Sharing of Fire Fighting Resources

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1. Introduction

The Canadian Interargency Forest Fire Centre (CIFFC) was created in June of 1982 with the primary mandate to facilitate the exchange of wildland fire fighting resources, including personnel, equipment and aircraft between member agencies. The exchange of resources is implemented under the Mutual Aid Resource Sharing (MARS) agreement which was formalized in 1982. Since the establishment of CIFFC and the MARS agreement, resource sharing between agencies has increased through several stages.[1] The first stage can be termed *The Initial Era* (1982-1987) during which there was minimal sharing of resources, and the primary resources shared was suppression equipment. The second stage could be termed *The Building Era* (1988-1994) where there was increased sharing of resources including some personnel exchanges. The last (and current) state is an era of agencies lending resources as a standard practice, often to the limit of their capacity, and resource demand occasionally outstripping national availability. This shortfall has been seen during several years, most notably in British Columbia in 2003 and 2009 and is occurring with more frequency.[2]

There has been a growing recognition by the CIFFC Council of Directors and the Wildland Fire Management Working Group that the current levels of resource sharing will not be adequate for future activity. Several steps have been taken to address and mitigate these concerns; a survey of agencies was undertaken to identify obstacles to resource sharing, the development of a Wildfire Response Capacity and Advisory System has been launched; and a national resource demand model (based on an Ontario model) is under development.

[1] Interpretation of Stocks 2010, Forest fire management resource-sharing in Canada: The need for an expanded and more effective capability. Internal report.

[2] There is no specific data on the size of the shortfalls, it is is known that there are no resources available to deal with a fire event, agencies do not request any resources and instead modify fire management objectives to fit within available resources.

These are important steps but further steps will be required if Canada is to fully realize the potential of inter-agency resource sharing.

There are several instances in the recent past where there were insufficient resources available to meet the national demand. Trends in changing climates, fire occurrence and expansion of the wildland-urban interface all point to increased resource shortages (larger resource deficits, occurring more often) in the future. Add to that government fiscal trends of cost containment and reduction (and with it the likely situation that there will be no budget for additional suppression resources) and there is a two-pronged problem; greater resource demand and (at best) current levels of resources to meet the demand (which have already been shown to be insufficient during peak periods of fire load).

Clearly, a new solution to the problem is required; a solution that potentially provides more resources to agencies during peak demand while maintaining the status quo in agency resource establishment levels.

Although in Canada we have been sharing resources between agencies for more than twenty-five years, to the best of our knowledge, little is known about the strategic process that goes into the borrow/lend decision. When does an agency request resources is perhaps an easy question, but the more difficult, and perhaps more interesting, is “When and how much can we lend?”. Understanding the parameters that guide this decision among the various lending agencies could provide a profound understanding of the nature of lending in the country and provide some guidance to mitigating barriers to resource sharing. To this end, we have commenced a study of the factors which influence decision-making with respect to resource sharing across Canada. By conducting interviews with agencies across the country as well as CIFFC, and by building a game-theoretic model to capture key strategic aspects of resource-sharing, we aim to provide insights into resource-sharing across the country.

2. Interviews

During the period of September 2011 to March 2012 we conducted a series of interviews of agencies across the country and CIFFC. In particular we visited Ontario, British Columbia and Alberta in person, and held teleconferences with participants from Saskatchewan, Manitoba, Quebec, New Brunswick, Nova Scotia, Parks Canada and CIFFC. Whether conducted in person or over the telephone, the interviews had the same structure.

- Agencies were asked to describe how resource allocation decisions were done internally.
- Agencies were asked to describe how decisions related to importing resources were made as well as the key factors that influenced such decisions.
- Agencies were asked to describe how decisions related to exporting resources were made as well as the key factors that influenced such decisions.

- Agencies were asked to make general comments about CIFFC as to what they liked and what they thought could be improved.

While specific questions relating to each of the above topics were prepared and posed, participants were encouraged to talk freely about their experiences and expertise. In the rest of this section we outline the key ideas agencies reported.

2.1. Decision-making with Respect to Importing of Resources

We asked each agency to discuss how importing decisions were made as well as key factors that influenced the decision. There were commonalities across all agencies, but also some interesting differences. We first note that all agencies had similar hierarchical organizations (though the titles of the positions would sometimes differ across agencies). Typically the decision to import was made by the equivalent position across all agencies, though several agencies had a pre-approval mechanism allowing Provincial Duty Officers to make certain importing decisions without consulting further up the hierarchy.

Importing and exporting decisions critically depend on an agencies ability to plan for future events. If an agency is solely reactive as opposed to strategic, then it would be very challenging to import or export resources as these decision require pre-planning. What we did find interesting was that while all agencies described how they were able to strategically plan for future events, the time window for planning did differ significantly. Some agencies reported that at the provincial level they looked out 4-5 days, while other agencies stated that they tried to plan out for 10-14 days. Quality of weather forecasting was one factor which agencies said limited their ability to project, but we also noted that agencies which reported being large importers and exporters tended to try to have a longer planning time-horizon compared to agencies which did not import or export as frequently (though this was not universal).

We outline the key factors relating to importing that were reported to us during the interviews.

- All agencies (except for SOPFEU (Quebec)) reported importing aircraft on a fairly regular basis. It was reported that the decision to import aircraft tended to be a fairly straightforward decision since they were usually able to arrive quickly, required limited advanced logistics, and could be released quickly once the threat was reduced. Several agencies reported the usefulness of quickstrike agreements with border agencies. The use of the compacts for aircraft was mixed. Some agencies said they would always go through CIFFC for aircraft, while others said they liked the compacts since the response could be very fast.

- Many agencies reported that before making a formal request to CIFFC, they would make informal phone calls to CIFFC and their neighbours. The role of these informal calls was to roughly determine the availability of resources and to let CIFFC and other agencies know that a request for resources was likely going to be placed soon.

This early information could prove useful to other agencies so that they could have some extra time for pre-planning export decisions..

- A number of agencies mentioned that the logistics involved in importing can be a barrier. At least two agencies explicitly stated that sometimes having more resources did not make things easier due to the logistical overhead of managing and integrating outside crews, particularly when personnel are already very busy with the high fire risk. However, other agencies mentioned that they did not find the additional logistics of importing to be an issue. These agencies tended to have highly mobile crews internally to start with and so were used to moving people around the province at short notice.

- All agencies reported that when selecting between import offers, all things being equal they tend to prefer ones where the logistics are simpler and costs are cheaper. That is, there was a stated preference for having crews all come from one agency if possible, or to follow a nearest-neighbour policy. Several agencies said explicitly that they let CIFFC address this since they thought that CIFFC did a good job in taking into account the logistics. That said, two agencies explicitly stated that they do take into consideration the training opportunities that arise due to the exchange of resources, and that they have (and plan to continue) explicitly imported people from across the country in order to try to equalize training opportunities. The rationale for doing this was to help ensure and improve the national capacity.[3][4]

- When asked about whether agencies ever pre-empively requested resources through CIFFC due to concerns that other agencies may get the needed resources first, all agencies stated that they did not go this with general requests (though they have discussed it), though several agencies admitted that when it came to requesting specialists (like, for example, Parks Canada's burnout team) it was done. Agencies were very open about the fact that they did compete with each other when it came to helicopters.

