessary to more fully understand the theory and empirical measurement. Section 3 then presents a more complete description of the theory. Section 4 shows that this simple idea sheds new light on a number of current policy debates on how profit policy should be structured. Section 5 develops the theoretical basis for using observed changes in firms' stock market value to infer the size of the prizes they were competing for. Section

6 presents the empirical measurement of the changes in firms' stock market values. Section 7 uses the theory of Section 5 and the data of Section 6 to estimate the size of the prizes. Finally Section 8 presents a brief conclusion.

2. Background

A. The Acquisition Cycle

This section describes the typical acquisition cycle for a major aerospace system.[6] The F16 will be used as an example since its procurement was fairly typical of the procedures now used. The DoD divides the procurement process into four phases with a "milestone" marking the beginning of each new phase. The milestones are identified because a system must pass on upper-level review to proceed from one phase to another. The milestones are numbered 0 through IV and the phases from first to last are called concept exploration, demonstration and validation, full scale development, and full rate production. This is illustrated in Figure 2.1

Figure 2.1

Procurement Phases

Milestone 0 :	The beginning of concept exploration
Milestone I :	The beginning of demonstration and validation
Milestone II :	The beginning of full scale development
Milestone III:	The beginning of full rate production

Milestone 0 marks the beginning of research and development specifically targeted towards a new system. To pass milestone 0 a service must demonstrate that a need exists for a new type of system. Thus pre-milestone 0 activity consists largely of consensus building within the services and DoD over what sorts of needs are most urgent.

In the late sixties the fighters currently being developed by the Navy and Air Force (the F14 and F15) were large heavy airplanes with extensive and elaborate avionics.[7] Thus they had the ability to deliver large payloads of weapons over long distances and also had extensive beyond-visual-range capabilities (i.e. - the ability to detect and destroy an opposing fighter well before visual contact can be made.) These fighters exhibited three related problems, however. First they were extremely expensive. Second, they were not particularly maneuverable and thus not well suited to engaging enemy aircraft at close range in dogfight situations. Third, the beyond-visual-range capabilities were proving to be not as effective as had been hoped because, among other reasons, pilots were reluctant to fire at a target until they could visually determine if it was a friend or foe.[8] Thus in the late sixties a consensus began to emerge that a smaller more maneuverable aircraft with less extensive beyond-visual-range capabilities and which cost considerably less than the F14 and F15 was required.

Even at this early (pre-Milestone 0) stage contractors were heavily involved (at their own cost) in preliminary design studies exploring what such a fighter might look like. Both Northrop and General Dynamics (G.D.) actually used their own funds to create detailed designs at this point.

Milestone 0 was passed in March of 1970[9] when DoD began funding a number of research studies on aspects of the proposed fighter concept, which was termed the light weight fighter (LWF). There is considerable evidence that companies were also spending their own money to attempt to increase their chances of becoming the prime contractor during this phase. For example, Lockheed and Northrop submitted design proposals for the new aircraft which were not directly solicited or funded by the DoD. In January of 1971 DoD formally requested all interested contractors to submit detailed proposals describing proposed designs for the new fighter. The firms submitting the two best proposals would be selected to continue into the next phase. Out of the five firms submitting proposals, the DoD selected G.D. and Northrop in April 1972.[10] This was milestone I.

In a Rand case study of the F16, the role of the pre-milestone I activity is summed up as follows.

> "That several-year period of studies and unsolicited proposals played a critical role in the evolution of the LWF prototype program by providing an extensive body of information for use in developing system requirements. Therefore when the call went out for candidate systems, the LWF advocates were ready with a concept that was well developed both in technical and operational terms and that had the backing of key personnel at many levels of the DoD."[11]

In particular the involved contractors were not simply passively performing design studies which they were hired to do. They were aggressively attempting to create designs that DoD would accept.

During the demonstration and validation phase G.D. and Northrop each built two prototypes which the DoD then ran through a series of tests. The prototypes were said to be "austere" in the sense that they consisted of the basic air platform without weapons or avionics. The cost of building the prototypes was largely paid for by the government. G.D. was awarded $37.9

million and Northrop received $39.1 million. However, the contracts with G.D. and Northrop imposed no specific obligations on either contractor to produce anything. Rather, once again, DoD was relying on the fact that both contractors had large incentives to do exactly what DoD wanted done. The previously quoted Rand study sums the situation up as follows.

> "The Air Force told the bidders that they could fulfill their contractural obligation by 'delivering a flatbed of bolts' if that represented their best effort using the contractual amount. However ... the competitive environment insured that [producing a fighter the government wanted] would be the real goal (not 'best effort') to which corporate funds would be committed if necessary. The importance in this arrangement of the potential for follow-on work cannot be overestimated. That is, if the program had clearly provided no expectation of follow-on business, the contractors would have had little motivation to devote so much of their talent and money."[12]

Milestone II occurred in January of 1975 when G.D. was selected to produce the F16. During full scale development G.D. integrated the weapons and avionics systems into the fighter, corrected some problems which had become apparent from the prototype tests, built the factory to produce the F16, and produced the first eight airplanes. Milestone III occurred in October 1977 when the DoD decided to authorize full rate production of the fighter. The first production aircraft flew on August of 1978 and approximately 120 have been delivered a year since then. At the end of 1986 the U.S. government had purchased 1,073 F16's and current plans are to purchase a total of 2,729.[13] Thus production will continue well into the 1990's.

A number of points should be noted about the acquisition process as described above. First, typically about 10% of the costs of the project occur before milestone II and 90% occur after. Full-scale development is the first phase of the project involving large amounts of money. This explains why DoD typically carries competition no further than milestone II.

Second, the point at which a single prime contractor is selected has varied between projects. In the sixties prototype competition was not used and very elaborate "paper competitions" where firms submitted extremely detailed design proposals were used to select a prime contractor at milestone I. In some rare instances in the seventies[14] competition was actually maintained until milestone III. However, in all twelve systems considered in this paper there was always a well defined "final contest" with the following characteristics.

(i) All contestants were known because each submitted a "final product" to the DoD for evaluation. The "final product" was a paper design study, prototype, or even an entire functioning factory depending on the contest.

(ii) There was a well-defined date on which the DoD announced a single winner from the group of contestants.

Third, at Milestone II the DoD signed a contract with G.D. essentially establishing a fixed price for full scale development and for the first three years of production.[15] However contracts for production of the annual lots in years four and thereafter were left to be negotiated by GD and the DoD on an annual basis. This situation is the rule. In fact in many cases only the full scale development contract is signed at milestone II and all production contracts are left to be negotiated on an annual basis. Ideally, DoD would like to be able to sign a single contract covering both full-scale development and all production when there are still two or more firms competing for the contract. Furthermore private firms might even prefer that such a long-term contract could be signed. After a single firm has set up a production line and other competitors' design teams have been disbanded it is true that there is only one possible source for the weapon. However, there is only one possible buyer.[16] Such a one-on-one situation creates potential "hold-up" problems on both sides so that both parties might prefer the certainty that a long-term contract could offer.[17]

However long-term production contracts are not possible for three related reasons. First, because of technical advances the nature of the airplane is constantly evolving in significant ways which substantially affect the cost of production. These cannot be anticipated and included in a contract. Second, congressional funding levels cannot be predicted by the DoD. Thus even if the DoD were willing to commit to purchase 200 airplanes per year of a fixed design for 10 years, it does not have authority to commit funds to do this. Third, DoD's own requirements are constantly changing as the nature of the perceived threat changes and a contract committing it to a course of action for 10 or more years would likely not be optimal even if Congress would allow it. Therefore an important aspect of the procurement process is that most production contracts are signed on an annual basis in a sole-source, sole-buyer environment.

Fourth it seems clear in the case of the F16 that the competing firms had a strong desire to be awarded the contract, that this motivated them to devote large amounts of time and money towards innovation, and that this played an important role in assuring the success of the project.

B. The Regulatory Contract

As in any cost-based regulatory system, DoD regulations specify procedures for calculating the cost (and price) of producing a weapon system given the production technology being used. These regulations must confront the same sorts of issues faced in other regulated industries. How should joint costs be allocated between defense and non-defense work and between various defense projects? How should capital be depreciated? What sorts of costs should not be allowed? What is the cost of capital?

The entire set of regulations governing defense procurement is codified in the Code of Federal Regulations Title 48, chapters 1-3. The parts of these regulations specifically describing how to calculate cost and prices are often referred to as profit policy.[18] The nature of these regulations will not be described in any detail in this paper. However it should be noted that the regulations are distinctly different in a number of respects from the rules used in public utility regulation. The regulations, broadly speaking, reimburse contractors for most operating costs plus give them a "fee" which is a complicated function of various classes of operating costs and capital costs.[19]

Goldberg's [1976] insightful theory of regulation as an administered contract represents the best way to understand the impact of these regulations on the procurement process. In Goldberg's view, there exists an implicit long run contract between the regulator and regulated firm which describes how the regulator will treat the regulated firm over time in varying circumstances and conditions. The codified regulatory structure often describes important aspects of this implicit contract. For example in public utility regulation the implicit contract can be viewed as the regulator's commitment to review the utility's rate structure periodically and adjust prices to guarantee that the firm will earn a fair rate of return on its capital. Utilities will only invest in long lived capital equipment because they believe government will honor this long-run implicit contract.

Profit policy regulations play an analogous role in defense procurement. The implicit contract between DoD and defense contractors is that when individual contracts are negotiated, the DoD's negotiation objective will <u>not</u> be to get the absolutely lowest price possible on that individual contract. Rather the DoD's objective will be to pay the contractor a "fair" price where "fair" is determined by existing profit policy regulations. Existing regulations are very explicit on this point. For example, the preamble to profit policy regulations includes the following statement.

"Effective national defense in a free enterprise economy requires that the best industrial capabilities be attracted to defense contracts. These capabilities will be driven away from the defense market if defense contracts are characterized by low profit opportunities. Consequently, negotiations aimed merely at reducing prices by reducing profits with no realization of the function of profit, cannot be condoned."[20]

Thus profit policy regulations can be viewed as playing two roles in the procurement process. First, when government actually signs some form of cost-reimbursement contract with a firm for a particular project, profit policy regulations determine which costs will be reimbursed and to what extent. However, much more importantly, these regulations describe government's implicit commitment as to how it will reimburse firms when it negotiates other contracts in the future.

Profit policy thus represents government's promise to choose a particular negotiation target when it negotiates the price of a particular contract with a firm. The actual outcome of the negotiation depends not only on government's negotiation target but also on the relative negotiation strengths of the two parties. For example, if government needs a particular system very badly and no other firm is able to produce this system or a good substitute, the firm producing this system should do much better in the annual negotiations determining the price of that year's production. Thus profit policy represents a key factor, but not the only factor, determining the price a firm will actually receive on the series of annual production contracts for a given weapons system.

3. Theory

The standard regulated public utility is engaged in a one-step process-production. The regulator attempts (among other things) to guarantee that the regulated firm earns zero economic profit on this step. The defense sector differs fundamentally from this standard paradigm because it is engaged in a two-step process-innovation and production. The first step is at least as important as the second. In fact a basic assumption underlying current U.S. defense policy is that the optimal strategy involves having a smaller number of more technically sophisticated weapons than the enemy. Given this strategy, it is critically important for the United States to maintain an innovative lead. Thus the DoD must find some way to induce defense contractors to exert large amounts of effort directed towards generating the types of innovations that DoD would find most useful. A good regulatory policy would still presumably attempt to guarantee that regulated defense firms earn zero economic profit overall. However, *a priori* there is no reason to require that firms earn zero profits on each step. In fact, the major theoretical point of this paper is that there is a very good reason to structure the regulatory process so that negative economic profit is earned in the innovation phase and positive profit is earned in the production phase.

The theory is most easily explained by segmenting it into four parts.

Part 1: Prizes for innovation are required.

The argument of Part 1 is that DoD is unable to directly purchase the innovative efforts of firms. Therefore it must indirectly give firms the incentive to provide this effort by establishing rewards for successful innovation. This is true for two reasons.

First, there is a moral hazard problem. The amount of innovation produced is obviously only stochastically related to the amount of effort exerted. Furthermore it is difficult to monitor the level of effort a firm is exerting. "Exerting more effort" might amount to the following sorts of behavior.

(i) Assigning the firm's best engineers to the project. Peck and Scherer [1962] particularly stress the importance of this issue and call it the "talent allocation" problem. They state

> "The highly talented technical and managerial personnel in a weapons firm affect the success or failure of programs to a degree rarely reflected in salary differentials. Since few if any companies are so well staffed that they can assign first-rate scientists, managers, and engineers to every project they undertake, important qualitative resource allocation decisions must be made."[21]

(ii) Having management devote large amounts of time and effort to deciding which approaches and projects would be most likely to be successful.

(iii) Keeping a research team together at the firm's own expense for periods of time when no business exists. Peck and Scherer [1962] also stress the value of a functioning research team.[22]

None of these is easily observable or measurable by the DoD. Therefore DoD's only alternative is to attempt to give firms an incentive to exert this effort by promising to reward successful innovation with prizes.

However even if level of effort was totally observable, a second factor would still necessitate the use of prizes. This is that firms are very likely to possess private information about which sorts of projects are more likely to yield the kind of results of most value to DoD. To illustrate this idea suppose that exerting effort consisted only of spending money and DoD could exactly monitor the amount of money spent. Furthermore assume that two possible projects exist for a firm to explore, project A and B. Assume as well that DoD can also monitor whether money is spent on project A or B. Therefore DoD could simply directly order the firm to exert given levels of effort on each project and directly monitor that this occurred. However now suppose as well that project A is likely to produce high benefits to DoD but will yield very few commercial spin-offs for the firm. Project B is the reverse. It is likely to produce very low benefits for the DoD but will yield a number of useful ideas which the firm can use in its commercial business. Furthermore suppose that because of its greater technical expertise only the firm is aware of this fact. Both projects appear to be similar to the DoD. If the firm were simply hired to perform research (which is possible by assumption because research effort is directly monitorable) the firm would have an incentive to recommend project B. In order to give the firm an incentive to choose project A, the DoD must pay the firm not according to the amount of effort it exerts but instead according to the value of the ideas produced. That is, successful innovations must be rewarded with some sort of prize.

Another way of stating this second point is that an optimal research program should be somewhat decentralized so that firms can make decisions based upon their private information. However when delegating some decision-making to firms, DoD must simultaneously provide the firms with incentives to make the decisions which are best from the DoD perspective. Establishing prizes for innovation accomplishes this. An example of this is that companies will often fund prototypes for a particular system which they believe has great potential even if no-one in DoD at that time yet agrees.[23] Thus when there are prizes for successful innovation firms have an incentive to use their own funds if necessary to pursue research projects which they strongly believe will eventually yield results of great value to the DoD.

<u>Part 2</u>: A regulatory structure which directly provides larger prizes for higher quality innovations is not possible.

The argument of Part 1 does not by itself establish the regulatory principle that defense firms should earn positive profits on production contracts. In principle government could commit to R&D incentive contracts of the form $w(x)$ where $x \in X$, X is the space of all possible innovations and $w(x)$ is the wage the contractor will receive if the innovation x results. Then production contracts could be priced to yield zero economic profit and the payment of higher wages to more valuable innovations would provide the incentive for innovation. Furthermore $w(x)$ could be chosen so firms were just willing to perform the R&D and thus earned zero economic profit in the R&D phase as well.