- Several agencies mentioned that the fatigue levels of their own crews was a factor when it came to making import decisions. Some agencies said that importing had been discussed when it was thought that their own crews were fatigued, but had never been acted on. Other agencies said that they had imported due to fatigue of their own crews.

- All agencies reported that cost was not a key factor when it came to making an import decision. If the case could be made that the resources were needed for the

[3] This was not true for aircraft. There were clear preferences for different aircraft depending on the retardant used.

[4] It was mention! ed, several times, that in the past there had been strong preferences for crew from some agencies over others but more recently this was less of an issue due to the standardization taking place through CIFFC.

situation at hand, then it was important that they were obtained and there tended to be little financial barrier. However, directors did keep track of seasonal costs related to importing and would sometimes need to account for the costs.

- Agencies with a lot of experience importing were asked about whether they ever released imported crews early. One agency reported that the manning-down decision was actually very difficult since regions to where the imported crews were sent tended to be quite risk averse in the days after the situation that led to the import decision. Another agency said that even if it was possible to send crews home earlier, they had never done it before. While not stated explicitly, we hypothesize that it was for a similar reason as the risk aversion issue mentioned by the first agency.
- Several agencies reported political issues relating to ensuring that their own Type 2 contracts were being used effectively before importing outside crews. This particular political issue could be mitigated somewhat by illustrating the imported crews were specialists doing different types of jobs than the Type 2 crews. It was also mentioned that political messages were sent through importing; that the situation on the ground was serious.
- Agencies reported that they predict that their rate of importing will either stay the same in the future or will increase. The projected increase was mainly due to two factors: predicted cuts in manpower or increased positive experience with resource sharing which has led to a change in attitude towards importing.

2.2. Decision-making with respect to Exporting of Resources

There was a wide range of experience across the agencies when it came to exporting resources. Some agencies routinely exported large teams, while other agencies would send out crews every two to three years. Experience with exporting aircraft also varied widely, depending on the aircraft resources controlled by any particular agency. As we expected, all agencies stated that their primary responsibility was to their own jurisdiction and resources offered for export were viewed as surplus at the moment of export. That said, in emergency situations all agencies indicated that they were willing to take on some additional risk. This was in line with the repeated emphasis that there was a strong feeling of community across the agencies.

The factors which influenced exporting decisions relating to crews, aircraft and equipment were very different and thus we separately report our findings.

2.2.1. Equipment

We found the attitude about lending equipment was similar across agencies; it was deemed to be a fairly non-complicated decision, and depended heavily on when in the year a request was made. In particular, there was a preference to lend equipment towards the end of the season since it was universally understood that it was unlikely to be returned until the season was over.

2.2.2. Aircraft

The export of aircraft was also reported to be a straightforward decision. It was reported that it was easier to determine when and whether they were available for export, and the short-term commitment and the ease of recall meant that risk could be handled effectively, easing the decision-making procedure. A number of agencies reported that cost-recovery was an important consideration when it came to exporting aircraft. For many agencies, the reimbursement for exporting aircraft went back into fire programs. It was also mentioned that not having aircraft sitting idle was important as it helped justify the resource politically.

2.2.3. Personnel

The export of personnel was a significantly more challenging decision compared to equipment or aircraft. We noted that agencies tended to fall into one of two categories. The "small" agencies had relatively less personnel than the "large" agencies and, for this reason, tended not to export crews at the same frequency as the "large" agencies. While all agencies faced similar issues related to risk management and followed fairly similar procedures, we did note that different concerns arose.

- All of the "small" agencies mentioned that the logistics of putting together one or two 20-person Incident Management teams was challenging and was a factor which did play into their exporting decision. They had to ensure that they were not drawing down the resources from a single region and had to balance training opportunities for their personnel. While the "large" agencies also mentioned the logistical overhead of exporting, it was not with the same urgency.
- A number of the "small" agencies noted that because they could only offer up a relatively small number of crews, they felt that they were, sometimes, overlooked by CIFFC. Several agencies mentioned that they would be interested in coordinating more on a regional level, and organizing so that several "small" agencies could band together and provide teams with members coming from multiple agencies.
- A number of the "small" agencies mentioned that they found the long deployment of crews when exporting difficult. Since they had a small staff to start with, they were simply unable to let people go for the entire deployment. This resulted in them not participating even though they thought that there were situations where they would have been able to contribute if there had been a shorter time commitment.
- We asked agencies whether and how they judged requests from CIFFC and whether information in the request played any role in their export decision. All the "small" agencies stated that they would take requests at face value. The "large" agencies,

however, replied that they did evaluate CIFFC requests and that the requests did influence their export decisions. For example, one agency said that if they received a highly hedged or speculative request and it would involve a lot of effort to organize something then they might not be interested. Another agency stated that they strongly prefer having a request with a confirmed assignment.

- The “large” agencies all discussed crew fatigue as a concern which plays into their exporting decisions. They will decide not to export if they believe their crews are fatigued or at high risk of becoming fatigued. The ”small” agencies either did not mention this or stated that it was not a factor they had been faced with.

Finally, one interesting point raised by all agencies, “large” and “small”, was how important it was to have a mechanism in place so that exported crews could be recalled in case of emergencies. All agencies stated that they were loathe to recall crews since it was considered “bad form”. However, having the *possibility* to recall made certain risk-management decisions significantly easier.

2.2.4. Benefits of Resource Exporting

We asked agencies to discuss the benefits they receive from exporting resources. When it came to exporting aircraft, the response was that the cost-recovery was the key benefit. However, cost-recovery was never mentioned as an important benefit when discussing crew-exporting. Instead, certain intangibles were mentioned by all agencies.

- Networking and the development of community was mentioned by many agencies. It was felt that the fire-fighting community is “one big family” and that this has largely developed through the exchange of personnel through the years.

- Agencies emphasized that by exporting their crews, the crews were able to obtain additional training and experiences which they might not be able to receive at home. Agencies which do not have many opportunities to export personnel were concerned that their crews were losing out on important training opportunities.

- Several agencies reported that exporting improved morale for crews. The crews enjoyed being busy, felt that their expertise was acknowledged and valued by being chosen to be exported to another agency, and that the trip itself was seen as a perk.

- A number of agencies who had imported resources in the past mentioned that they feel an obligation to export resources as it is the way in which they can payback for the help they received in the past.

- A minor benefit, but one acknowledged by several agencies, is that exporting was viewed as a “good news story” and that there was often interest from the political level encouraging resource exports if part of the country was facing significant fire threat.

One agency made another interesting argument in favor of resource exporting. They argued that it allowed them to maintain their capacity, even during quiet years, since they could show that their people, equipment and aircraft were being used. This has benefits both at the agency level, and also for the national capacity.

2.3. Information in the Daily CIFFC Report

We were interested in the type and quality of information provided to CIFFC each day, as well as how these reports were used by the agencies in their own planning. It was universally agreed and understood that the numbers concerning available resources were soft estimates and that the numbers merely indicated a minimum level available for export. We were reportedly told that if CIFFC wanted more accurate information then they could call and then it would then be provided. However, the effort required to generate accurate information, and the fact that numbers could fluctuate throughout the day, meant that agencies saw limited value in spending too much time in fine-tuning their reported information. This uncertainty was particularly relevant when it came to reporting personnel numbers. Agencies typically reported that they were more confident in the accuracy of their aircraft availability. We also noted a difference between "large" agencies and "small" agencies in that the smaller agencies tended to be more confident in the accuracy of their reports. One agency, in particular, even stated that because they are small they do have a pretty good understanding as to what their status is at any given point in time. That said, this agency still waited for a phone call from CIFFC before going through the work to precisely determine availability. Several agencies mentioned that they would appreciate it if CIFFC would be even more proactive with making phone calls since this would allow the agencies to potentially start accurately determining what resources are available, rather than scramble to fill a CIFFC request. The longer timeframe could make logistical issues, for example, simpler.

Agencies also mentioned political pressures which arise from the CIFFC reports. One agency said that it underreports its available crews in the CIFFC reports since they are nervous that by reporting that crews are available for export they will be judged as having a surplus and thus may find their resources cut. To avoid this, the agency reported that while they submit low numbers in the reports, they provide a significantly more accurate picture during the weekly CIFFC phone calls. On the other hand, another agency reported that their personnel tend to be very sensitive about the CIFFC reports in that there are often many questions as to why the numbers reported are low. Morale was reportedly increased by being able to list that crews were available for export.

2.4. General Comments about CIFFC

Overall, all agencies interviewed were very positive about CIFFC and the role it plays as broker in facilitating resource exchange. Comments such as "wonderful", "no headaches", "just ask and it is done" were heard when people were asked about their overall thoughts and impressions of CIFFC. It was argued that interagency resource-sharing would not work on the national level without CIFFC since the overhead of calling and coordinating with all provinces would be too much for individual agencies to bear. Appreciation was also expressed for CIFFCs help with demobilization, logistics and record keeping, for example. Every agency interviewed also mentioned the important work CIFFC has done with respect to standardization of equipment and training across the country. It was repeatedly stated that this has greatly improved resource sharing by being instrumental in resolving conflicts and ensuring that an agency has a clear understanding as to what is being imported and what should be offered for export.

Side effects of resource sharing were also repeatedly mentioned. One particular benefit mentioned was that the exchange of personnel between agencies has provided training opportunities and has improved information flow throughout the country, allowing for new ideas to be disseminated. This was viewed as having a very important role when it came to modernizing the nation's firefighting capacity.

Finally, everyone interviewed talked about the important role CIFFC has played in developing community through the exchange of resources and through the working groups. We were repeatedly told about the "tightknit" fire community and how this has led to increased respect and improved working relations across the country. This intangible benefit of resource sharing, and CIFFC's role in developing it, should not be undervalued or understated.

2.4.1. Comments concerning where improvements could be made

While there was universal support for CIFFC, some concerns and suggestions for improvement did arise during the interview process. These were all mentioned by more than one agency.

- Several agencies expressed concerns that as resource sharing becomes increasingly more common, CIFFC will not be able to cope at its current staffing levels and technology use. There was also interest expressed in having CIFFC be more involved with projects relating to such things like standardization of information systems and technology transfer. It was recognized that CIFFC simply does not have the manpower to do this currently.

- Several agencies mentioned that there was a certain lack of transparency when it came to some of CIFFCs decisions. For example, some agencies felt they did not entirely understand how CIFFC prioritized resource requests and would have liked to have had the rationale for certain decisions explained. This point was particularly emphasized by "smaller" agencies who would like to be more involved in exporting resources. It was also mentioned that information from CIFFC concerning the likelihood that teams would be released early, for example, would be nice to have.

- A number of agencies were interested in having CIFFC become more involved in the exchange of Type 2 crews. There was the perception that Type 1 crews were being requested for jobs which could be adequately handled by Type 2 crews (i.e. for mop-up). It was thought that by using Type 2 crews for such situations, this would reduce the pressure on the Type 1 crews and would allow smaller agencies to better participate in the export of resources. It was suggested that CIFFC monitor the use of imported crews so as to develop a better understanding as to how these teams were being deployed.

- The smaller agencies are eager to participate in resource exchanges but are faced with challenges since a resource request may simply be too large for an agency to be able to fill on its own. There were concerns that the smaller agencies were being overlooked in favor of larger agencies which were able to fill large resource requests. In addition to not being able to "help out" as much as they would want, there were concerns about missed training and certification opportunities for their staff, thus reducing the national capacity. One proposal to mitigate this was to encourage more cooperation between agencies in a particular region (e.g. the Atlantic region) to field regional teams for export.

2.4.2. Other Comments

As mentioned at the start of this section, overall the agencies interviewed were all pleased with how CIFFC operated. While every agency had some suggestions as to how CIFFC could be improved, there was no interest in changing CIFFC significantly. In particular, CIFFC was considered to be vastly superior to systems used in other countries (i.e. National Interagency Fire Center (US) (NIFC)). Additionally, there was strong resistance against the idea of centralizing resources further. It was felt that having resources controlled at the agency level was the right way to do things with CIFFC playing the role of resource broker. There was also strong resistance against the idea of having national policies dictating provincial priorities.

2.5. CIFFC

We interviewed CIFFC since we were interested in their perspective on resource sharing.

We were first interested in how CIFFC matches lending and receiving agencies. CIFFC reported that they use the daily report information as an initial guide as to the minimum availability from an agency and that if more specific information was required then the agencies were contacted explicitly. That is, the daily report was a rough indication of availability and CIFFC would use this number to help determine which agency to contact when trying to find resources for a request. If the number reported was too low (and CIFFC was trying to satisfy a large request) then the chances that the agency with the low report would be contacted was small. CIFFC indicated that when trying to find resources they did prefer to simplify logistics and would prioritize having all resources come from a single agency if possible. However, the receiving agency's preferences were respected and so they could specify where they wanted resources pulled from, if possible.