However, it is clear that the transactions costs of writing out a legally enforceable objectively verifiable contract describing all possible innovations and the price which would be paid for each one would be prohibitively costly if not impossible for all but the most trivially simple R&D projects. Some R&D occurs within well-defined programs with fairly well-defined objectives. Even in these cases it seems unlikely that DoD could provide a legally enforceable contract covering all possible design improvements. However, a large fraction of firms' R&D is directed towards identifying more basic new ideas and concepts for weapons development. As explained in Part 1, the R&D process is somewhat decentralized in order to allow firms to use their own private information in deciding which avenues of R&D to explore. To sign a legally enforceable contract directly rewarding the results of this more far-ranging basic R&D would literally require government to list the possible universe of innovations and the prize attached to each one. This is obviously impossible.

One other option would be for government to simply announce that it would evaluate the quality of each new innovation and award a prize based on the evaluated quality. One might imagine creation of a "DoD prize panel" which annually assessed the results of all firms' efforts and awarded prizes accordingly. Such a scheme would probably be totally infeasible due to the subjectivity of any such evaluation. Firms would all claim their research was unfairly evaluated and one could imagine endless congressional investigations into such a scheme. (It might also be politically difficult to award large prizes.)

Thus transactions costs prevent the writing of legally enforceable contracts which directly reward innovation. The option of relying on government to evaluate each innovation and assign it a "fair" reward based on its quality is too subjective to work. Therefore it is not possible to directly pay larger prizes for higher quality innovations.

Part 3: Contracts which provide economic profit on production contracts will roughly provide prizes for good innovations and larger prizes for more important innovations.

The obvious objectively verifiable signal of whether a firm has created a successful new weapons design is whether DoD chooses to purchase it. Thus a regulatory system could create prizes for innovation by guaranteeing that any firm which becomes a prime contractor on a new weapons system will earn positive economic profit on the production contracts for the weapons system. In such a system firms which can successfully generate ideas good enough to be adopted by the government would receive prizes in the form of economic profit on the production phase of the system.

Furthermore if profit is awarded approximately as a percentage of cost (i.e. -- the profit earned on a system doubles if the system is twice as expensive) this might in a very rough sense also tend to award larger prizes for better innovations for two reasons. First, systems which prove to be useful will be purchased in larger quantities. Second, there is probably some sense in which a 30 billion dollar project is more important to government than a 30 million dollar project.

Finally, note that such a system will also provide incentives for the firm to continue to innovate and improve its product even after it is initially adopted. This is because it can guarantee more sales (and thus more profit) by improving the system. Constant upgrading of existing systems is a very important part of the over-all innovative effort in defense procurement, so this is an important point.

Part 4: A rent-seeking model describes the equilibrium response of innovation and over-all profit to prize levels.

Note that the existence of prizes or economic profit in the latter phase of a weapons acquisition program does not necessarily imply that firms must be earning positive profits overall. In fact if entry and exit are possible, firms must be earning zero expected economic profit. The explanation for how these profits are dissipated is that firms spend money on innovation attempting to win the prizes. A rent seeking model of the sort originally analyzed by Tullock [1967], thus captures the nature of firms' behavior.

A simple formal model of this rent-seeking behavior will now be analyzed in order to elucidate the interconnection between prize levels, economic profit and innovation. In order to most clearly and simply illustrate the key ideas, it will be assumed that firms are risk neutral and they are competing to be the prime contractor on only one weapons system. Let n denote the number of firms. Two separate time horizons will be modeled. In the short run no entry or exit will be possible; thus n will be a fixed number. In the long run entry and exit will be possible; thus n will be determined by a zero profits equilibrium condition. Let R denote the expected discounted revenue stream the winner will receive and let C denote the expected discounted stream of incremental costs the winner will have to incur. Thus the prize to winning, π, is given by

$$\pi = R - C \tag{3.1}$$

Assume that each firm has a fixed cost of operation equal to some positive value, F. Let x_i denote firm i's expenditures on innovation. Finally let $p_i(x_1, \ldots, x_n)$ denote firm i's probability of winning the contest given the expenditure levels. The major properties of this rent-seeking model only depend on p_i exhibiting the natural property that a firm's probability of winning increases if it spends more and decreases if other firms spend more. However in order to obtain closed form solutions for the equilibrium and in order to guarantee that an equilibrium exists, a particular functional form will be assumed for p_i given by

$$(3.2) \qquad p_i = \frac{x_i^e}{\sum_{j=1}^{n} x_j^e} .$$

where e is a parameter between 0 and 1.[24]

The parameter e is a measure of the responsiveness of a firm's probability of winning to changes in its level of effort directed towards innovation. To see this consider, $\partial p_i/\partial x_i$ evaluated where $x_j = x$ for every j; this will be the expression of interest in the subsequent analysis because symmetric equilibria will be calculated.

$$(3.3) \qquad \frac{\partial p_i}{\partial x_i}(x, \ldots, x) = \frac{e(n-1)}{xn^2}$$

This expression increases in e.

Three factors are likely to affect the size of e. First, and most obviously, if increases in effort cause a larger increase in the expected quality of innovation then e will be larger. Second, e will tend to be larger if the distribution of quality of innovations given the expenditure level is less variable.[25] Finally, e will be larger if government is able to actually select the firm producing the highest quality innovation as the winner of the contest. For example it is argued that political considerations of various sorts can play a strong role in determining the winner of a contest. The third factor is probably the only one of the three that DoD has any control over. Presumably by convincing firms that the quality of the firms' designs will be more important in determining the winner, it could raise firms perceptions of e.

Equilibria for both time horizons can now be defined. In both horizons attention will be restricted to symmetric equilibria.[26] In the short run an equilibrium is simply described by the expenditure level of each firm, x. The expenditure level x is an equilibrium given n if x is an expected-profit-maximizing level of expenditure for each firm (given the others are choosing x and there are n firms). Formally, x is an equilibrium given n if it satisfies

$$x \in \underset{\hat{x} \geq 0}{\operatorname{argmax}} \quad \frac{\hat{x}^e}{(n-1)x^e + \hat{x}^e}\,\pi - \hat{x} \tag{3.4}$$

In the long run, when entry and exit are possible an equilibrium is an ordered pair (x,n) where x is the expenditure level for each firm which chooses to enter and n is the number of firms. Obviously a long run equilibrium must satisfy (3.4). In addition there must be no incentive for entry or exit -- i.e. -- each contestant must be earning expected profits of zero.[27]

$$\frac{\pi}{n} - x - F = 0 \tag{3.5}$$

First consider short-run equilibrium. The objective function in (3.4) is globally concave in $\hat{x}$. Therefore it can be replaced by its first order condition. This is given by

$$(3.6) \qquad x = \frac{(n-1)e}{n^2} \pi .$$

The equilibrium exhibits a number of natural properties. As n increases innovation expenditures per firm decrease but aggregate innovation expenditures (nx) increase. As e increases each firm is tempted to spend more because the responsiveness of p_i to x_i is greater, and consequently the equilibrium level of x is higher. Finally as the size of the prize increases each firm spends more attempting to win it in equilibrium.

A question of great interest is how aggregate expenditures on innovation vary with the size of the prize. From (3.6),

$$(3.7) \qquad \frac{\partial (nx)}{\partial \pi} = \frac{(n-1)}{n} e.$$

Thus aggregate expenditures increase when π increases but by less than π increases. Therefore in the short run, increases or decreases in the size of the prize are partially but not totally absorbed by changes in the level of innovation. Note that e affects how responsive the aggregate innovation level is to changes in the prize. This makes good intuitive sense. If e is higher, expenditures on innovation have a bigger incremental impact on a firm's chance of winning. Thus an increase in the size of the prize causes a bigger reaction on the part of contestants.

A long run equilibrium satisfies (3.5) and (3.6). It is straightforward to show that the unique non-negative solution to these two equations is given by

$$(3.8) \qquad n = \frac{(1-e)(\pi/F) + \sqrt{(1-e)^2(\pi/F)^2 + 4e(\pi/F)}}{2}$$

$$(3.9) \qquad x = F\left\{ \frac{2(\pi/F)}{(1-e)(\pi/F) + \sqrt{(1-e)^2(\pi/F)^2 + 4e(\pi/F)}} - 1 \right\}.$$

Increases in the prize therefore increase both the number of firms and expenditures per firm in the long run. This result is consistent with the short-run analysis. Suppose the prize level is increased. In the short run existing firms will increase their expenditures on innovation. However aggregate expenditures will increase by less than the increase in the prize by (3.7). Thus the existing firms will earn positive expected profits. This causes more firms to enter in the long run.

The major conclusion to be derived from the rent seeking formulation is that the size of prizes which DoD offers will have an important effect on the rate of innovation in the defense sector. Even over a time horizon where entry and exit are impossible, increasing the prize level by one dollar will not simply cause firms' profits to increase by one dollar. Rather some fraction of the dollar will be channeled into increased expenditures on innovation. The fraction of the increase which is transformed into innovation depends on parameters of the environment (in this paper's model, e) but in principal could be very large.[28] If entry and exit are possible, then changing the prize level has no effect at all on the long run level of profits. Thus an increase of one dollar in the prize level causes an increase in innovation expenditures of one dollar as well.

4. Implications for Regulatory Policy

The purpose of this section is to outline a number of implications that this theory has for how profit policy should optimally be structured. It does not attempt to completely and formally explore all the implications of this theory for regulatory policy. Such an analysis would require a detailed description and consideration of the current rules for determining prices which is beyond the scope of this paper. Rather it simply attempts to show that the idea of "prizes for innovation" is an extremely useful organizing principal when thinking about regulatory issues in defense contracting. Eight implications will be listed and discussed.

Implication #1: Profit policy's primary function may not be to control profits. Rather it may be to control the rate of innovation.

An ongoing and seemingly never-ending debate in policy-making circles in Washington concerns whether defense profits are too high or too low and whether price levels allowed under profit policy should therefore be adjusted to correct this problem. Every few years Congress (usually through the GAO) or the DoD produces a new calculation of accounting rates of return and the debate begins anew.[29] The debate over whether price levels should be raised or lowered then focuses on the problems with using accounting-based numbers and over what a "fair" profit rate should be. However the implicit assumption which all sides in the debate seem to agree with is that the only effect of raising (lowering) allowed profit levels on production by some amount would be to raise (lower) firms' overall profit levels by the same amount and possibly induce some entry on exit. Since profit policy is seen simply as a tool for regulating firms' overall profit levels, the entire debate thus focuses on whether overall profits appear too high or too low.

If this paper's theory is correct, the most important function of profit policy may be to regulate the level of innovative activity in the defense sector. Therefore an important focus of the debate should be whether an adequate level of innovation currently exists or not. Even if entry and exit into the defense sector were impossible, a share of any increase in profit levels earned on production contracts will be transformed into increased innovative activity. If entry and exit are possible, long run profits will necessarily be zero. Thus profit policy has no effect at all on long run profits. Rather the only long run effect of profit policy is to determine the rate of innovation.

There is some evidence to suggest that entry and exit in the defense sector is no more difficult than in a range of other industries, although more evidence needs to be gathered on this point. Peck and Scherer [1962] document that, if anything, rates of turnover of firms in the defense sector appear to be higher than in similar non-defense industries.[30] One reason for this may be that potential entrants are able to easily establish a "toehold" in the industry by first becoming a subcontractor -- i.e. -- producing a sub-system of a major weapons system under contract to one of the larger "prime contractors" dealing directly with the government. Between 50 and 60 percent of a weapons system is normally subcontracted by the prime contractor.[31] Thus a firm can enter the industry and gain experience without initially having to commit massive amounts of capital.

Note that the existence of overall positive or negative profits in a given year is not inconsistent with the claim that profits are on average zero. Industry profit will tend to vary from year to year for a number of reasons. First, existing pricing rules probably do not fully reflect changes in market rates of interest. Thus profits are above (below) average when market interest rates are low (high).[32] Second, prices of widely used inputs in the defense sector may rise (fall) unexpectedly, thus reducing (increasing) the profits of all firms which had signed fixed price contracts not anticipating the change. Third, recall that relative bargaining power together with the pricing rules determine firms' actual profit levels. In times of military buildup when excess capacity dwindles, firms' bargaining power increases and profit levels appear to rise.[33]

Much of the ongoing debate on profit policy can thus be viewed as attempts to "even out" these yearly variations[34] in industry profit levels. This may be a good idea and deserves further formal investigation. However surely the debate should also be concerned with the effect that long-run average profit levels are having on innovation.

<u>Implication #2</u>: The correct regulatory principal may be set price equal to full cost plus a percentage of full cost where "full cost" means operating cost plus capital cost.

Let OC denote the operating cost of producing a particular weapon, K denote the capital stock used in producing it and r denote the normal rate of return on capital.[35] Then the pricing rule being suggested is

$$(4.1) \qquad p = (1+\gamma)\ (OC + rK)$$

where γ is a positive real number. Thus the price equals the full cost of production plus a percentage of full cost. This scheme clearly establishes prizes for innovation but so would many other pricing schemes. It has two desirable features which may make it the preferable rule.

The first feature is that the prize is bigger for projects which involve greater expense. This might be thought to roughly insure that firms producing more useful innovations will receive larger prizes for two reasons. First, even after a design is initially judged successful and DoD decides to produce and purchase it, more information on the value of the new system will be forthcoming as it begins to be used in the field. Systems which ultimately prove most valuable will be purchased in greater quantities over a longer period of time. Thus larger prizes will be paid to systems which ultimately prove to be most useful. Second, there is probably a sense in which innovation which affects a 30 billion dollar program is more important than innovation which affects a 30 million dollar program.

Many pricing schemes other than the one in (4.1) would have the property of awarding larger programs a bigger prize. For example until the mid-seventies the DoD's pricing rule probably more closely resembled

$$p = (1+\gamma)\ (OC)\ . \tag{4.2}$$

The markup γ was chosen large enough to not only cover capital costs but also to provide a prize. Currently, the DoD's pricing rule probably is closer to

$$p = (1+\gamma)\ OC + rK\ . \tag{4.3}$$

That is capital costs are explicitly accounted for and reimbursed. However the measure of "size" is still operating cost. An alternative rule that might appeal to economists involved in rate of return regulation would be to give firms a higher rate of return on production contracts. This would be implemented by the following sort of rule.

(4.4) $$p = OC + (1+\gamma)\ rK$$

Even though all of these rules provide larger prizes for larger projects only (4.1) exhibits a second desirable feature as well. This is that the firm has no incentive to distort its mix of capital and non-capital expenditures away from the minimum cost ratio.[36] Rule (4.1) provides an equal profit for the firm regardless of whether the firm spends it on operating costs or capital costs. The other rules provide a greater profit for one of the two inputs and thus bias the firm's choice in favor of the more highly rewarded input. This result is standard in the literature on the behavior of the profit-maximizing firm under regulatory constraint so will not be formally derived here.[37]

This formulation very clearly explains the nature of the confusion in the current debate over profit policy and incentives for capital investment. It is clear that the old scheme represented by (4.2) did not provide any incentive for capital investment. Supporters of the new scheme, represented by (4.3), have argued that it must provide adequate incentives because the economic cost of capital is fully reimbursed. However they ignore the fact that operating costs are being <u>more</u> than fully reimbursed. This still creates an incentive for firms to distort their input mix away from capital towards operating costs.

Implication #3: There may be tradeoff between encouraging innovation and encouraging productive efficiency.

The remarks under Implication 2 demonstrate that prizes for innovation can be created without necessarily biasing the firm's capital-labor choice. However, all the pricing rules discussed above, including (4.1) have the property that firms incurring higher costs will also earn higher profits. This was argued to be a desirable feature of a system which attempts to award larger prizes to more important innovations. However it will also clearly give firms the incentive to attempt to maximize production cost once they have been selected to produce a system. Thus the most natural method of implementing a prize system may also, unfortunately, create disincentives for firms to minimize production cost. Note that firms are not merely indifferent about production costs under these pricing rules. They actually strictly prefer higher production costs. The question of how to design pricing rules which simultaneously attempt to deal with the problems of creating prizes for innovation and incentives to minimize production cost is clearly an important topic for future research.