CIFFC was particularly concerned about burdening agencies. They said that they did note that some agencies would conduct "fishing expeditions", particularly early in the season, where tentative resource requests were made. CIFFC tried to discourage this since it could place an unfair burden on lending agencies who would go through the effort to determine whether they could lend resources or not. Instead of tentative requests, CIFFC preferred that agencies commit to their requests with a "you either want them or not" attitude. That said, CIFFC thought it was very important to be kept up to date with the fire and resource situation. By having a clear idea as to what the situation on the ground was like, CIFFC said it was able to start some of the background work so that once a request came in, they would be able to respond to it quickly. CIFFC also mentioned that part of their pre-planning and planning involved issues such as demobilization, crew recycling and other strategic and long-term issues. They stated that they have found it useful to have a CIFFC liason officer on the ground at the receiving agency so to be able to provide information back to CIFFC about the situation, coordinate demobilization, and keep track of other details which might be overlooked, without having to place an additional burden on the receiving agency staff. They indicated that they hope to expand the use of liason officers in the future.

When asked what were the key challenges in resource sharing, from their perspective, CIFFC mentioned delays. They said that sometimes it can take a day or more for agencies to get back to them with complete information on resource availability. This can have a domino effect since CIFFC does not want to ask a second agency for resource availability at the same time, viewing this as potentially wasted effort. Thus delays from potential lending agencies can lead to a domino effect, delaying the coordination of resource transfer. CIFFC was interested in encouraging and supporting agencies to do some pre-planning in order to speed up response-time.

3. Game-Theoretic Model

Based on the results from the interviews, we developed a model with the intent to capture and analyse strategic issues arising during the resource-sharing process. In particular, we place the resource-sharing problem into a game-theoretic framework and then analyze the strategies of the different participants.

In any game-theoretic analysis, one must specify who the participants are, what their possible actions are, and what benefit they incur from taking certain actions in different situations. In the next section we describe these three aspects of the model, introducing our notation. We then proceed to analyse a simple case with only two participants, before generalizing to multiple participants. We want to emphasize that this is a model and thus certain assumptions are made. We explain the assumptions we make, and believe that the conclusions we are able to draw from the model are useful in two ways. First, it helps to highlight some of the key factors in the decision making process with respect to resource sharing, and second, may be useful in understanding how things could change under different sets of properties and assumptions.

3.1. The Model

We start by assuming that there is a specific agency which we call the *distressed agency*, D, which requires additional resources, S_D. We assume that D is non-strategic and that S_D is an honest report of its needs. We assume that there is a set, E, of *exporting agencies*, which can potentially offer resources to D. Each agency $i \in E$ has a set of *local resources*, R_i, but their ability to share resources is influenced by their local fire conditions, summarized by their fire load Ω_i. We assume that the fire load of an agency is drawn from some known distribution.

Based on our interviews, we determined that a key decision for an exporting agency was how much *effort* to put into determining how much resources they were willing to share. We capture this in our model, by a *search function*, $s_i(B)$ which captures the amount of effort agency i must exert in order to make available B resources for export. We assume that each agency has their own search function. We also assume that s_i is monotone and convex, which captures diminishing marginal returns of searching for additional resources. We note that some agencies may have some set amount of resources, B_i^*, which are considered to be always available, and so $s_i(B) = 0$ for all $B \leq B_i^*$. For simplicity, our model will assume the resources are expressed numerically as non-negative real numbers, i.e. $R_i, B_i \in \mathbb{R}_+$. The results can be extended to the case where resources are sets of items.

The process works as follows. The distressed agency announces S_D through CIFFC. Each exporting agency sees the requests and then determines, through their search procedure, how much resources they would potentially supply. They announce this as a *bid*, $B_i \geq 0$, indicating how much resources they have available. CIFFC then decides which resources will be allocated to D, and selects H_i resources from agency i to transfer, where $B_i \geq H_i \geq 0$. Agency i observes its true fire load, Ω_i and receives some utility, u_i from the entire process.

3.1.1. Utility Functions

As is typically done, we use utility functions in our model as a way of comparing agencies' preferences for different outcomes. If there are two situations or outcomes, then the one which is assigned the higher utility is considered to be more preferred. The flexibility of using utility functions allows us to model tradeoffs in different settings, and, most importantly, capture the influence different decisions have on the outcomes that arise. In our model, our goal is not to draw quantitative conclusions, but instead focus on qualitative outcomes.[5] We

[5] A common misconception about utility is that it is equivalent to money. A person can derive utility from having or losing money but there need not be (nor is there usually) a linear relation between the two concepts. Additionally, one can derive utility from non-monetary events, such as successfully achieving some goal.

assume that the exporting agencies are rational and thus are interested in making decisions so as to maximise their (expected) utility. However, the utility of an agency is complex since it depends on multiple criteria which need to be balanced appropriately. We assume that the utility functions of agencies can be decomposed into four parts as described in the following.

Fire Damage: A key constraint is that each exporting agency should meet the resource demands to fight fires within its own jurisdiction. The challenge is that an agency must make a decision as to how much to offer for export with only probabilistic information that approximates Ω_i. After exporting some set of resources, agency i has some amount x of resources available for its own use. Given fire load, Ω_i, we represent the fire response cost by the function $f(\Omega_i, x)$. If $x \geq \Omega_i$ then we assume that the resource needs are met and so the maximum utility of zero is provided. If $x < \Omega_i$ then $f(\Omega_i, x)$ determines the penalty to the utility incurred by the agency. We assume that $f(\cdot, \cdot)$ is convex in order to reflect the increasing severity of consequences as the shortfall of resources increases. We believe that this is a reasonable assumption since it captures risk aversion of agencies. In particular, we assume that the fire damage function has the following form:

$$f_i(\Omega_i, x) = \begin{cases} 0 & \text{if } x \geq \Omega_i \\ -(\Omega_i - x)^\alpha & \text{otherwise} \end{cases}$$

with $\alpha > 1$.[6]

Social Goodwill: An important motivator across all agencies was the positive mores that come from exporting. Everyone wanted to help their neighbours, there were often small political benefits associated with exporting, and it acted as a morale boost for personnel. We capture this by using a *social goodwill* function applied to the resources exported, $sg_i(x)$, where $sg_i(x) \geq 0$ for any amount, x, of exported resources.

Cost Benefit: If an agency i is asked to export x resources then it derives some value from the amount that it gets paid via cost recovery. We denote this by $cb_i(x)$.[7]

Search Cost: The search cost, $s_i(x)$ is simply the cost to the agency of seaching whether some amount of resources, x, can be made available. As previously mentioned, we assume that $s_i(\cdot)$ is monotonic and convex. Note that an agency incurs cost $s_i(x)$ whether or not any of its resources are chosen by CIFFC to be used by the distressed agency D.

[6] Technically, an agency will be making a decision as to how much resources to report before they know the true fire load. Instead, they must work with a probabilistic model and the expected fire load. To be completely correct, the fire damage function should be computed taking into account the probabilistic model. However, for the sake of simplification, we abuse notation and use Ω_i to also represent the expected fire load and so $f(\cdot, \cdot)$ is really the expected fire damage.

[7] In our interviews we noted that different agencies had different attitudes towards recouping their costs. Thus the function $cb_i(\cdot)$ may differ between agencies.

In our analysis, we use a linear combination of the four components described above. Given input parameters, total resources R_i, fire load Ω_i, bid B_i, and amount of exported resources H_i, we can express agency i's utility as follows:

$$u_i(R_i, \Omega_i, B_i, H_i) = f_i(\Omega_i, R_i - H_i) + sg_i(H_i) + \mathrm{cb}_i(H_i) - s_i(B_i). \tag{3.1}$$

We note that we could also use a weighted linear combination, and that this would not qualitatively change our conclusions.

3.1.2. Strategies and Solutions

Given the utility function in Equation 3.1, one observes that there is a clear interdependency between an agency's utility and the actions taken by others. In particular, an agency has to determine how much effort it will put into formulating a bid B_i, while also being concerned by how much it will actually export, H_i. The agency gains by having a high H_i value since we assume that social goodwill and cost recovery increase with H_i. However, cost incurred from fire damage increases, for a given fire load. The amount H_i also depends critically on CIFFC's allocation procedure and *on the bids of the other agencies.* Thus we are in a partially competitive setting and the tools provided by game theory are appropriate.

We define a (pure) strategy for agency i as $\sigma_i : \{\Omega_i\} \times \{R_i\} \mapsto \mathbb{R}$ where $\sigma_i(\Omega_i, R_i) = B_i$ specifies that if agency i's expected fire load is Ω_i then it will offer $B_i \leq R_i$ resources for export. We note that a strategy for an agency will specify its export levels for each possible expected fire load, but where it is clear from the context we drop Ω_i and R_i to simplify notation. We say that a strategy profile is a vector $\sigma = (\sigma_1, \ldots, \sigma_n)$ which specifies a strategy for each agency, and use the notation $\sigma = (\sigma_i, \sigma_{-i})$ where σ_{-i} is a vector specifying a strategy for each agency except for agency i. If all other agencies are following strategies specified by σ_{-i} then agency i's *best response* is the strategy which maximizes its expected utility. A *Bayes Nash equilibrium* is a strategy profile such that every agent is best-responding to the others. That is, each agent is playing a strategy which maximizes its expected utility, given the strategies being followed by the others.

If we return to our model, we see that there are some strategies which no rational agent would select and thus we can ignore. In particular, given S_D, an agency has no incentive to propose $B_i > S_D$. It knows that it will be asked to export (and benefit from exporting) at most S_D, while the search costs incurred from the excess $B_i - S_D$ would not be compensated. Bidding $B_i = S_D$ would yield the same benefits for a lower search cost.

3.1.3. CIFFC's Role

CIFFC is assumed to be a non-strategic entity in the process. However, its rules for determining how to select resources from the exporting agencies to send to D, can have an influence on the strategic behaviour of the exporting agencies. We consider two different scenarios in the following analysis.

$i \setminus j$	Full (S_D)	Partial ($B_j < S_D$)	Nothing (0)
Full (S_D)	$u_i(R_i, \Omega_i, S_D, S_D)$, $-s_j(S_D)$	$u_i(R_i, \Omega_i, S_D, S_D)$, $-s_j(B_j)$	$u_i(R_i, \Omega_i, S_D, S_D)$,0
Partial ($B_i < S_D$)	$-s_j(B_i)$, $u_j(R_j, \Omega_j, S_D, S_D)$	$u_i(R_i, \Omega_i, B_i, B_i)$, $u_j(R_j, \Omega_j, B_j, \max[S_D - B_i, 0])$	$u_i(R_i, \Omega_i, B_i, B_i)$,0
Nothing (0)	0,$u_j(R_j, \Omega_j, S_D, S_D)$	0, $u_j(R_j, \Omega_j, B_j, B_j)$	0,0

Table 3.1: *The utility outcomes when two agencies compete to fullfill a request of resources. We assume that agency i has priority over agency j.*

3.2. A Two Agency Case

We start our analysis by studying a situation where there are two exporting agencies. The interaction proceeds as follows. First the distressed agency reports its needs, S_D. Then each exporting agency announces some amount B_i of resources it is willing to export and CIFFC decides on the allocation. We assume the following procedure, minimising logistics costs, is used.

- If only one agency announces $B_i \geq S_D$ then $H_i = S_D$ and $H_j = 0$ for $j \neq i$.
- If both $B_i, B_j \geq S_D$ then if agency i is closer to D then $H_i = S_D$ and $H_j = 0$. Otherwise, $H_j = S_D$ and $H_i = 0$.
- If $B_i, B_j < S_D$ then if i is closer to D then $H_i = B_i$ and $H_j = \min[B_j, S_D - B_j]$. This is reversed if j is closer to D.

We are able to partition both the strategy spaces of the agencies. We say that an agency makes a *full* offer if $\sigma_i = B_i = S_D$. We say that an agency makes a *partial* offer if $\sigma_i = B_i < S_D$. We are also able to partition the outcome space for each agency into the following categories. We say that an agency *covers* the contract if they export $H_i = S_D$, an agency is *unused* if they do not export any resources. Agencies *split* the contract if both agencies export resources, with priority given to the closest. Agencies also have the option to do *nothing*. In this case they recieve no benefit from exporting nor do they take on additional risk by reducing their own resources.

3.2.1. Analysis

Table 3.1 captures the possible outcomes and utilities of the bidding process. The rows represent the strategy adopted by agency i, and the columns represent the strategy adopted by agency j. We assume that agency i is located closer to the distressed agency and thus is given priority when the decision is made as to how to fill the distressed agency's request.

There are certain observations that can be made directly from Table 3.1 given certain assumptions about the utility functions of the agencies. We start by assuming that all agencies are aware of their parameters for the utility functions.

Case 1: $u_i(R_i, \Omega_i, S_D, S_D) \geq u_i(R_i, \Omega_i, B_i, B_i)$ **for all** $B_i < S_D$ If the utility of agency i when it provides the full amount of resources, S_D, is greater than when it offers and provides any lesser amount, then agency i is best off when it offers the full amount. That is, its dominant strategy is $\sigma_i(\Omega_i, R_i) = S_D$. The best response for agency j, in this situation, is to do nothing. If it does anything else, then it will incur the search costs, but will not be compensated in any way since it will not be selected to provide resources. One can trivially argue the other direction in that if agency j offers nothing then agency i is best off finding and offering S_D since this maximises its utility. Thus, there is an equilibrium $\sigma^* = (S_D, 0)$.

Case 2: $u_i(R_i, \Omega_i, B_i, B_i) \leq 0$ **for all** $0 < B_i \leq S_D$ If the utility of agency i is such that the costs of offering any resources is higher than any benefit it would receive from exporting then clearly agency i is best off not offering anything. Agency j's best response is to offer $B_j^* = \arg\max_{B_j} u_j(R_j, \Omega_j, B_j, B_j)$. There is an equilibrium $\sigma^* = (0, B_j^*)$.