Implication #4: A negative effect of dual sourcing may be to reduce innovation.

Dual-sourcing involves having two firms build separate assembly lines for the same weapons system and then competitively bid for shares of successive annual production lots. Partially due to Congressional pressure this has become an extremely common practice for procurement of missiles in the 1980's and there is a strong possibility that it may be used in future procurements of some airplanes.[38] The standard analysis of the costs and benefits of this practice is as follows. The obvious cost is that the non-recurring costs of setting up the production facility must be incurred twice. A not-quite-so-obvious cost is that the individual firms will move more slowly down their learning curves given that they are splitting production. These costs are offset by two benefits. The first benefit is that firms will strive to minimize production costs as part of the competition to win more production. The second cited benefit is that any economic profit which would have been earned in a sole-source situation will be competed away.

From the perspective of this paper the second cited benefit may in fact be an additional cost. Namely, the removal of all economic profit on production contracts will also remove firms' incentives to innovate in an effort to win them. Thus dual-sourcing illustrates the point made in implication 3. Although dual-sourcing may encourage productive efficiency it may also discourage future innovation. See Riordan and Sappington [1987] for a theoretical model analyzing closely related ideas.

<u>Implication #5</u>: Encouraging buy-ins may reduce innovation.

The term "buy-in" is used in the literature to describe two different practices by firms. The first practice is where a firm purposely bids well below its expected cost on a multi-year production contract, with the intention that government will bail the firm out when it becomes clear that the price was much too low. The second practice is where a firm purposely bids well below its expected cost for the first annual production contract of a new system in order to win the right to be the prime contractor. The firm expects to lose money on the first contract but hopes to recover its profit by earning positive economic profit on all subsequent annual production contracts which will be negotiated in a sole source environment.

It is clear that the first practice is undesirable. However this paper's theory also suggests that the second practice may not be desirable. This is somewhat surprising. Suppose that the winning prime contractor expects to earn 20 million dollars in expected discounted profit by taking advantage of profit policy's generous rules and its sole source position. An economist's initial reaction might be that having an auction where the right to be the prime contractor was auctioned off for 20 million dollars would be the ideal solution to the "problem" of economic profit on production contracts. This is exactly what a competitive buy-in situation would accomplish.

However this view ignores the possibility that economic profit on production contracts may not be a "problem" but rather a desirable feature of the current system which provides incentives for innovation. Thus a government policy of actively encouraging firms to bid well below their cost on initial production contracts may not be a good policy if it is felt that the current level of economic profit earned on production contracts is generating a correct level of innovation. Rather a policy where DoD attempts to select the firm based on its predicted production cost and design quality may be more appropriate.

<u>Implication #6</u>: The current regulatory system encourages vertical integration of innovation and production.

It is clear that firms which design new weapons will have an incentive to integrate downstream into production if the rewards for excellent designs are in the form of profits on production contracts. Thus the vertical integration of the R&D and production functions in the United States defense industry may be due to the regulatory structure rather than to any natural economic advantage of performing both functions within the same firm. This suggests that it would be interesting to investigate how separately the R&D and production functions are organized within the same firm.

<u>Implication #7</u>: Different pricing rules may be appropriate for different sectors of the defense industry.

Current profit policy rules are intended to apply uniformly to all defense contracts. However the need and importance of innovation clearly varies among sectors in the defense industry. This suggests that pricing rules should vary from sector to sector depending on how much innovative activity is required. In particular pricing rules for more standard products should provide less economic profit.

Implication #8: It could be difficult to provide adequate prizes if the defense sector was publically owned.

It is periodically suggested that the defense sector should be nationalized.[39] The theory of this paper suggests a possible problem with this idea. Namely it is probably difficult to award large prizes to executives of nationalized companies. At a minimum this is an issue which would have to be carefully studied and dealt with by any nationalization scheme.

5. Estimation Theory

A number of possible approaches to empirically measuring the size of the prizes created by current regulatory policy exist. This section will explain why two possible approaches are unsatisfactory and then develop the underlying theory necessary to use a third approach which is the one used in this paper.

A. Other Possible Approaches.

One obvious approach to measuring the size of prizes earned by firms would be to use accounting data to measure the return on assets earned by firms on their production activities. This approach has a number of problems, however. First, accounting measures of assets and income are inaccurate in a variety of ways. Second, accounting data only provides a measure of <u>accounting</u> profit. To calculate <u>economic</u> profit one must take the accounting rate of return and subtract the "normal rate of return earned by firms of this risk class." It seems to be impossible to find a non-controversial method of calculating what a normal rate of return should be for major defense contractors.

Analysis of accounting data is the time-honored approach taken by the profit studies periodically undertaken by DoD and Congress. The inevitable outcome of any new such study is a fierce debate over whether the study proves that profit rates are too high or too low. An excellent example concerns DoD's most recent study [DoD 1985] which concluded that current profit rates were approximately normal - i.e. - no economic profit was being earned. The GAO [Comptroller General of the United States 1986] responded by arguing that a "correct" analysis of exactly the same accounting date unambiguously showed that defense firms were earning large positive economic profits. The GAO and

DoD disagreed on a number of interpretations of how to use the accounting data and also on what a normal rate of return was for defense firms.[40] Thus it is unlikely that any accounting-based measure of the size of prizes could be calculated which would be widely accepted as non-controversial and correct by a majority of the defense community.

A second possible approach would be to use the pricing regulations of profit policy to determine the rate of return the regulations currently allow. The approach perhaps exhibits even more serious problems than the first approach. First, the major problem of the previous approach is also a problem here. Analysis of the pricing rules will only yield the <u>accounting</u> profit earned by firms. To calculate the <u>economic</u> profit, one must subtract a "normal" rate of return which is difficult to determine. Second, profit policy allows fairly broad ranges of accounting profit to be earned. Thus, at best, an analysis solely based on profit policy rules would yield a fairly broad range of possible prizes. Third, the prize level earned by firms depends not only on the level of profits guaranteed by profit policy pricing rules but also on firms' bargaining power.

This last problem can be explained as follows. The goal of the second approach would be to calculate the economic profit that profit policy rules allow a contractor to earn as a function of his estimated costs. Suppose this was done and it was determined that the profit rate was γ - i.e. - a contractor with estimated costs of $\hat{C}$ would be allowed economic profit of $\gamma\hat{C}$.

Now suppose a firm and contracting officer are negotiating over the price that will be paid for next year's production of some weapon. The firm and contracting officer will agree on an estimate of the production cost, $\hat{C}$. This then determines the contract price, $\hat{p}$, according to the formula

$$(5.1) \qquad \hat{p} = (1+\gamma)\,\hat{C}.$$

Suppose the firms actual costs of production turn out to be C. Then the firm's actual profits can be written as

$$(5.2) \qquad \pi = \gamma\hat{C} + (\hat{C}-C)$$

In particular there are two sources of profit for the firm. First there are markups on estimated costs, as determined by profit policy. (This is the term $\gamma\hat{C}$.) However, the firm can also increase its profits by producing the item for a lower cost than anticipated. (This is the term $(\hat{C}-C)$.)

A careful analysis of profit policy rules will only shed light on the magnitude of the first of these two terms. However, it seems to be the case that firms with strong bargaining power are able to substantially increase their profits by negotiating cost estimates substantially higher than what the actual costs will be. Scherer [1964], for example, examines a large group of fixed price production contracts and finds "an almost perfectly consistent tendency to underrun target costs or base prices." He finds the average underrun varied between 1.25% to 2.25% depending on how it was calculated.[41] Thus simply analyzing profit policy rules will not yield a correct estimate of firms' economic profits.

B. Use of Stock Market Data

The problems of the above two approaches can be totally avoided by a very different approach using stock market data. The basic idea is to calculate the stock market value of firms competing for a prime contract award the day before it was announced which firm won and the day after it was announced which firm won. Suppose there was no prize - i.e. - suppose the winner will earn zero economic profit on the production contracts. Then the stock market value of the firms should not be affected by the announcement. However, if the winning firm will earn positive economic profit its market value should rise and the losers' should fall. Furthermore the size of the changes in market value should be related to the size of the prize. The purpose of this section is to carefully outline a theory which describes the relationship between the observed changes in market value and the unobserved size of the prize. The theory will allow one to calculate the size of the prize associated with a given contest based on observation of the changes in market value.

Before doing this however, note that this approach does not suffer from the problems of the previously described approaches. First, it does not rely on any accounting data. Second, it is directly measuring <u>economic</u> profit and not <u>accounting</u> profit. If the winning firm will earn zero economic profit on all production contracts its market value will not change on the day of the announcement. Third, the change in market value of the firms reflects all anticipated changes in profits whether they are due to profit policy markups, bargaining power, or whatever.

The critical assumption underlying this approach is, of course, that the market's perception of the size of the prizes is accurate. The defense industry is closely studied by large numbers of professional analysts. Furthermore the award of a major new weapons system is a very prominent event which is widely discussed and analyzed by the financial community prior to the award date. Because of government's formalized procurement procedures it is always known precisely which firms are competing to be the prime contractor for a particular system. Thus there seems to be a good case that the market value of competing firms should reflect a fairly well-considered evaluation of the economic profit to be earned by the winner.

C. The Model

A simple formal model of how the prize level and the contestants' probabilities of winning determine observed changes in market values will now be described. The following notation will be used:

π ,	The dollar value of the prize that firms are competing for.[42]
n ,	The number of firms competing.
q ,	The probability as evaluated by the market that no firm will win and that the project will be cancelled.[43]
p_i ,	The market's evaluation of the probability that firm i will win the contest conditional on the project not being cancelled. Thus each p_i is between zero and one and the p_i's sum to one.
p ,	The vector of probabilities, $(p_1, \ldots, p_n)$.
p^* ,	The vector of probabilities (1/n, ..., 1/n) - i.e. - when $p = p^*$ each firm has an equal chance of winning.
M_i^B ,	The market value of firm i on the day before the winner is announced.
M_i^A ,	The market value of firm i on the day after the winner is announced.
V_i ,	The change in the market value of firm i, $M_i^A - M_i^B$.
V_W ,	The change in the market value of the winner.

V_L , The sum of the change in the market value of the losers.

W , The index number of the winning firm.

It is important to note which variables can and cannot be directly measured. Obviously π cannot be directly measured. Neither can p or q. All the other variables are directly measurable.

It will be assumed that investors are risk neutral with respect to the risk of which (if any) firm will win the contract. This seems reasonable since the contest risk is clearly idiosyncratic and thus diversifiable.[44]

An estimator of π is simply a real-valued function which maps the directly observable variables into an estimate of π. Formally, an estimator is therefore a function of $(V_1, \ldots, V_n)$ and W. Let e $(V_1, \ldots, V_n, W)$ denote an estimator. A good estimator is unbiased in the sense that it will on average estimate the size of the prize correctly.

Note that all the data analyzed in Section 6 is for contests which were not cancelled. Thus there is a sort of "survivor bias" in the data. This must be formally dealt with by calculating expected values of estimators conditional on the project not being cancelled. Therefore let E(/p,q) denote the expectation operator given p and q conditional on the project not being cancelled. An unbiased estimator can now be defined.

Definition:

The estimator e is unbiased given p and q if

(5.3) $$E(e(V_1, \ldots, V_n, W)/p,q) = \pi$$

If an estimator is conservative in the sense that it tends to underestimate the size of π this will also be useful, since a conservative estimator will establish a lower bound for π.

Definition:

The estimator e is conservative given p and q if

$$E(e(V_1, \ldots, V_n, W)/p,q) \leq \pi. \tag{5.4}$$

The estimator is strictly conservative if the inequality in (5.4) is strict.

Finally recall that p and q are not directly observable. Therefore it will be important to attempt to establish that an estimator is unbiased or conservative independent of p and/or q. Such estimators will be called uniformly unbiased or uniformly conservative.

Definition

An estimator e is

uniformly unbiased over p given q		(5.3) holds for every p
uniformly unbiased over q given p	if	(5.3) holds for every q
uniformly unbiased over p and q		(5.3) holds for every p and q.

Definition

An estimator e is

uniformly conservative over p given q		(5.4) holds for every p
uniformly conservative over q given p	if	(5.4) holds for every q
uniformly conservative over p and q		(5.4) holds for every p and q.

D. Analysis of the Model

Consider the situation on the day before the prize is awarded. Firm i has a $(1-q)p_i$ probability of winning the prize π. Thus its market value is $(1-q)p_i\pi$ higher than it otherwise would be.[45] Now consider the situation the day after the award. Suppose firm j won. Firm j's market value will increase to be π greater than it otherwise would be. All the losing firms' values will drop back down to zero above what they otherwise would be. This proves the following proposition.

Proposition 1:

Suppose firm j wins. Then

$$(5.6) \qquad V_i = \begin{cases} [1 - p_j(1-q)]\pi, & i = j \\ - p_i(1-q)\pi, & i \neq j \end{cases}$$

proof:

As above. QED

An immediate corollary of this is the following.

Corollary 1:

No matter which firm wins,

$$(5.7) \qquad V_W + V_L = q\pi.$$

Therefore (i) $V_W > -V_L$ if $q > 0$.

(ii) $V_W = -V_L$ if $q = 0$.

proof:

This follows immediately from Proposition 1.

QED.

Thus the observed increase in the market value of the winner should always be greater than or equal to the sum of the observed decrease in the market values of the losers and strict inequality is evidence that $q > 0$ - i.e. - the market perceived some positive probability that no winner would be announced and the project would be cancelled.

There is a very natural intuitive explanation for Corollary 1 based on an arbitrage argument. First suppose that q equals zero - i.e. - one of the n competitors will definitely receive π. Suppose an investor purchased 100% of the stock of all n companies. Then the investor would definitely receive π dollars on the day of the announcement. Therefore on the day before the announcement the sum of the market values of the n firms must be π dollars higher than it otherwise would be. Of course after the announcement the winner's market value is π dollars higher than it otherwise would be and the losers' market values are equal to zero above what they otherwise would be. Thus the sum of the market values of the n firms after the announcement is also equal to π above what it otherwise would be. Since the sum of the market value of the n firms is the same before and after the announcement, the increase in the value of the winner must exactly equal the decrease of the value of the losers.[46]

Thus when $q = 0$, an announcement that a particular firm has won produces no news from the standpoint of the value of all n firms. It was already known that one of the n firms would win and this was incorporated into the market's estimate of the aggregate value of the firms. However when $q > 0$, there is a chance that no firm will win and the project will be cancelled. Thus an announcement that a particular firm has won produces new information from the standpoint of all n firms. The project will not be cancelled and one of the firms will receive π. Thus the aggregate value of all firms should increase from $(1-q)\pi$ to π above what it otherwise would be, or equivalently, $V_W + V_L$ should equal $q\pi$. This is the result of Corollary 1.

The next step in determining a useful estimator of π is to calculate the expected value of V_W and $-V_L$. This is done in Proposition 2.

<u>Proposition 2</u>:

$$(5.8) \qquad E(V_W/p,q) = \left[(1-q) \sum_{i=1}^{n} p_i(1-p_i)\right]\pi + q\pi$$

$$(5.9) \qquad E(-V_L/p,q) = \left[(1-q) \sum_{i=1}^{n} p_i(1-p_i)\right]\pi$$

proof:

Expression (5.9) follows immediately from (5.7) and (5.8). Therefore it is sufficient to prove (5.8). If firm i wins, V_W will equal $[1-p_i(1-q)]\pi$ by (5.6). Firm i will win with probability p_i conditional on some firm winning.[47] Therefore the expected value of V_W is given by

$$(5.10) \qquad \sum_{i=1}^{n} p_i[1-p_i(1-q)]\pi.$$

This can be rewritten as (5.8)

QED

A useful estimator of π can now be constructed. Let k(p) denote the function

$$(5.11) \qquad k(p) = \frac{1}{\sum_{i=1}^{n} p_i(1-p_i)}.$$

Then define a class of estimators e_p as follows:

(5.12) $e_p = V_W + V_L - k(p)V_L$

Proposition 3 now establishes that e_p is a uniformly unbiased estimator over q given p.