The above two cases made strong assumptions about both the structure of the agencies utility functions and the knowledge that the agencies have about each other. A more interesting scenario is when agencies do not have full information about certain aspects of their utility functions (such as fire load) but are aware that the utility of agency i is such that it might be interested in making a partial offer $B_i \leq S_D$. An equilibrium in this scenario is a pair of offers, (B_i^*, B_j^*), such that the expected utility of each agency is maximised, *given the beliefs (captured by probability functions) that the agencies have about each other*.

We start by analyzing the decision process of agency j, under the assumption that agency i has offered $0 \leq B_i \leq S_D$. Given the procedure for allocating the resources, for any offer of resources, B_j, the maximum in which agency j will actually export is

$$H_j = min(B_j, S_D - B_i).$$

Agency j's utility is

$$u_j(R_j, \Omega_j, B_j, H_j) = f_j(\Omega_j, R_j - H_j) + sg_j(H_j) + cb_j(H_j) - s_j(B_j) \tag{3.2}$$

There are two cases.

Case 1 (unconstrained), $B_j < S_D - B_i$**:** Agency j's export is limited by its own capacity. Thus, $H_j = B_j$. The utility of agency j is

$$u_j^{(1)} = f_j(\Omega_j, R_j - B_j) + sg_j(B_j) + cb_j(B_j) - s_j(B_j). \tag{3.3}$$

Case 2 (constrained) $B_j > S_D - B_j$**:** Agency j's export is limited by the size of the outstanding request. Thus, $H_j = S_D - B_i$. The utility of agency j is

$$u_j^{(2)} = f_j(\Omega_j, R_i - S_D + B_i) + sg_j(S_D - B_i) + cb_j(S_D - B_i) - s_j(B_j). \tag{3.4}$$

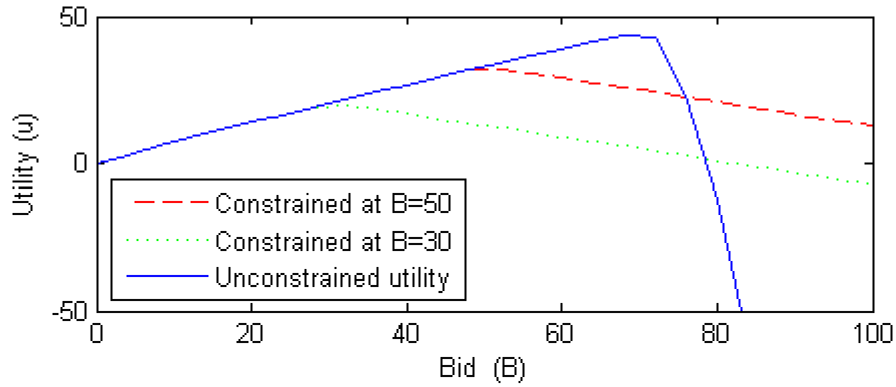

Figure 3.1: *Constrained and Unconstrained Utility Curves where* $S_D = 100$*. The solid line is the unconstrained case where the utility of agency* j *is not constrained by an offer from agency* i*. The dashed line is the case where the maximum amount that agency* j *can export is 50 while the dotted line is the constrained utility when the maximum that can be exported is 30. Other parameters were* $\Omega_j = 70$ *and* $R_j = 100$*.*

Note that as B_i or B_j increases, it is more likely that the utility of agency j is constrained.

In an agency where search costs are small relative to benefits of exporting and penalties of fire damage, the utility of j in unconstrained case increases with B_j until a threshold equal to $R_j - \Omega_j$. This threshold represents the amount of resources that can be exported before incurring a utility penalty due to fire damage. Past the threshold point, utility decreases rapidly. Without taking the actions of i into account (*i.e.* if we assume i's bid is very small), j's utility is maximized by bidding a value at the threshold (or slightly past the threshold if fire damage permits).

In practice, j's utility follows the unconstrained curve of Case 1 for small bids , B_j, where $B_j = S_D - B_i$, that is, until j's bid equals the remaining contract left after B_i's bid; or for large bids where $B_j = S_D > B_i$. For the other cases, where $S_D > B_j > S_D - B_i$, the utility of agency j becomes constrained and decreases earlier than in the unconstrained case as the additional search cost incurred is not balanced by any positive benefit the agency can obtain by exporting. An example of this is shown in Figure 3.1.

In agencies where search costs are high, the costs may make exporting a large amount of resources prohibitively expensive well before penalties from fire damage are applied. However, the same conditions of constraining the amount of resources that are exported still applies.

3.3. Best Responses Strategies

To quantify the best response for j for a given bid B_i by i, we must first define j's belief of the likely bids that will be submitted by i. Let $p(x)$ be the probability density function reflecting j's belief that $B_i = x$, and $P(x)$ is the cumulative density function.[8]

To calculate the expected utility of j for a bid B_j, we integrate the utility curve as specified by Equations 3.3 and 3.4 over the probability distribution $p(x)$. Recall that when $B_j \le S_D - B_i$, j is unconstrained; and when $B_j > S_D - B_i$, j is constrained. These conditions can be rewritten as $B_i \le S_D - B_j$ and $B_i > S_D - B_j$, respectively, giving us the following equation:

$$
\begin{aligned}
&E_{B_i}[u_j(\Omega_j, R_j, B_j)] = \int_0^{S_D-B_j} u_j^{(1)} p(x)\,dx + \int_{S_D-B_j}^{S_D} u_j^{(2)} p(x)\,dx \\
&= \int_0^{S_D-B_j} [f_j(\Omega_j, R_j - B_j) + sg_j(B_j) + cb_j(B_j) - s_j(B_j)] p(x)\,dx \\
&\quad + \int_{S_D-B_j}^{S_D} [f_j(\Omega_j, R_i - (S_D - x)) + sg_j(S_D - x) + cb_j(S_D - x) - s_j(B_j)] p(x)\,dx \\
&= (f_j(\Omega_j, R_j - B_j) + sg_j(B_j) + cb_j(B_j) - s_j(B_j)) P(S_D - B_j) - s_j(B_j) \\
&\quad + \int_{S_D-B_j}^{S_D} [f_j(\Omega_j, R_i - (S_D - x)) + sg_j(S_D - x) + cb_j(S_D - x)] p(x)\,dx
\end{aligned}
\tag{3.5}
$$

The utility curve follows the unconstrained curve of $u_j^{(1)}$ as B_j increases, until it reaches the maximum amount of available contract $S_D - B_i$; there, it stops being affected by benefits of increasing exports or penalties of fire damage, and gradually tapers off from increasing search costs. Given agency j's beliefs about the amount that agency i is offering for export, the best response for agency j is $\sigma_j(\Omega_j, R_j) = B_j^*$ where B_j^* maximizes Equation 3.5.