Proposition 3:

e_p is uniformly unbiased over q given p.

proof:

From (5.12)

(5.13) $E(e_p/p,q) = E(V_W/p,q) + E(V_L/p,q) - k(p)\, E(V_L/p,q)$

Substitution of (5.8) and (5.9) into (5.13) shows that $E(e_p/p,q) = \pi$.

QED

Note that the only difference between the estimators in the e_p class is the size of k(p). If k(p) is larger, the estimator produces larger estimates of π. From (5.11) it is easy to see that k(p) can be interpreted as a measure of the asymmetry of p. It is minimized if p is perfectly symmetric - i.e. - $p = p^*$. (Recall p^* is defined as (1/n, ..., 1/n).) It equals infinity if $p_i = 1$ for some i. The reason for this can be traced back to (5.8) and (5.9) which show that more asymmetric contests produce smaller expected changes in market values of the contestants.

This suggests two possible approaches for constructing plausible estimates of π given that p cannot be directly measured. The first would be to use e_p* which always produces the smallest estimates within the e_p class. Proposition 4 shows that e_p* is in fact uniformly conservative over p and q.

<u>Proposition 4</u>:

(i) $k(p*) = \frac{n}{n-1}$

(ii) Therefore e_p* is defined by

(5.14) $$e_{p*} = V_W + V_L - \frac{n}{n-1} V_L .$$

(iii) e_p* is uniformly conservative over p and q.

<u>proof</u>:

Parts (i) and (ii) are straightforward. To prove part (iii) first note that k(p) is minimized by choosing p = (1/n, ..., 1/n). Therefore

(5.15) $$e_p* \leq e_p$$

for every p. This means that

$$(5.16) \qquad E(e_p^*/p,q) \le E(e_p/p,q)$$

for every p. But the RHS of (5.16) equals π by Proposition 3.

QED

Proposition 4 thus provides an extremely conservative method for estimating π. If every entrant has an equal chance of winning, then e_p^* is an unbiased estimator. For any other p, e_p^* will underestimate π. This is a useful estimator because it provides an unambiguous lower bound on the size of π. However, it is clear that for the twelve contests considered, not every contestant had an equal chance of winning every contest. Therefore e_p^* will probably underestimate the true size of the prize. Thus it might be useful to calculate another estimate which is less conservative.

The estimator $e_p^*$is constructed by assuming that p is absolutely symmetric so that k(p) is minimized. If p is assumed to be less symmetric, k(p) will rise and a less conservative estimator is produced. Therefore one possible approach for constructing a less conservative, but still plausible estimator would be to assume that p was somewhat less symmetric. A natural assumption to make is that p is drawn from a uniform distribution - i.e. - every p is equally likely. Let E(/u,q) denote the expectation operator conditional on the project not being cancelled given that p is distributed uniformly and for a given q.

Definition

An estimator e is said to be unbiased uniformly over q given u if

(5.17) $$E(e \,/\, u,q) = \pi$$

for every q.

Now define the estimator e_u by

(5.18) $$e_u = V_W + V_L - k(u)V_L$$

(5.19) where $k(u) = \dfrac{n+1}{n-1}$.

Proposition 5 shows that e_u is unbiased in the above sense.

Proposition 5:

The estimator e_u is unbiased uniformly over q given u.

proof:

Straightforward but tedious calculus shows that

(5.19) $$E\left(\sum_{i=1}^{n} p_i(1-p_i)/u,q\right) = \frac{n-1}{n+1} .$$

Now from (5.18)

$$(5.20) \qquad E(e_u/u,q) = E(V_W + V_L/u,q) - \frac{n+1}{n-1} E(V_L/u,q) \ .$$

Substitution of (5.8) and (5.9) into (5.20) yields

$$(5.21) \qquad E(e_u/u,q) = q\pi + \frac{n+1}{n-1} (1-q)\pi \ E\left(\sum_{i=1}^{n} p_i(1-p_i)/u,q\right)$$

Substitution of (5.19) into (5.21) yields the desired result.

QED

Note that e_u is of the same form as e_{p^*}. They both equal $(V_W + V_L)$ plus a constant times $-V_L$. However $k(u)$ is greater than $k(p^*)$. Thus e_u does produce somewhat larger estimates of π.

For all the contests considered in Section 6 there are either two or three contestants. Table 5.1 shows the values of $k(p^*)$ and $k(u)$ for these two values of n.

Table 5.1

Values of $k(p^*)$ and $k(u)$

Number of contestants (n)	$k(p^*)$	$k(u)$
2	2	3
3	1.5	2

Thus the theory developed in this section has one testable prediction. This is that $V_W \geq -V_L$. It also provides two rules for calculating π based on observed values of V_W and V_L. Section 6 will now consider data from a number of major aerospace contests in order to test the prediction and then calculate the size of prizes which were offered in these contests.

6. Estimation of Changes in Market Value

A. Event-Study Methodology

This section considers twelve major aerospace projects and estimates the changes which occurred in the market values of firms competing to be the prime contractor resulting from the announcement of which firm was selected to be the prime. There is a well-established methodology in the accounting and finance literatures for estimating the effect of various events on firms' market values. Such studies are called "event studies." This basic methodology will be followed in this section.[48]

Data was gathered for twelve major aerospace systems. Daily stock market data for the involved firms was obtained from the CRSP tapes.[49] The name of the programs, the date on which a winner was announced and the identity of the winners and losers is presented in Table 6.1. Most of this data was contained in two Rand reports, Smith et. al. [1981] and Smith and Friedman [1980]. In addition the data was independently gathered directly from Wall Street Journal articles for every system.

Consideration was limited to one sector of the defense industry simply for tractability. The aerospace sector was chosen because there were a large number of major contests and innovation is clearly an important factor. Attention had to be limited to contests which occurred in 1963 or after since this is when daily stock returns from the CRSP files are available. The twelve projects considered include every major aerospace system which could be identified since 1963 for which a prime contractor was selected from a well defined competition among two or more firms except for the Apache AH64 helicopter. The reason this could not be included is that the winner of the

Table 6.1

Description of Events

Program	Date	Winner	Loser
F14	01/15/69	Grumman	McDonnell Douglas
S3	08/01/69	Lockheed	GD
E3A	07/08/70	Boeing	McDonnell Douglas
A10	01/18/73	Fairchild	Northrop
F16	01/13/75	GD	Northrop
UH60	12/23/76	United Technologies (Sikorsky)	Boeing (Vertol)
KC10	12/19/77	McDonnell Douglas	Boeing
A7	02/11/64	LTV	North American Douglas
C5A	09/30/65	Lockheed	Boeing Douglas
F15	12/23/69	McDonnell Douglas	Fairchild Rockwell
B1	06/05/70	Rockwell	Boeing GD
F18*	05/02/75	McDonnell Douglas Northrop	GD LTV

*For the F18 McDonnell Douglas and Northrop competed as a team against the team of GD and LTV.

competition, Hughes Helicopter, was privately owned at the time of the award so no stock market data was available.[50]

The method used to calculate the change in market values will now be described. To do this some notation will be necessary. Let t be a time index in days where day 0 is the formal announcement day, day -1 (+1) is one day before (after) the formal announcement day, etc. Let i be the index number of a particular firm. Then let n_t^i denote the number of common shares outstanding for firm i at the end of day t. Let p_t^i denote the price of a share of common stock of firm i at the end of day t. Finally let d_t^i be the value of all dividends which would be received by a person who purchased one share of stock of firm i at the end of day t-1 and sold the share of stock at the end of day t.

Let Y_t^i denote the daily return of firm i on date t. In terms of the above variables it is defined by

$$(6.1) \qquad Y_t^i = \frac{p_t^i - p_{t-1}^i + d_t^i}{p_{t-1}^i} .$$

The market value of firm i at the end of day t, denoted by M_t^i, can be defined by

$$(6.2) \qquad M_t^i = n_t^i p_t^i .$$

Finally let X_t^i denote the daily market rate of return. This is defined by

$$(6.3) \qquad X_t^i = \sum_{i \varepsilon I} w_t^i Y_t^i$$

where I is the index set of all firms recorded on the CRSP tapes[51] and w_t^i is weighting factor defined by

$$(6.4) \qquad w_t^i = \frac{M_{t-1}^i}{\sum_{j \varepsilon I} M_{t-1}^j} .$$

This is the daily return that an investor would experience if he owned an equal fraction of all firms in the market.

The naive (and most straightforward) approach to calculating the change in market value for a given firm would be to simply take the difference between the firm's market value before and after the event. However there are two major problems with this naive approach. First, it ignores the effects of market-wide movements in stock prices. Second, it does not provide a precise method for determining whether an observed change in market value is unusually large relative to the normal variation in the market value of the company.

The standard event-study methodology is designed to deal with both these issues. It is based on the assumption that a particular firm's daily return is stochastically related to the daily return of the market according to

$$(6.5) \qquad Y_t^i = \alpha_i + \beta_i X_t^i + u_t^i$$

where the u_t^i are independent normal random variables with zero mean and variance σ_i^2. The procedure is to estimate α_i, β_i, and σ_i^2 and then use these estimates to predict what daily returns should have been on the event days given the market returns on those days. One can then factor out market-induced changes by subtracting the predicted return from the actual return to get an excess return. The excess return on date t can be multiplied by the market value of the firm on date t-1 to yield an estimate of the change in the firm's market value on date t in excess of changes in value related to market wide movements. Finally the estimation procedure allows one to construct confidence intervals for the estimated excess returns so one can statistically test in a precise way whether observed daily returns were unusually large during the event days. The procedures used and results obtained will now be described in more detail.

B. Estimation of Daily Excess Returns

For each event, relationship (6.5) was estimated for each firm by regressing the firm's daily return on the market's daily return for days -120 to -21.[52] Since it is hypothesized the announcement generated an unusual change in the firm's values, the relationship was estimated for days well away from the announcement day. Table 6.2 presents the estimates of α and β and the standard error of the regression for each firm for each event. Each item in the column labelled "Firm" consists of the weapon name followed by a natural firm abbreviation. Thus, for example, the first element in column one, "F14 GRU", denotes "F14 Grumman".

Table 6.2
Regression Results

FIRM	ALPHA	BETA	s
F14GRU	-0.000030	1.765013	0.029250
F14MCD	-0.002160	1.221200	0.017926
F14TOT	-0.001900	1.308783	0.015433
S3LOC	-0.004080	0.649246	0.019207
S3GD	-0.003800	0.514725	0.016017
S3TOT	-0.004010	0.585501	0.012714
E3ABOE	-0.000350	1.952020	0.026361
E3AMCD	-0.000370	1.944650	0.021605
E3ATOT	-0.000500	1.942444	0.018178
A10FAI	-0.001380	0.840284	0.024690
A10NOR	-0.000010	-0.001160	0.014334
A10TOT	-0.000510	0.247853	0.012233
F16GD	0.000222	0.943447	0.033225
F16NOR	0.001358	0.286198	0.023976
F16TOT	0.000311	0.701402	0.021858
UH60UT	-0.000180	0.943623	0.009970
UH60BOE	0.000997	1.609505	0.014397
UH60TOT	0.000357	1.277268	0.008864
KC10MCD	0.000250	1.800084	0.013909
KC10BOE	0.000817	1.905701	0.014570
KC10TOT	0.000512	1.859442	0.010677
A7LTV	-0.000370	1.746591	0.023624
A7ROC	-0.001870	1.226747	0.015775
A7DOU	-0.000800	1.272312	0.019907
A7LOS	-0.001710	1.229965	0.014011
A7TOT	-0.001630	1.272680	0.013373
C5ALOC	0.001857	1.163980	0.011214
C5ABOE	0.001944	1.616939	0.013187
C5ADOU	0.001974	2.378576	0.017463
C5ALOS	0.001924	1.790401	0.012277
C5ATOT	0.001877	1.532639	0.009706
F15MCD	-0.001350	1.910256	0.017058
F15FAI	0.001314	2.367252	0.028112
F15ROC	-0.001430	0.820210	0.011711
F15LOS	-0.001240	0.942262	0.010898
F15TOT	-0.001350	1.422715	0.010769
B1ROC	-0.001130	0.816629	0.018172
B1BOE	-0.000350	1.952020	0.026361
B1GD	0.001339	0.482653	0.027026
B1LOS	0.000001	1.448159	0.019828
B1TOT	-0.000520	1.204532	0.013292
F18MCD	0.000204	0.559305	0.027493
F18NOR	0.000816	0.423986	0.020484
F18GD	0.004213	1.132315	0.034505
F18LTV	0.001504	1.160060	0.031500
F18WIN	0.000242	0.523092	0.021848
F18LOS	0.003310	1.136364	0.027833
F18TOT	0.001377	0.759242	0.018203

Note that a number of "artificial firms" have been created in order to estimate (6.5) for them as well. For each event with three or more contestants, the artificial firm consisting of all the losers was created. This is denoted LOS. For every contest the artificial firm consisting of every contestant was created. This is denoted by TOT. Finally, for the case of the F18, the competition was between two teams consisting of two firms each. The artificial firm consisting of the two winners is denoted by F18WIN. It is straightforward to construct the daily returns which would have occurred for any artifical firm defined to be the union of any group of firms. Let I denote the set of index numbers of firms which are desired to be united in the artificial firm. Let Y_t^a denote the daily return of the artificial firm. This is defined by.

$$(6.7) \qquad Y_t^a = \sum_{j \varepsilon I} w_t^j Y_t^j$$

where

$$(6.8) \qquad w_t^i = \frac{M_{t-1}^i}{\sum_{j \varepsilon I} M_{t-1}^j} .$$

The value Y_t^a is the daily return that an investor would have earned on day t from a portfolio which consisted of an equal share of all the firms in I. Relationship (6.5) was estimated for all the artificial composite firms.

This provides a convenient and direct method for directly estimating V_L (by using the LOS firm) and $V_H + V_L$ (by using the TOT firm).

The regression results are now used as follows. Let $\hat{\alpha}_i$, $\hat{\beta}_i$, and s_i be the estimated values of α_i and β_i and the standard error for firm i. For days -20 through +20 firm i's return can be predicted using the actual market return by the equation

$$(6.9) \qquad \hat{Y}_t^i = \hat{\alpha}_i + \hat{\beta}_i X_t^i .$$

Then the excess return of firm i on day t can be defined as

$$(6.10) \qquad E_t^i = Y_t^i - \hat{Y}_t^i .$$

Thus E_t^i is the daily return of firm i on day t corrected for movements in the entire market.

In order to test whether or not there were significant excess returns associated with the contest announcement the distribution of E_t^i under the null hypothesis that there was no effect can be calculated. Under this assumption E_t^i is distributed normally with mean zero and variance $\sigma_i^2 \gamma_i^2$

where

$$(6.11) \qquad \gamma_i^2 = \left[1.01 + \frac{(X_t^i - \bar{X})^2}{\sum_{t=-120}^{-21} (X_t^i - \bar{X})^2} \right]$$

and

$$(6.12) \qquad \bar{X} = \frac{\sum_{t=-120}^{-21} X_t^i}{100} .$$

Let Z_t^i denote the following .

$$(6.13) \qquad Z_t^i = \frac{E_t^i}{s_i \gamma_i}$$

This is the t-statistic for E_t^i and has 98 degrees of freedom. Thus for any firm i and any day t, one can test whether E_t^i is significantly different from zero by using the t-statistic Z_t^i.