A similar analysis is needed to determine what agency i's best response to agency j's action. The strategy is not symmetric since recall that agency i is given priority in the process. If agency j offers for export the entire request of $B_j = S_D$, then agency i's best response is the following:

$$
\sigma_i(\Omega_i, R_i) = \begin{cases} S_D & \text{if } u_i(\Omega_i, R_i, S_D) > 0 \\ 0 & \text{otherwise.} \end{cases}
$$

If agency j offers $B_j < S_D$ then, given the priority scheme assumed, agency i will be able to export whatever it offers. Thus, $\sigma_i(\Omega_i, R_i) = B_i^*$ where

$$
B_i^* = \arg\max_{B_i} \left[f_i(\Omega_i, R_i - B_i) + sg_i(B_i) + cb_i(B_i) - s_i(B_i) \right].
$$

[8] During our interviews, agencies reported making informal calls to other agencies and CIFFC in order to get a "feel" for what was going on. These actions clearly map into belief formation for the model.

3.4. Numerical Examples

In this section we provide several examples to illustrate how different parameters influence the utilities (and thus decisions) of the agencies. In particular, we look at how utility of agency j is influenced by the offer amount, B_j, and the maximum amount that can be exported by agency j, which we denote by T (recall that this is a function of the offer of agency i). We recall that the utility of agency j increases until either one of two situations occurs: *(i)* the offered amount B_j exceeds the maximum available export amount, T, or *(ii)* B_j exceeds the fire threshold. In situation *(i)*, utility falls off slowly as benefits from social goodwill is capped, but the search cost continues to increase; in situation *(ii)*, utility drops rapidly due to fire damage.

In our examples we used the following parameters, unless explicitly stated.

- $S_D = 100$
- $R_i, R_j = 100$
- $sg_j(B) + cb_j(B) = B$
- $f_j(\Omega_j, B) = 0$ if $B \leq 50$ and $f_j(\Omega_j, B) = -(\Omega - B)^{1.8}$ if $B > 50$
- $s_j(B) = 0.2B^{1.136}$
- Agency j's beliefs about the size of $T = S_D - B_i$ follow a Poisson distribution with $\lambda = 50$.

Figure 3.2 (left) shows one such utility surface with the following default parameters (all subsequent plots will be based on modifications from the default parameters). Regions of high utility are coloured red, with colours changing toward green and blue as utility decreases.

The maximum value of the unconstrained curve represents the amount that agency j should offer, assuming there were no other agencies. We note that in the setting we have presented, the offers made (and the utility achieved) by an agency reasoning about the unfulfilled request (and thus the other agencies offers) is very close to that achieved by simply making an offer which maximizes its utility when ignoring the other agency. However, there is some benefit when the offers are larger. Reasoning about the available unfulfilled request reduces the chances of organizing and making an offer which is larger than when is possible to export. By avoiding or reducing these situations, an agency saves on search costs and reduces loss of utility from fire damage.

We are interested in understanding how sensitive an agency's utility was to the size of the remaining unfulfilled request. Figure 3.3 (left) presents the expected utility when the size of the unfulfilled request is expected to be small ($\lambda = 20$). Figure 3.3 (right) shows the expected utility when the expected size of the unfulfilled request is large ($\lambda = 80$). When the unfulfilled request is large then there is little difference between the utility achieved by simply ignoring other agencies and taking them into account, while if the unfulfilled request

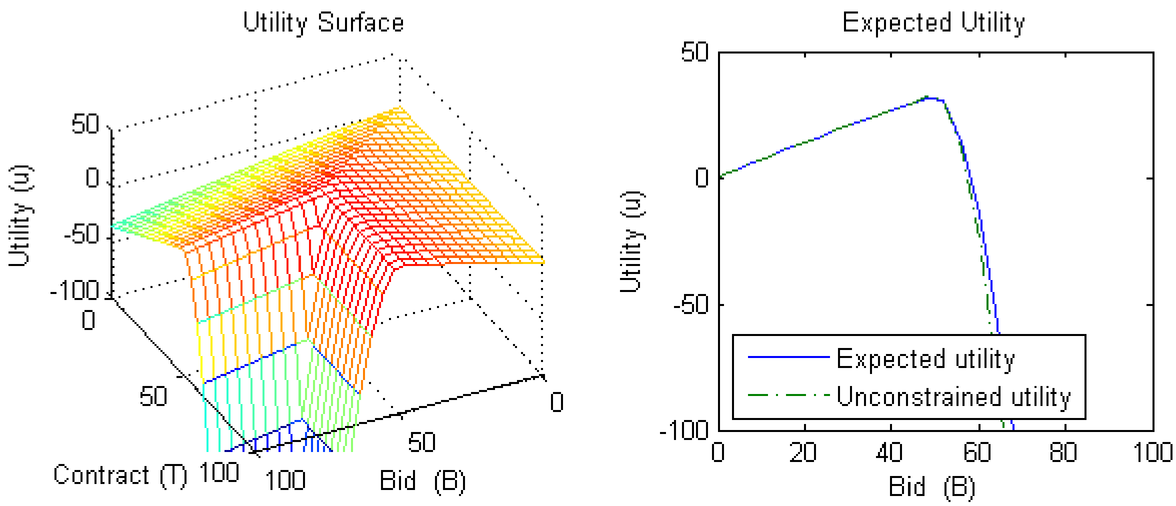

Figure 3.2: *Utility surface (left) and expected utility (right) when using our default parameters.*

is likely to be small, then we observe that this constraint does effect the expected utility of the agency.

Figure 3.4 illustrates the utility surface and expected utility when the fire threshold is lowered ($\Omega_j = 20$ units), meaning that the agency sees a reduction in utility due to fire losses quickly, which constrains the amount that it is willing to offer. Conversely, Figure 3.5 illustrates the case where fire levels are high (Ω_j= 80 units). In this case, the agency has a lot of flexibility in its offer before fire damage becomes an issue and the expected utility and unconstrained curves appear almost coincident.

Figure 3.6 ilustrates one of the main deterrents to exporting. When search costs are too high, they begin to outweigh the social goodwill and cost benefits derived from exporting. Here, we have increased the coefficient of the search cost function from 0.2 to 0.6: $s(B) = 0.6B^{1.136}$. Notice the significant distortion of the utility surface, and the negligible gain in expected utility for any export offer.