Tables (6.3) and (6.4) present the aggregated results across all twelve events. Table (6.3) presents the average daily excess returns. The first column, labelled WIN, gives the average daily return of the winning firm. Let E_t^W denote the entry for date t in the WIN column. Let I_W denote the set of twelve index numbers for the twelve winning firms.[53] Then E_t^W is defined by

(6.14) $$E_t^W = \sum_{i \varepsilon I_W} E_t^i \;/12$$

The second column, labelled LOS, gives the average daily return of the losing firm. Let E_t^L denote the entry for date t in the LOS column. Let I_L denote the set of twelve index numbers for the twelve losing firms.[54] Then E_t^L is defined by

(6.15) $$E_t^L = \sum_{i \varepsilon I_L} E_t^i \;/12 \;.$$

The third column labelled TOT gives the average daily return for all contestants, both winners and losers. Let E_t^L denote the entry for date t in the TOT column. Let I_T denote the set of twelve index numbers of the artificial TOT firms. Then E_t^T is defined by

(6.16) $$E_t^T = \sum_{i \varepsilon I_T} E_t^i \;/12 \;.$$

Table (6.4) presents the t-statistic for the daily returns in Table (6.3). Let E_t^ℓ denote an entry in Table (6.3) (where ℓ equals W,L, or T). Each of the twelve elements E_t^i for $i \varepsilon I_\ell$ is independent of the other eleven and is essentially normally distributed with mean zero and variance $s_i^2 \gamma_i^2$, under the null hypothesis.[55] Therefore E_t^ℓ is normally distributed with mean zero and variance given by

Table 6.3

Daily Excess Returns

DATE	WIN	LOS	TOT
-20	-0.0126	-0.0067	-0.0095
-19	0.0010	0.0038	0.0009
-18	0.0154	0.0032	0.0095
-17	0.0027	0.0027	0.0018
-16	0.0052	0.0022	0.0043
-15	0.0051	0.0048	0.0041
-14	0.0000	0.0024	0.0045
-13	0.0024	-0.0006	0.0005
-12	-0.0016	-0.0049	-0.0030
-11	-0.0025	-0.0008	-0.0003
-10	0.0153	-0.0005	0.0071
-9	0.0110	0.0103	0.0115
-8	0.0067	-0.0025	0.0000
-7	0.0081	-0.0079	-0.0024
-6	0.0051	0.0060	0.0069
-5	0.0007	0.0127	0.0071
-4	0.0003	0.0005	-0.0010
-3	0.0030	0.0055	0.0040
-2	0.0087	0.0069	0.0055
-1	0.0155	0.0106	0.0169*
0	0.0760*	-0.0284*	0.0167*
1	0.0098	-0.0324*	-0.0107*
2	-0.0168*	-0.0065	-0.0119*
3	-0.0231*	0.0005	-0.0120*
4	-0.0096	0.0056	0.0007
5	-0.0039	-0.0010	-0.0018
6	0.0018	-0.0012	0.0000
7	-0.0041	-0.0029	-0.0030
8	-0.0053	0.0005	-0.0019
9	-0.0103	-0.0108	-0.0091
10	-0.0016	-0.0096	-0.0047
11	-0.0122	-0.0049	-0.0077
12	-0.0018	0.0024	0.0023
13	-0.0017	-0.0009	-0.0013
14	0.0034	0.0003	0.0015
15	0.0002	0.0054	0.0036
16	0.0056	0.0017	0.0016
17	0.0003	-0.0017	-0.0022
18	0.0050	0.0050	0.0046
19	-0.0084	0.0059	-0.0005
20	0.0036	0.0065	0.0052

*Significant at the 99% level ($t_{.005} = 2.6$)

Table 6.4

t-Statistics for Daily Excess Returns

DATE	WIN	LOS	TOT
-20	-1.982	-1.280	-2.285
-19	0.157	0.726	0.216
-18	2.423	0.611	2.282
-17	0.424	0.514	0.432
-16	0.818	0.420	1.034
-15	0.794	0.907	0.975
-14	0.000	0.458	1.082
-13	0.377	-0.114	0.120
-12	-0.251	-0.932	-0.719
-11	-0.392	-0.152	-0.072
-10	2.403	-0.095	1.702
-9	1.725	1.952	2.750
-8	1.054	-0.477	0.000
-7	1.247	-1.467	-0.564
-6	0.796	1.136	1.647
-5	0.110	2.412	1.700
-4	0.047	0.095	-0.239
-3	0.472	1.051	0.962
-2	1.364	1.313	1.317
-1	2.423	2.011	4.035*
0	11.853*	-5.370*	3.974*
1	1.540	-6.177*	-2.568*
2	-2.647*	-1.242	-2.863*
3	-3.644*	0.096	-2.890*
4	-1.507	1.068	0.168
5	-0.615	-0.191	-0.433
6	0.283	-0.229	0.000
7	-0.643	-0.550	-0.717
8	-0.837	0.096	-0.458
9	-1.617	-2.059	-2.184
10	-0.251	-1.830	-1.127
11	-1.922	-0.936	-1.852
12	-0.283	0.457	0.552
13	-0.268	-0.172	-0.313
14	0.536	0.057	0.361
15	0.031	1.031	0.865
16	0.882	0.325	0.385
17	0.047	-0.325	-0.529
18	0.785	0.955	1.105
19	-1.324	1.128	-0.120
20	0.567	1.241	1.251

*Significant at the 99% level ($t_{.005} = 2.6$).

$$(6.17) \qquad \sum_{i \varepsilon I_{\ell}} s_i^2 \gamma_i^2 /144 .$$

The t-statistic for E_t^{ℓ} (with infinite degrees of freedom) is therefore given by

$$(6.18) \qquad Z_t^{\ell} = \frac{12 E_t^{\ell}}{\sqrt{\sum_{i \varepsilon I_{\ell}} s_i^2 \gamma_i^2}} .$$

The daily returns for the winner, loser, and total firms are graphed in Figures (6.1) to (6.3). Daily returns are significant at the 99% level are circled.

Figure 6.1 Excess Daily Returns For Winners

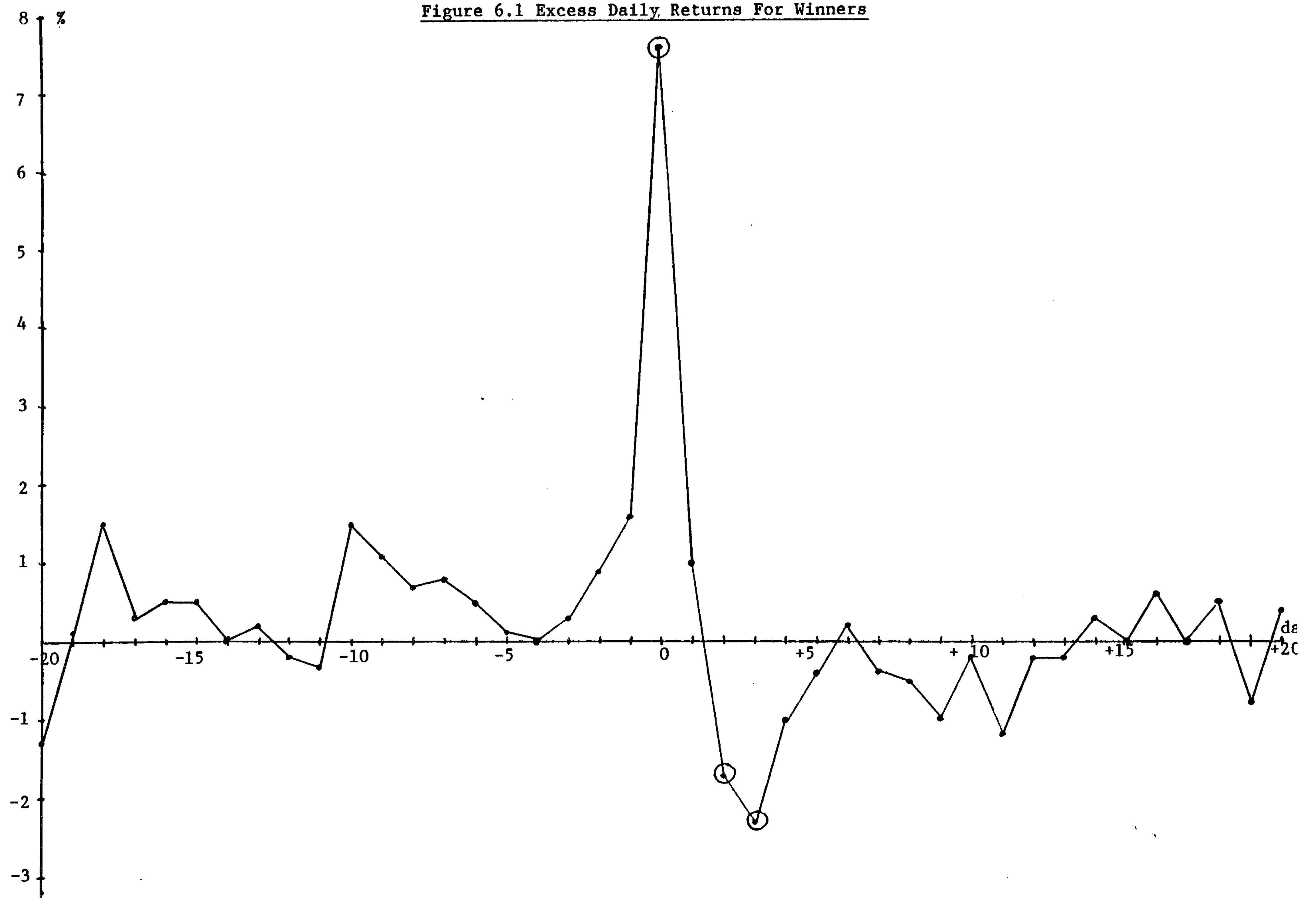


Figure 6.2 Excess Daily Returns For Losers

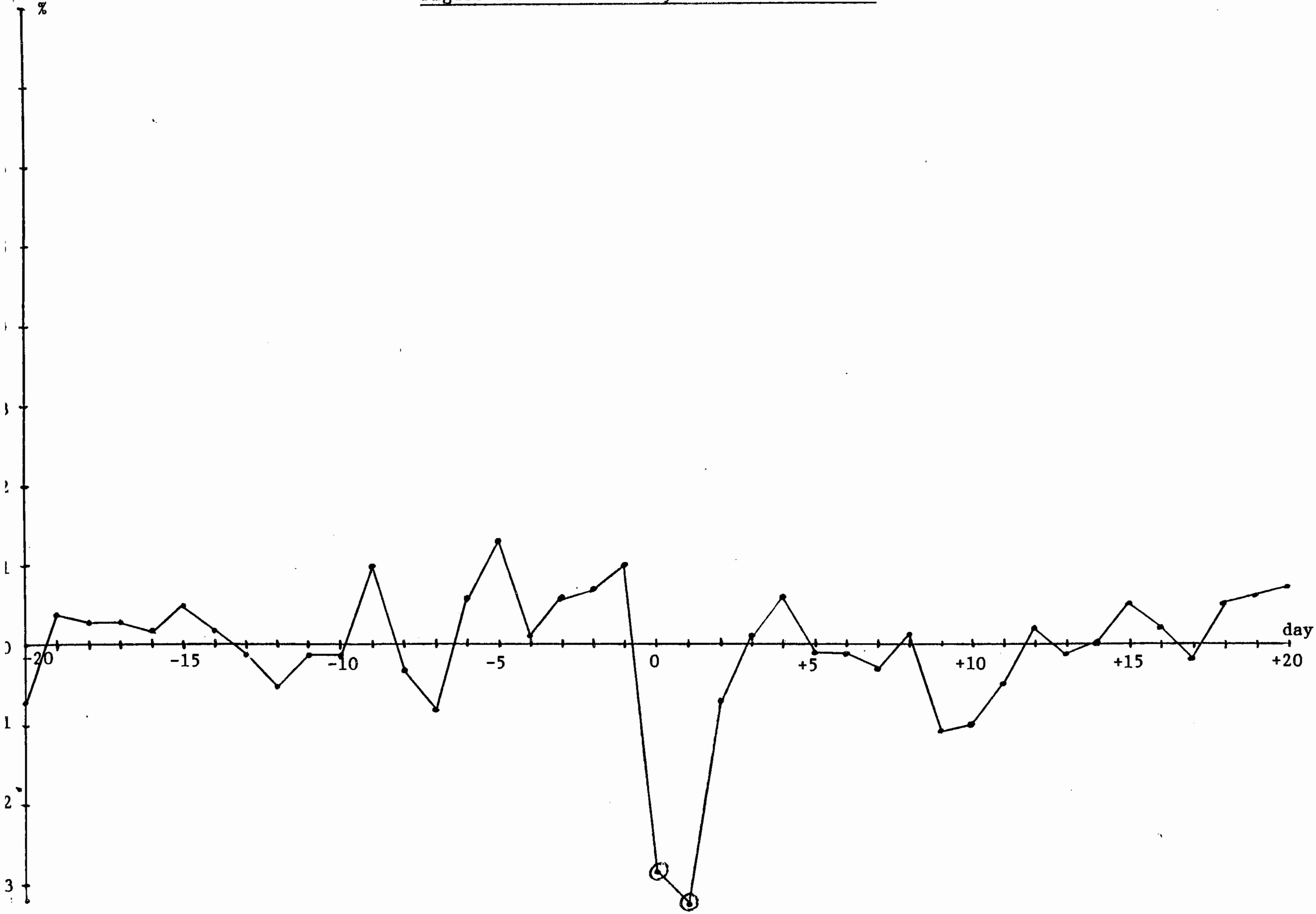
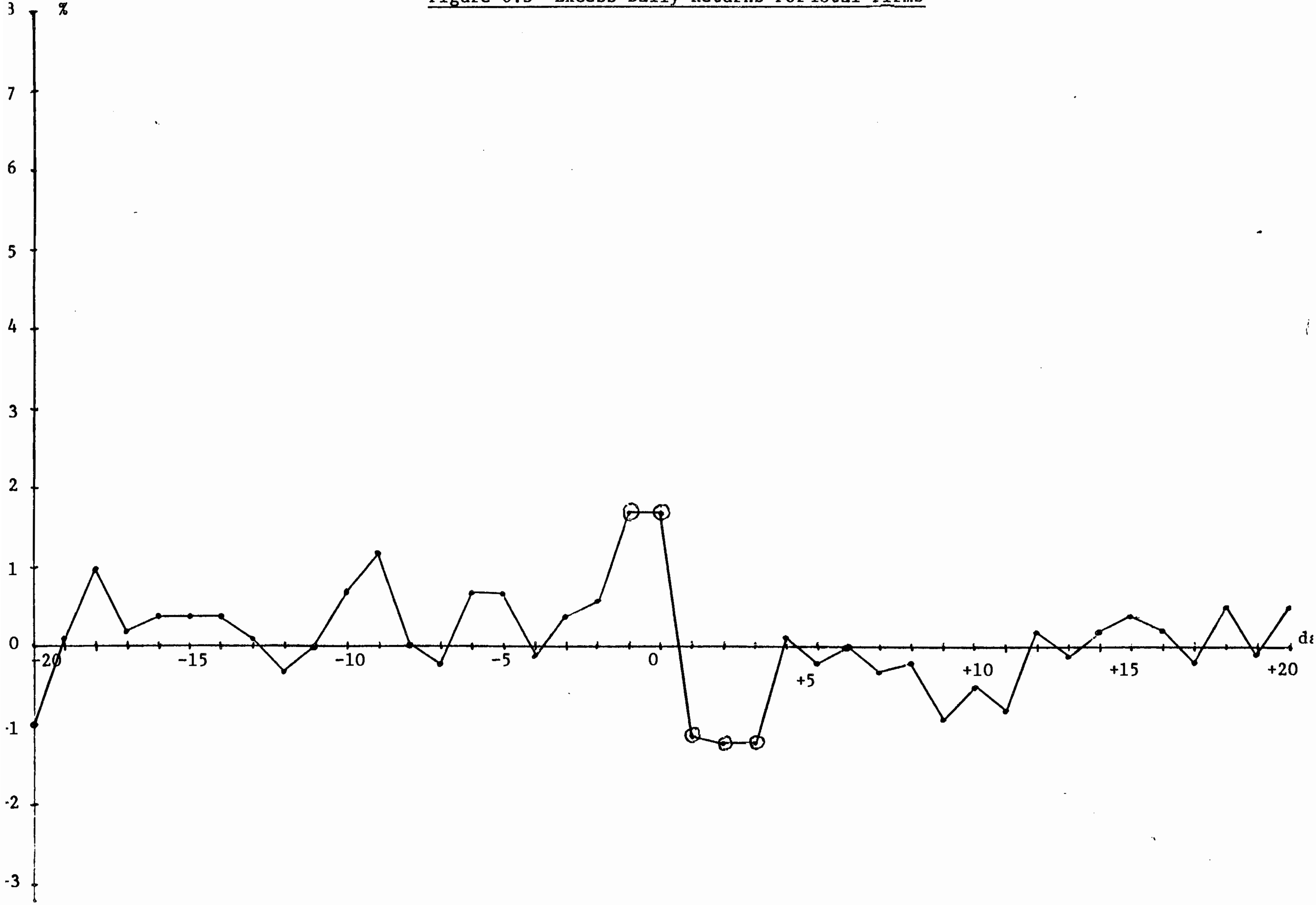


Figure 6.3 Excess Daily Returns For Total Firms



C. Choice of An Event Window

The above data can now be used to investigate the last major question which must be answered in order to calculate V_W and V_L. This concerns which day or days the announcement information was incorporated into the price of the stock. Define the "event window" to be the set of days on which the announcement information was incorporated into the stock price. Let (μ,ν) denote the event window beginning on day μ and running until day ν. Thus (μ, ν) consists of $\nu - \mu + 1$ days.

Without looking at the data, a knowledge of the DoD's announcement procedures suggests that the event window should be assumed to be the two day interval of day 0 and day 1. In theory, DOD's formal announcement procedure is to issue a press release to announce its decision on the formal announcement day (day 0) <u>after</u> the market has closed for the day. Thus news from this press conference should not affect the market value of firms until day 1. In practice the DoD often informs one or more Senators or Congressmen who represent the state which will benefit most from the decision and the decision is sometimes formally announced by them much earlier in the day, often before the market closes. Even if the formal announcement is delayed until after the market closes, a significant number of individuals may be informed of the decision through the politicians' offices prior to the market's close and use this information to trade on.[56] Thus the day on which the information regarding which firm won is incorporated into the stock market value of the firm is probably day 0 or day 1 for most events. Given that it is not possible to directly ascertain which contests were announced on day 0 by a congressional office and which were not, the correct assumption based on a knowledge of DoD's announcement procedure would be to assume that the event occurred on day 0 and 1 for every contest.

Examination of the data is Figures (6.1)-(6.3) provides some support for the claim that the market become aware of the announcement on day 0 or 1 for most contests. The highest daily return for the winning firms was on day 0. The return on day 1 was also positive, although not as large. For the losers, the two days with statistically significant (at the 99% level) daily returns were days 0 and 1. The return on day 1 was even slightly larger (in absolute value) than the return on day 0.

However the data also exhibits some puzzling behavior which suggests that using the two-day event window of days 0 and 1 would not be appropriate. To understand this, first suppose that the market did become aware of the announcement of who won on day 0 or day 1 for all twelve contests. Then one would expect the graphs of daily excess returns for the winners, losers, and total firms to look similar to those graphed in Figures (6.4) - (6.6). The major characteristic of all three graphs is that the daily returns are undisturbed for every day except days 0 and 1. For the winners (losers), the daily return on the announcement days is significantly positive (negative). To the extent that q is greater than zero, the aggregate market value of all contestants is also somewhat positive on the announcement days.

Examination of Figures (6.1) - (6.3) shows that the actual graphs depart from the stylized predicted graphs in one important qualitative fashion. It seems that the market value of <u>all</u> firms (both winners and losers) increased for two or three days prior to day 0 and then decreased for two days after day 1. This same phenomena is illustrated by all three graphs. It is most

Figure 6.4

Stylized Predicted Daily Excess Returns For Winners

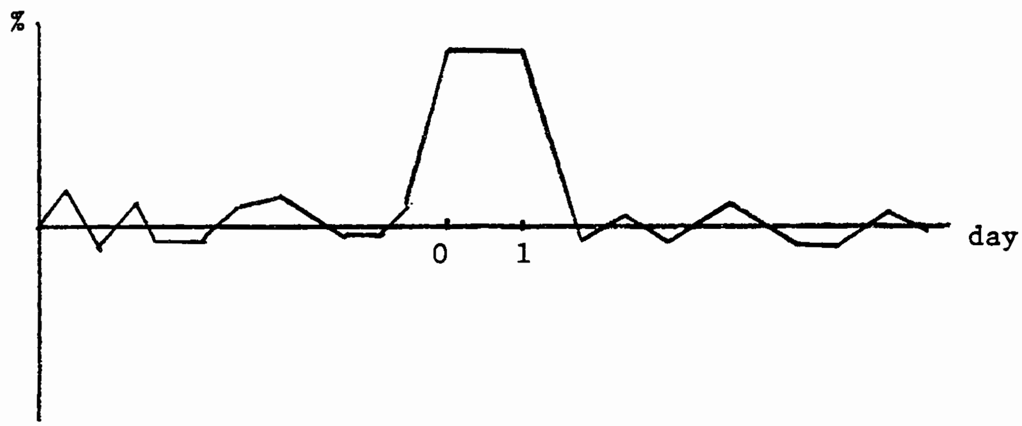


Figure 6.5

Stylized Predicted Daily Excess Returns for Losers

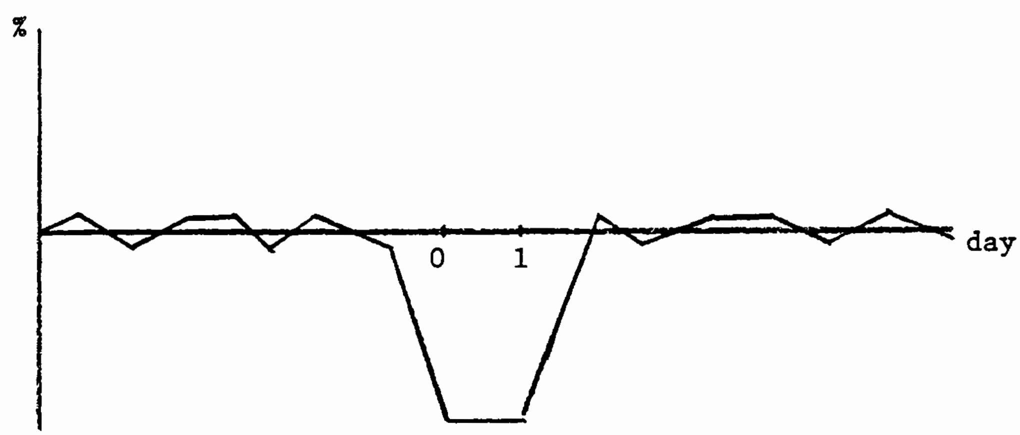
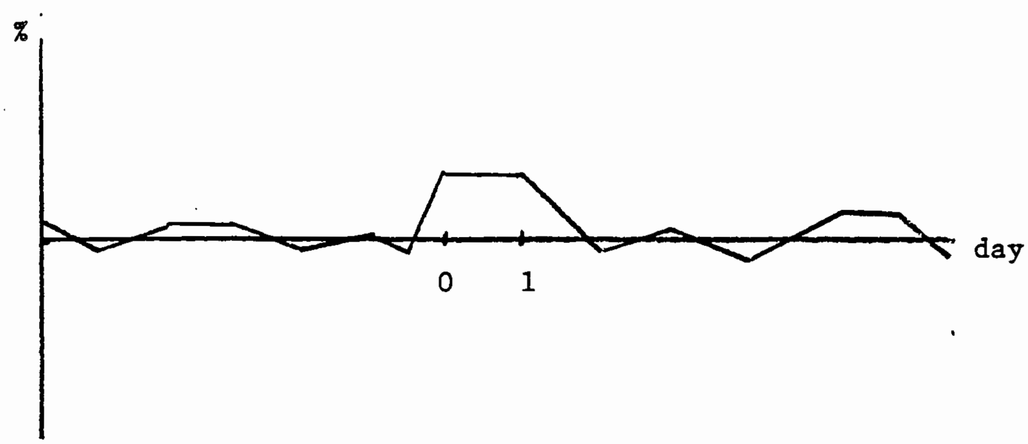


Figure 6.6

Stylized Predicted Daily Excess Returns For Total Firms



clearly illustrated in Figure (6.3) which graphs daily returns for the total firms. The market value of all contestants increased significantly on days -1 and 0 and decreased significantly on the following three days. Daily returns were positive for days -3 to 0 and then negative for days 1 to 3. Figure (6.2) shows that the market value of the losers increased significantly on days -1 and was somewhat positive on days -3 and -2. Figure (6.1) exhibits the same behavior. The positive returns of the winners on days 0 and 1 were followed by two days of significantly negative returns on days 2 and 3. Furthermore returns were positive on days -3 and -1 preceding the announcement.

Thus it appears that a sort of "speculative bubble" effect occurred for the twelve contests. Prices were bid up immediately before and possibly even on the announcement day, only to crash back down immediately after. Even the market value of winners declined somewhat in days following the announcement while even the market value of losers increased somewhat in the days preceding the announcement.

One must factor out the effects of this temporary surge and fall in stock prices in order to estimate the permanent change in firms' values resulting from the announcement. The correct procedure for doing this is to enlarge the event window to include the two or three days of abnormal returns on either side of the announcement day. In this way the calculation of changes in firms' values will ignore any price rises which were immediately negated. The above examination of the data suggests that including two days on either side of days 0 and 1 is necessary since the two days preceding day 0 all have fairly large positive returns while the two days following have negative returns. Returns appear more normal outside this six day window.

The returns of firms aggregated over various possible sizes of event windows will now be calculated in order to provide a more quantitative assessment of the bubble effect and how large an event window must be assumed in order to factor it out. Let $C^i_{\mu,\nu}$ denote the compound excess return to firm i over the days μ to ν. This is defined by

$$(6.19) \qquad C^i_{\mu,\nu} = \left[\prod_{t=\mu}^{\nu} (E^i_t + 1) \right] - 1.$$

Let $E^i_{\mu,\nu}$ denote the non-compound excess return given by

$$(6.20) \qquad E^i_{\mu,\nu} = \sum_{t=\mu}^{\nu} E^i_t \quad .$$

As will be seen, for the small number of days in the event windows being considered, the compound and non-compound returns are almost exactly the same. Although the compound return is the correct return to use for calculating changes in market values over the event, it is also useful to calculate the non-compound return because it is the sum of normal random variables with known means, variances, and covariances and thus its distribution can also be calculated. In particular one can test whether the observed value of $E^i_{\mu,\nu}$ is significantly different from zero.

It is straightforward to show that $E^i_{\mu,\nu}$ is normally distributed with mean zero and variance $(\sigma^i_{\mu,\nu})^2$ defined by

$$(6.21) \qquad (\sigma^i_{\mu,\nu})^2 = \sigma_i^2(\gamma^i_{\mu,\nu})^2$$

where

$$(6.22) \qquad (\gamma^i_{\mu,\nu})^2 = m + \sqrt{m} \quad .01 + \frac{(\phi(i,\mu,\nu) - \bar{X})^2}{\sum_{t-120}^{-21} (X^i_t - \bar{X})^2}$$

$$(6.23) \qquad \phi(i,\mu,\nu) = \sum_{t=\mu}^{\nu} X^i_t \,/m$$

$$(6.24) \qquad m = \nu - \mu + 1$$

$$(6.25) \qquad \bar{X} = \sum_{t=-120}^{-21} X^i_t/100$$

Therefore $Z^i_{\mu,\nu}$, as defined below, is a t-statistic (with 98 degrees of freedom) for $E^i_{\mu,\nu}$.

$$(6.26) \qquad Z^i_{\mu,\nu} = \frac{E^i_{\mu,\nu}}{s_i \gamma^i_{\mu,\nu}} \quad .$$

As for the daily returns, the average of the event window returns over all twelve contests for winners, losers and total firms can be calculated. Let $C^{\ell}_{\mu,\nu}$ denote the compound return over the event window for group ℓ (recall ℓ can equal W,L, or T). It is defined by

$$(6.27) \qquad C^{\ell}_{\mu,\nu} = \sum_{i \varepsilon I_{\ell}} C^{i}_{\mu,\nu} /12 .$$

The average non-compounded return is similarly defined by

$$(6.28) \qquad E^{\ell}_{\mu,\nu} = \sum_{i \varepsilon I_{\ell}} E^{i}_{\mu,\nu} /12 .$$

Each $E^{i}_{\mu,\nu}$ can be viewed as normal with mean zero and variance $s_i^2(\gamma^{i}_{\mu,\nu})^2$.[57]

They are also independent of one another. Therefore $E^{\ell}_{\mu,\nu}$ is also normally distributed with mean zero and variance $(\sigma^{\ell}_{\mu,\nu})^2$ defined by

$$(6.29) \qquad (\sigma^{\ell}_{\mu,\nu})^2 = \frac{\sum_{i \varepsilon I_{\ell}} s_i^2(\gamma^{i}_{\mu,\nu})^2}{144} .$$

Therefore $Z^{\ell}_{\mu,\nu}$ is the t-statistic (with infinite degrees of freedom) for $E^{\ell}_{\mu,\nu}$ where $Z^{\ell}_{\mu,\nu}$ is defined by

$$(6.30) \qquad Z^{\ell}_{\mu,\nu} = \frac{12\ E^{\ell}_{\mu,\nu}}{\sqrt{\sum_{i \epsilon I_{\ell}} s_i^2\ (\gamma^{i}_{\mu,\nu})^2}} \ .$$

Tables (6.5) to (6.7) present, respectively, the compound returns, non-compound returns and the t-statistics for the non-compound returns for a variety of different event windows. Each table first considers the two day event window consisting of days 0 and 1. It then expands the window thirteen times by adding two days at a time (one on each side) up to the event window from -13 to +14. Then each table considers the event window consisting solely of day 0 and expands it thirteen times by adding two days at a time (one on each side) up to the event window from -13 to +13.

Table (6.5) also supports the conclusion of the graphical analysis that expansion of the event window by two days on either side of days 0 and 1 (i.e. -- so the event window is day -2 to 3) captures most of the speculative effects in the vicinity of the announcement. Further expansion leaves the cumulative percentage changes relatively unchanged. Thus in the next section it will be assumed that the event window is (-2,3).

Table (6.5) shows that simply using the two day event window of 0 and 1 may overstate the percentage changes of the winners and losers. As the event window is expanded, the percentage changes of both the winners and losers decrease somewhat in absolute value. Figure (6.1) shows that the winners experienced large price drops on days 2 and 3 which were larger than the price rises on days -1 or -2. Thus expanding the window reduces the winners' percentage change. Similarly Figure (6.2) shows that the losers experienced

Table 6.5

Compound Excess Returns For Various Event Windows

μ	ν	WIN	LOS	TOT
0	1	0.0851	-0.0601	0.0057
- 1	2	0.0825	-0.0558	0.0100
- 2	3	0.0656	-0.0499	0.0033
-3	4	0.0580	-0.0390	0.0081
-4	5	0.0545	-0.0394	0.0058
-5	6	0.0582	-0.0298	0.0128
-6	7	0.0594	-0.0276	0.0165
-7	8	0.0604	-0.0342	0.0113
-8	9	0.0548	-0.0469	0.0017
-9	10	0.0656	-0.0452	0.0089
-10	11	0.0701	-0.0505	0.0084
-11	12	0.0647	-0.0487	0.0102
-12	13	0.0618	-0.0547	0.0064
-13	14	0.0685	-0.0544	0.0085
0	0	0.0760	-0.0284	0.0167
-1	1	0.1024	-0.0496	0.0226
-2	2	0.0916	-0.0501	0.0155
-3	3	0.0684	-0.0447	0.0071
-4	4	0.0584	-0.0389	0.0072
-5	5	0.0563	-0.0273	0.0133
-6	6	0.0640	-0.0244	0.0197
-7	7	0.0656	-0.0351	0.0132
-8	8	0.0664	-0.0368	0.0109
-9	9	0.0667	-0.0365	0.0133
-10	10	0.0834	-0.0455	0.0162
-11	11	0.0669	-0.0512	0.0080
-12	12	0.0631	-0.0541	0.0073
-13	13	0.0645	-0.0548	0.0070

Table 6.6

Non-Compound Excess Returns For Various Event Windows

μ	ν	WIN	LOS	TOT
0	1	0.0858	-0.0608	0.0060
-1	2	0.0845	-0.0567	0.0110
-2	3	0.0700	-0.0493	0.0045
-3	4	0.0634	-0.0381	0.0092
-4	5	0.0599	-0.0386	0.0064
-5	6	0.0624	-0.0271	0.0135
-6	7	0.0635	-0.0239	0.0174
-7	8	0.0663	-0.0314	0.0132
-8	9	0.0626	-0.0447	0.0041
-9	10	0.0721	-0.0440	0.0109
-10	11	0.0752	-0.0495	0.0103
-11	12	0.0709	-0.0479	0.0123
-12	13	0.0676	-0.0537	0.0080
-13	14	0.0734	-0.0539	0.0101
0	0	0.0760	-0.0284	0.0167
-1	1	0.1013	-0.0502	0.0229
-2	2	0.0932	-0.0498	0.0165
-3	3	0.0730	-0.0437	0.0085
-4	4	0.0638	-0.0376	0.0082
-5	5	0.0606	-0.0258	0.0135
-6	6	0.0676	-0.0211	0.0204
-7	7	0.0715	-0.0319	0.0151
-8	8	0.0729	-0.0339	0.0131
-9	9	0.0737	-0.0344	0.0156
-10	10	0.0874	-0.0446	0.0180
-11	11	0.0727	-0.0503	0.0100
-12	12	0.0693	-0.0528	0.0093
-13	13	0.0700	-0.0542	0.0086

Table 6.7

t Statistics For Non-Compound Excess Returns For Various Event Windows*

μ	ν	WIN	LOS	TOT
0	1	9.556	-8.215	1.020
-1	2	6.682	-5.440	1.328
-2	3	4.527	-3.868	0.444
-3	4	3.552	-2.590	0.787
-4	5	3.003	-2.348	0.490
-5	6	2.856	-1.505	0.944
-6	7	2.691	-1.229	1.126
-7	8	2.629	-1.510	0.799
-8	9	2.340	-2.027	0.234
-9	10	2.557	-1.893	0.590
-10	11	2.543	-2.031	0.532
-11	12	2.296	-1.882	0.608
-12	13	2.103	-2.027	0.380
-13	14	2.201	-1.961	0.463
0	0	11.853	-5.370	3.974
-1	1	9.236	-5.552	3.188
-2	2	6.599	-4.278	1.784
-3	3	4.372	-3.175	0.778
-4	4	3.371	-2.411	0.662
-5	5	2.897	-1.496	0.986
-6	6	2.973	-1.126	1.370
-7	7	2.928	-1.585	0.944
-8	8	2.804	-1.582	0.770
-9	9	2.682	-1.519	0.867
-10	10	3.025	-1.873	0.952
-11	11	2.405	-2.019	0.505
-12	12	2.199	-2.033	0.451
-13	13	2.137	-2.008	0.401

*$t_{.005} = 2.6$

large price increases on days -1 and -2 which were larger than price drops on days 2 or 3. Thus expanding the window also reduces the losers' percentage change in absolute value. Therefore expansion of the window beyond days 0 and 1 produces a more conservative estimate of the price changes.

Note that choice of a larger event window than (-2,3) would not change the results significantly. Also note that expansion of the window around day 0 to yield event windows of the form (-t,t) yields similar results. Expansion of the window to run from day -3 to day 3 captures most of the speculative effects and yields very similar percentage changes to those from using the window(-2,3).

Finally, some note should be taken of the statistical significance of the percentage changes as presented in Table (6.7). In general the t-statistics become smaller in absolute value as the event window is expanded. This is for two reasons. First, the percentage changes become smaller in absolute value over the first two expansions. However, for the remaining expansions, the percentage changes remain relatively constant. The continuing reduction of the t-statistics reflects the fact that a large percentage change is more likely to occur over a longer event window. (It is unusual for G.D. stock to fall 10% in one day. However the same change over two years would be much less surprising). Because of this second effect, expansion of the event window beyond (0,1) necessarily reduces the statistical significance of the results somewhat below what they "should" be. Unfortunately this was necessary in order to factor out speculative movements in the neighborhood of the announcement.

Note, however, that the percentage changes of the WIN, LOS, and TOT firms are all strongly in accord with the theoretical predictions of the previous section. First, the percentage change of the WIN firms is significantly positive at the 99% level in accord with the prediction that V_W is positive. Second, the percentage change of the LOS firms is significantly negative at the 99% level in accord with the prediction that V_L is negative. Finally the percentage change of the TOT firms is positive but not significantly so. This agrees with the prediction that $V_W + V_L$ is non-negative.

D. Estimation of Changes in Firm Value

The remaining analysis of this paper will now focus on the event window (-2,3). Table (6.8) presents non-compound percentage changes (E), t-statistics for the non-compound percentage changes (t), the compounded percentage changes (C), and changes in firm value for all firms. The changes in firm value are calculated using the compound percentage change. Let $V^i_{\mu,\nu}$ denote the estimated change in value of firm i over (μ,ν). It is calculated by

$$(6.31) \qquad V^i_{\mu,\nu} = C^i_{\mu,\nu} \quad M^i_{\mu-1} \ .$$

where $M^i_{\mu-1}$ denotes the market value of firm i on day μ-1.

Table 6.8
Firm Data For Event Window (-2,3)

FIRM	E	t	C	V (thousands of dollars)
F14GRU	0.0289	0.402	0.0286	8574
F14MCD	0.0241	0.547	0.0220	27613
F14TOT	0.0254	0.672	0.0244	37941
S3LOC	0.0853	1.798	0.0811	22471
S3GD	-0.0343	-0.867	-0.0348	-9146
S3TOT	0.0259	0.825	0.0251	13552
E3ABOE	0.0532	0.821	0.0328	8964
E3AMCD	0.0693	1.305	0.0705	25751
E3ATOT	0.0573	1.283	0.0557	35568
A10FAI	0.1397	2.305	0.1321	6403
A10NOR	-0.1364	-3.875	-0.1298	-13914
A10TOT	-0.0476	-1.585	-0.0485	-7550
F16GD	0.0686	0.840	0.0626	13592
F16NOR	-0.1107	-1.880	-0.1191	-13013
F16TOT	0.0073	0.136	0.0049	1599
UH60UT	0.0473	1.930	0.0478	44727
UH60BOE	-0.0637	-1.799	-0.0625	-59619
UH60TOT	-0.0080	-0.365	-0.0079	-14928
KC10MCD	0.0263	0.769	0.0263	23836
KC10BOE	-0.0590	-1.651	-0.0580	-71616
KC10TOT	-0.0221	-0.842	-0.0220	-47104
A7LTV	0.0689	1.188	0.0695	3484
A7ROC	0.0198	0.511	0.0192	8095
A7DOU	0.0150	0.307	0.0130	1301
A7LOS	0.0189	0.551	0.0183	9547
A7TOT	0.0234	0.713	0.0231	13209
C5ALOC	0.0166	0.603	0.0148	8910
C5ABOE	-0.0331	-1.022	-0.0346	-28882
C5ADOU	-0.1024	-2.388	-0.1051	-27250
C5ALOS	-0.0503	-1.669	-0.0512	-56014
C5ATOT	-0.0273	-1.144	-0.0276	-46811
F15MCD	0.0632	1.508	0.0601	42842
F15FAI	-0.1824	-2.644	-0.1943	-13264
F15ROC	-0.0691	-2.405	-0.0769	-43866
F15LOS	-0.0804	-3.006	-0.0886	-56589
F15TOT	-0.0076	-0.288	-0.0104	-14056
B1ROC	0.0915	2.050	0.0811	33128
B1BOE	-0.0759	-1.173	-0.0747	-28298
B1GD	-0.0811	-1.222	-0.0801	-18565
B1LOS	-0.0756	-1.552	-0.0738	-45062
B1TOT	-0.0088	-0.268	-0.0111	-11312
F18MCD	0.1472	2.181	0.1437	82012
F18NOR	0.1722	3.424	0.1773	19705
F18GD	-0.0872	-1.029	-0.0867	-38330
F18LTV	-0.1152	-1.490	-0.1116	-16398
F18WIN	0.1513	2.820	0.1500	102278
F18LOS	-0.0932	-1.364	-0.0919	-54133
F18TOT	0.0360	0.804	0.0334	42448

Note that the percentage changes calculated for each firm are not as well-behaved as the averages that we analyzed in Part C. Many of the individual firm changes are not statistically significant and some are of the wrong sign. This is a common feature of many event studies. The large unexplainable variance in daily stock returns makes it difficult to generate statistically significant results on an event-by-event basis. The standard approach is therefore to aggregate over many events.[58]

Also note that for some of the twelve events it may well have been the case that one firm had an extremely high probability of winning and that the favorite in fact won. In this case the announcement would have very little effect on stock prices and normal variation might easily cause the stock prices to move in the "wrong" direction. Thus the existence of some individual firm returns with the wrong sign in no way violates the theory.

7. Estimation of Prizes

Table (7.1) uses the estimator derived in Section 5 together with the estimates of changes in market value derived in Section 6 to calculate the size of prizes that firms were competing for in each event. Recall from Section 5 that the estimators derived were of the form

$$(7.1) \qquad (V_W + V_L) - k\, V_L$$

where k is a positive number and that two methods for calculating k were selected, one more conservative than the other. The columns labelled "V_W" and "V_L" give the values of V_W and V_L for each event as calculated from Table (6.8). The columns labelled k_{LOW} and k_{HIGH} give, respectively the lower (more conservative) and higher (less conservative) value of k. Then the columns labelled π_{LOW} and π_{HIGH} give the dollar value of the estimated prize using, respectively, k_{LOW} and k_{HIGH}. Note that the last row of Table (7.1) gives the average value over all twelve contests. Thus the estimated average prize over the twelve contests is between 47 and 67 million dollars.

The natural question to ask is whether this is "large" or not. Two methods to answer this question are available. The first method is to compare the prize to the average market value of the competing firms. This is done in Table (7.2). The column labelled "M_B" gives the average market value of the contestants on the day before the event (day -3). Then the columns labelled $\pi_{LOW}(\%)$ and $\pi_{HIGH}(\%)$ give, respectively π_{LOW} and π_{HIGH} as a percentage of the average firm value. Thus on average the estimated prize is between 10.2% and 14.6% of the average value of the firms competing for it.

Table 7.1

Estimated Size of Prizes for Event Window

EVENT	V_W*	V_L*	k_{LOW}	k_{HIGH}	π_{LOW}*	π_{HIGH}*
F14	8574	27613	2	3	-19039	-46652
S3	22471	-9146	2	3	31617	40763
E3A	8964	25751	2	3	-16787	-42538
A10	6403	-13914	2	3	20317	34231
F16	13592	-13013	2	3	26605	39618
UH60	44727	-59619	2	3	104346	163965
KC10	23836	-71616	2	3	95452	167068
A7	3484	9547	1.5	2	-1290	-6063
C5A	8910	-56014	1.5	2	36917	64924
F15	42842	-56589	1.5	2	71137	99431
B1	33128	-45062	1.5	2	55659	78190
F18	102278	-54133	2	3	156411	210544
AVG	26601	-26350			46779	66957

*In thousands of dollars.

Table 7.2

Estimated Prizes as a Percentage of Average Firm Value

EVENT	M_B*	π_{LOW}(%)	π_{HIGH}(%)
F14	777480	-2.4	-6.0
S3	269953	11.7	15.1
E3A	319278	-5.3	-13.3
A10	77835	26.1	44.0
F16	163194	16.3	24.3
UH60	944811	11.0	17.4
KC10	1070543	8.9	15.6
A7	190610	-0.7	-3.2
C5A	565349	6.5	11.5
F15	450515	15.8	22.1
B1	339692	16.4	23.0
F18	317723	49.2	66.3
AVG	457249	10.2	14.6

*In thousands of dollars.

The second method is to compare the estimated prize to the expected discounted revenue stream that the winning firm will receive. The rationale behind this method requires a bit more explanation. Suppose that the winner will be involved in producing the weapon for T years. Let R_t denote the expected revenue that the winner will receive in year t of the project. Also assume that the owners of the firm use a discount rate of r to value these expected revenues. The discount rate reflects the time-value of money as well as any discounting due to the uncertainty of the revenue stream. Let R denote the present discounted value of revenues that the winning firm will receive. This is defined by

$$(7.2) \qquad R = \sum_{t=1}^{T} \frac{R_t}{(1+r)^t}$$

Now suppose that the firm expects to earn α dollars of economic profit on every dollar of revenue it receives (where α is between 0 and 1). Thus α is the economic profit rate that DoD is in fact allowing. The value of the prize to the winner, denoted by π, is defined by

$$(7.3) \qquad \pi = \sum_{t=1}^{T} \frac{\alpha R_t}{(1+r)^t}$$

From (7.2) and (7.3) it is clear that

$$(7.4) \qquad \frac{\pi}{R} = \alpha.$$

That is, calculating the prize as a percentage of expected discounted revenues yields the economic profit rate which firms expect to earn.

The value of π has of course been estimated. It remains to estimate R in order to calculate α. This is done as follows. First the DoD's estimate of the constant dollar cost of the weapon system at the time of the announcement is determined. Let C_t be the nominal dollar cost in year t and let s be the DoD's discount factor for inflation. Then let C denote the DoD estimate of the constant dollar cost of the weapon. This is defined by

$$(7.5) \qquad C = \sum_{t=1}^{T} \frac{C_t}{(1+s)^t}$$

The second step is to estimate R based on C. These two steps will now be described in more detail.

Since the 1970's the DoD has been required to file a quarterly report to Congress called the Selected Acquisition Report (SAR) for each of its major weapons systems being procured. These contain the DoD's estimate of the constant-dollar cost of the program. The SAR estimate of the constant dollar cost of the project at the time of the announcement was available for seven of the twelve systems. These are the F15, B1, A10, F16, UH60 and E3A. Four of the systems were awarded before the SAR system was put in place and thus no SAR data was available. These are the F14, S3, A7 and C5A. Finally SAR data for the KC10 was not readily available although it presumably exists.[59]

To obtain estimates of C for the five systems with no SAR data, the following procedure was used. Cost estimates for all twelve systems as reported by the Wall Street Journal at the time of the announcement were gathered. The Wall Street Journal never explicitly stated whether it was reporting a nominal or real dollar estimate of cost. The SAR estimate of both the nominal and real dollar cost for the seven systems with SAR data was therefore compared to the WSJ for the seven systems for which SAR data was available. The WSJ estimate was always very close to the real dollar SAR estimate. Therefore for the remaining five systems, the WSJ estimate of cost was used as an estimate of C.

There are three possible reasons why DoD's estimate of the real cost of the system, C, may differ from the firms' calculation of expected discounted revenues, R. The first is that firms may expect the cost to be different than DoD's estimate. This might be true either because DoD has purposely used an incorrect estimate of C in the SAR as part of its strategy for dealing with Congress or because DoD and the firms simply disagree on expected costs. No attempt was made to correct for this factor.

The second reason is that not all of the cost of a weapon system is paid to the prime contractor. The cost includes money which is directly paid to firms which manufacture some major subcomponents of the system. The major such item for aerospace projects is the engine. The cost also includes the value of government supplied equipment and services. No system-by-system data on the fraction of government cost which was actually received by the prime contractor as revenue could be located. However, a Rand case study of the F16 contained data for the cost of the F16 prototype phase which showed that 68% of government's cost was paid to the prime contractors.[60] Since this is the only available estimate, it will be assumed that 68% of government's total cost figure is received by the prime contractor as revenue.

The third reason that C and R may differ is that firms may use a different discount rate than the DoD - i.e. - r may not equal s. The discount rate used by DoD in its SAR reports varied between 6.58% and 6.86%. This may correct for inflation but certainly makes no allowance for any sort of risk. Discount rates used by firms are likely to be much higher. For example, the DoD policy group responsible for a major revision of profit regulations in 1979 assumed that firms' discount rate was 15% for the purposes of their analysis. This was "based on an informal survey of industry that indicated hurdle rates averaged between 15-20%. 15% was selected as a conservative number."[61]

It is not possible to choose a single non-controversial estimate of the discount rate used by firms. Therefore the procedure followed here will be to present two different estimates of R. The first estimate is extremely conservative. It will be assumed that firms used the same discount rate as was used by DoD (which was between 6.58% and 6.86%). Therefore, given the second factor described above as well, this estimate of R is defined by

$$R = .68C \tag{7.6}$$

This estimate is more conservative in that it produces a smaller estimate of α, the economic profit rate. The less conservative estimate used will be

$$R = .34C. \tag{7.7}$$

It is one-half the size of the former estimate and corresponds approximately to firms using a discount rate double that of the DoD -- i.e. -- approximately 13% or 14%.

The first column of Table (7.3) presents the estimated acquisition cost of the twelve systems which was calculated as described above. The next three columns present the estimates of α for the lower prize estimate, π_{LOW}, using the various estimates of R. The last three columns present the same estimates using π_{HIGH}.

Note that the value π/C is also displayed. This is not an economic profit rate but instead has the following interpretation. Suppose we were told that DoD was planning to purchase a new system whose estimated cost was x billion dollars. Then $(\pi/C)x$ is the size of the prize which we would estimate the winning firm will receive.

The estimates of the economic profit rate averaged over all twelve events is presented in the last row of Table (7.3). Estimates vary from 1.63% to 4.68%. Thus every dollar of revenue received by a prime contractor on production contracts generates somewhere between 1.63 and 4.68 percent of pure economic profit. The value of (π/C) is between 1.11% and 1.59%. The typical new aerospace system is estimated to cost in the neighborhood of 30 billion dollars. Based on this paper's estimates, we would expect the prize associated with such a project to be valued at between \$333 million and \$477 million.

Table 7.3

Estimated Economic Profit Rates

		π_{LOW} As a Percentage of			π_{HIGH} As a Percentage of		
EVENT	C*	C	.68C	.34C	C	.68C	.34C
F14	3400000	-0.56	-0.82	-1.65	-1.37	-2.01	-4.03
S3	3200000	0.99	1.46	2.91	1.27	1.87	3.74
E3A	2150900	-0.78	-1.15	-2.29	-1.98	-2.91	-5.82
A10	2143400	0.95	1.40	2.79	1.60	2.35	4.71
F16	4376800	0.61	0.90	1.79	0.91	1.34	2.68
UH60	2890800	3.61	5.31	10.62	5.67	8.34	16.68
KC10	1900000	5.02	7.38	14.76	8.79	12.93	25.85
A7	1500000	-0.09	-0.13	-0.26	-0.40	-0.59	-1.18
C5A	5200000	0.71	1.04	2.09	1.25	1.84	3.68
F15	5988100	1.19	1.75	3.50	1.66	2.44	4.88
B1	9853800	0.56	0.82	1.65	0.79	1.16	2.32
F18	8016600	1.95	2.87	5.74	2.63	3.87	7.74
AVG	4218367	1.11	1.63	3.26	1.59	2.34	4.68

*In thousands of dollars.

It should be noted that all the estimates calculated in this paper are quite conservative. The most conservative estimate presented should be interpreted as a sort of absolute lower bound on the size of the prizes. The least conservative estimate presented should be interpreted as a reasonable but mildly conservative estimate. Since the conservative bias of the estimates was built in at a number of different stages of their construction it might be useful to summarize the sources of conservatism in the estimates.

First, when the estimator functions were constructed in Section 5, the more conservative choice was definitely biased downward. The less conservative choice was unbiased under the fairly moderate assumption that the vector of contestants' probabilities of winning is uniformly distributed across contests -- i.e. -- any vector is equally likely. In particular if there tends to be a "favorite" firm in most contests, then even the less conservative estimator will underestimate the prize.

Second, in Section 6 it was shown that an event window of (0,1) should be used based on DoD announcement procedures. This produces very large changes in firms' values and thus very large estimates of the prizes. However, part of the change in value seemed to be quite temporary in that it was cancelled out by compensating movements in the days immediately around the announcement. Therefore an event window of (-2,3) was used, which produces smaller estimates of changes in firm's values and thus smaller estimates of the prizes.

Third, in this Section the discount rate of firms was assumed to be about 6.5% (the DoD's estimated inflation rate) or 13%. The former estimate is clearly an absolute lower bound while even the latter estimate is probably moderately conservative.

8. Conclusion

This paper first argues based on theoretical grounds, that informational and incentive constraints inherent in the innovation process require that regulatory institutions create prizes for innovation. Since the quality of an innovation is difficult to objectively describe or measure, the most natural method for awarding prizes is to allow firms to earn positive economic profit on production contracts. Explicit recognition of this role of profit regulation generates interesting perspectives on a number of important policy issues involving regulatory design. The value of the prizes offered on twelve major aerospace systems were calculated. The prizes are clearly large enough to support the contention that their existence is an important aspect of the current regulatory structure.

This paper suggests a number of interesting avenues for future research. First, the methodology developed in this paper for using stock prices to measure the economic profit anticipated to be earned on a program could be used to investigate a variety of issues. For example, it is often argued that the introduction of dual-sourcing in missile procurement has lowered the profitability of these programs to firms. This paper's methodology could be used to investigate this. Another example is that for programs currently being awarded, DoD officials might find it useful to estimate expected profit rates immediately after they award a program by examining stock returns. Second, it would be very interesting to directly estimate short and long run elasticities of private R&D expenditure with respect to profit rates. The "rent-seeking" paradigm advanced in this paper suggests that profit policy should be viewed as a tool for regulating the pace of innovation. Thus direct verification that R&D expenditures respond to profit levels would provide useful support for the theory. Furthermore, for policy purposes it is important to know the magnitude of the elasticities. Third, the data on daily stock returns in the neighborhood of the announcement suggest a number of interesting questions. Does the statistically significant pattern that prices rise before the announcment and fall after the announcement hold true for a larger set of contests? Does the data suggest that inside trading occurs prior to the formal announcment and has this pattern changed over time? Does the data suggest that the market learns that a winner will be announced (i.e. -- that q equals 0) some time before the announcment day and has this pattern changed over time? Investigating these questions would require data on more contests and possibly option price data as well as stock price data. Fourth, a careful formal theory of the optimal regulatory structure given that prizes for innovation must be supplied needs to be developed.

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Footnotes

1. See pages 123-128.

2. See Department of Defense [1985] and Comptroller General [1986] for examples of the current debate.

3. See Adams [1981] for a comprehensive description of such activities.

4. See, for example, Fox [1974], Gensler [1984], Gorgol [1972], Peck and Scherer [1962], Scherer [1964], and Smith, et. al. [1981].

5. A selection from this voluminous literature is Baron and Besanko [1986], Laffont and Tirole [1986], Riordan and Sappington [1987], Rogerson [1984b, 1988], and Tirole [1986]. See these papers for further references.

6. This section relies heavily on two excellent Rand studies, Smith and Friedman [1980] and Smith et. al. [1981]. See these two studies for more complete descriptions.

7. Radar and other electronic equipment.

8. See Smith et. al. [1981] and Fallows [1981] for more extensive discussion.

9. The milestone system was not adopted by DoD until late in 1971 at which time the F16 had already progressed through what would have been milestones 0 and I. Therefore the first two milestones have been placed at the approximate dates they would have occurred had the system been in place.

10. The other three contestants were Boeing, LTV, and Lockheed.

11. Smith et. al. [1981], page 85.

12. Smith et. al. [1981]

13. General Dynamics [1986].

14. The UH60 and AH64 helicopters.

15. Actually there was a very small amount of cost sharing and the three production contracts were options for the government to exercise. See Smith et. al. [1981] for details.

16. Even when foreign sales are a possibility the DoD must approve them.

17. See Williamson [1975] for a thorough discussion of the "hold-up" problem.

18. An important revision to profit policy has occurred since the last printing of the CFR. See Federal Register [1987].

19. My long-run research goal is of course to develop a good theoretical understanding of how these rules should optimally be structured. The purpose of this paper is simply to develop one important principal which any such theory must incorporate -- i.e. -- prizes must be supplied to induce innovation.

20. Code of Federal Regulations, Title 48, 215.901 (c).

21. Peck and Scherer [1962] page 501. Also see pages 501-507 for further discussion.

22. Pages 180-181.

23. For example a number of prototype predecessors of the F16 and AH64 were privately funded by firms. See Smith et. al. [1981], pages 84 and 155-158.

24. When e is greater than 1 the model is less well-behaved because various objective functions are no longer globally concave. See Schmalensee [1976]. Rogerson [1987] has shown that unique equilibria still exist in this case. However, the analysis is more complicated and reveals no extra insights. Thus this paper only considers the case where $0 \leq e \leq 1$.

25. It is straightforward to formalize this argument using the notion of mean preserving spreads. To intuitively understand this result consider the case where there is no uncertainty in the innovation process. A given level of expenditure yields a given deterministic quality of innovation and a higher expenditure produces a higher quality innovation. Suppose all firms are spending x dollars. Then if one firm were to increase its expenditures by one cent it would produce a higher quality innovation than all its rivals with probability one.

26. For $e = 1$ it is straightforward to show that there are no asymmetric equilibria. Although I cannot construct examples of asymmetric equilibria when $e < 1$, neither have I been able to prove that such equilibria never exist.

27. For expositional simplicity it is assumed that n can be any positive real number. It is straightforward but notationally cumbersome to formally allow for the constraint that n can only assume integer values.

28. One of the most interesting topics for future research suggested by this theory is to attempt to empirically estimate the short-run elasticity of innovation with respect to prize levels. I am currently working on this project.

29. Comptroller General of the United States [1971,1986] and DoD [1976, 1985] are the major such studies since 1970. See Bohi [1973] and Stigler and Friedland [1971] for academic economists' analyses of some of these issues.

30. See pages 123-128.

31. Gensler [1980], page 127.

32. See Osband [1987a, 1987b].

33. DoD [1985] provides some evidence on this point. See Greer and Liao [1986] for an extremely interesting empirical demonstration that excess capacity affects profitability.

34. Or multi-year variations in the case of defense buildups or slowdowns. The case for smoothing these multi year variations is probably stronger than the case for smoothing the shorter term variations.

35. There are extremely important conceptual and practical issues involved in determining all three of these values. For example much weapons production involves significant amounts of joint operating and capital costs. These issues are not considered in the following discussion. It is simply assumed that OC, K, and r have been determined.

36. See Teresewa [1984], pages 4-1 to 4-4, Rogerson [1984], Proposition 2b, and Tirole [1986] for analyses of a different factor affecting the firm's capital vs. non-capital input choice. This is that the firms may be subject to a "hold-up" problem.

37. See Bailey [1973] for a very nice treatment of this type of model as well as for references to the voluminous literature.

38. See Burnett and Kovacic [1987] for an excellent description of current dual-sourcing practices. Also see Anton and Yao [1987a,b], Seshadri, Chatterjee and Lilien [1987], and Riordan and Sappington [1987] for theoretical models.

39. See, for example, Galbraith [1969].

40. See Comptroller General of the United States [1986] for a step-by-step description of how the GAO and DoD analyses differ.

41. Scherer [1965], page 194.

42. The theory does not change if the possibility that different firms will receive different sized prizes is allowed for. It can be assumed that each firm i will receive a prize π_i if it wins where the π_i are determined prior to the contest as independent draws from a distribution with mean π. The theory remains essentially unchanged.

43. It will be seen that the data suggests that q is quite close to zero. The empirical estimates would not change significantly if it were simply assumed that q equaled zero. However, allowing a positive value of q does not significantly complicate the model so this possibility is allowed for. Also, allowing for positive values of q in the formal model makes it clear how to test if q equals zero.

44. It is straightforward to show that the estimator derived in this section retains its desirable properties even if inventors are risk averse. This will not be formally proven.

45. By "otherwise would be" it is meant the market value the firm would exhibit if it was not involved in the contest.

46. Note that this argument does not even depend on the investor being risk neutral. Thus if V_W is greater than $-V_L$ there seems to be no other reasonable explanation for this other than that $q > 0$.

47. Recall all expectations are calculated conditional on some firm winning.

48. See Brown and Werner [1980,1985] for detailed theoretical analyses of this methodology as well as for other references.

49. See Centre for Research in Security Prices [1986] for a detailed description of the data.

50. Hughes was subsequently purchased by McDonnell Douglas.

51. This includes all firms listed on the New York and American stock exchanges so is very close to the entire market.

52. In some cases another contest occurred in the days -120 to -21 with some overlap in contestants. In this case the regression was run on one hundred days chosen further back in time to avoid the overlap.

53. For the F18, the artificial firm F18WIN is used.

54. For the A7, C5A, F15, B1, and F18 there were two losers so the artifical LOS firm is used.

55. A t-distribution with 98 degrees of freedom is essentially normal.

56. See, for example Rice's [1971] description of the process for the C5A award, pages 16-17.

57. A t distribution with 98 degrees of freedom is essentially normal.

58. Although not reported in the paper the data in Table (6.8) was also calculated for the event windows (0,1) and (-1,1). In these cases most of the individual firm returns were statistically significant and of the right sign.

The reasons for using the more conservative window (-2,3) were explained in Part C.

59. SAR data used in this paper was obtained from case studies described in Dews et. al. [1979].

60. See Smith et. al. [1981], page 114. Engine manufacturing accounted for 27% of the total cost and government supplied equipment and services accounted for the remaining 5%.

61. This is quoted with David Koonce's permission from a personnel communication from him dated December 22, 1986. During 1979 Mr. Koonce was Chairman of the DoD Contract Finance Committee. He is now Director of Financial Analysis for Martin Marietta Corporation.