3.5. Modelling Smaller Agencies

According to our interviews, smaller agencies can face unique logistical challenges when making the decision to export. Due to having relatively fewer resorces on hand, searching for and guaranteeing the availability of exportable resources can be very expensive, especially when the request increases in size. This can be captured in our model by making the search cost function $s_j(B_j)$ decrease more rapidly. Figure 3.7 illustrates the utility surface and expected utility where the exponent of the search cost function is increased from 1.136 to 1.4 ($s(B) = 0.2B^{1.4}$). Note that the optimal bid is much smaller than the threshold of the

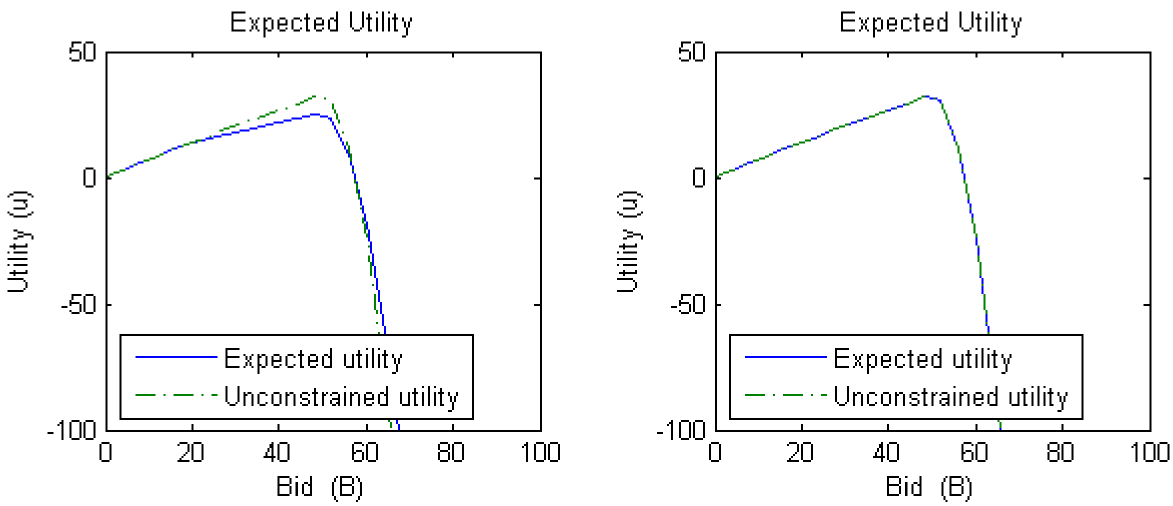

Figure 3.3: *Expected utility as a function of the size of the unfulfilled request. On the left, the expected size is small ($\lambda = 20$) while on the right the expected size is large ($\lambda = 80$).*

fire load, which was set at $\Omega_j = 50$.

If search cost is prohibitively expensive, with

$$-\frac{d}{dB_j}s_j(B_j) \geq \frac{d}{dB_j}sg_j(B_j) + \frac{d}{dB_j}cb_j(B_j)$$

at trivial values of B_j, then j will be disincentivized from offering resources at all. This effect is further exaggerated if j believes i is likely to make a large offer since it lowers the expected utility that can be gained from $sg_j(\cdot)$ and $cb_j(\cdot)$.

3.6. Extending to Many Agencies

The selection process can be generalized to a setting involving many agencies. If $E = 1, \ldots n$ is the list of agency sorted in descending order of bids, breaking ties by distance from D, then the process awards as much of S_D to agency 1 as possible; if any contract remains, then it repeats this process with agency 2, and so on.

Just as we established in Section 3.2, an agency j treats the preceding agencies $1, \ldots j-1$ as a single meta-agency, maintaining its beliefs about the amount of resources still required. The analysis presented in Section 3.2 applies with the caveat that the agency must also consider the possibility that some succeeding agency $k \in \{j+1, \ldots n\}$ may offer S_D. Let $\hat{i}$ be the meta-agency representing the preceding agencies $\{1, \ldots j-1\}$, with total offer $B_{\hat{i}}$. Let $p(x)$ be the probability distribution function for $B_{\hat{i}} = x$, and $P(x)$ be its cumulative distribution function. Let γ be the probability that at least one preceding agency from

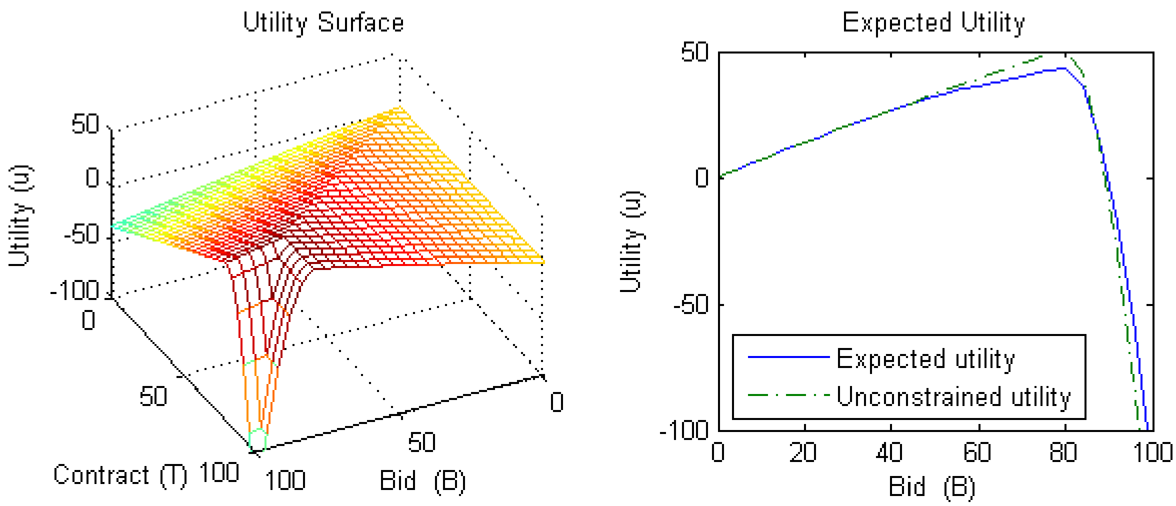

Figure 3.4: *Utility surface and expected utility when the fire threshold is low* ($\Omega_j = 20$)*.*

$\{1, \ldots j-1\}$ offers S_D, and δ be the probability that at least one succeeding agency from $\{j+1, \ldots n\}$ offers S_D. Then we have the following formulae for the expected utility of j:

If j offers S_D

$$E_{B_{\hat{i}}}[u_j(\Omega_j, R_j, S_D)] = (1-\gamma)u_j^{(1)}(S_D) - \gamma(s_j(S_D)). \tag{3.6}$$

If j makes a partial offer of B_j

$$E_{B_{\hat{i}}}[u_j(\Omega_j, R_j, B_j)] = (1-\delta)\left(\int_0^{S_D-B_j} u_j^{(1)} p(x)\,dx + \int_{S_D-B_j}^{S_D} u_j^{(2)} p(x)\,dx\right) - \delta(s_j(B_j)) \tag{3.7}$$

3.7. Alternative Selection Policies

We conducted our analysis under the assumption that CIFFC was using one particular policy for selecting which offers to use when fulfilling a resource request. In this section we consider a second policy, where CIFFC prioritizes offers by size, using the largest offers first. In a two-agency setting this will result in one agency completely exporting its entire set of offered resources, with the second making up the difference (if there is any). In a many-agency setting, this policy will tend to reduce the number of agencies that are involved in the exporting process. In either case, this may be in CIFFC's best interest as it would likely lead to lower overall transportation and logistics costs.

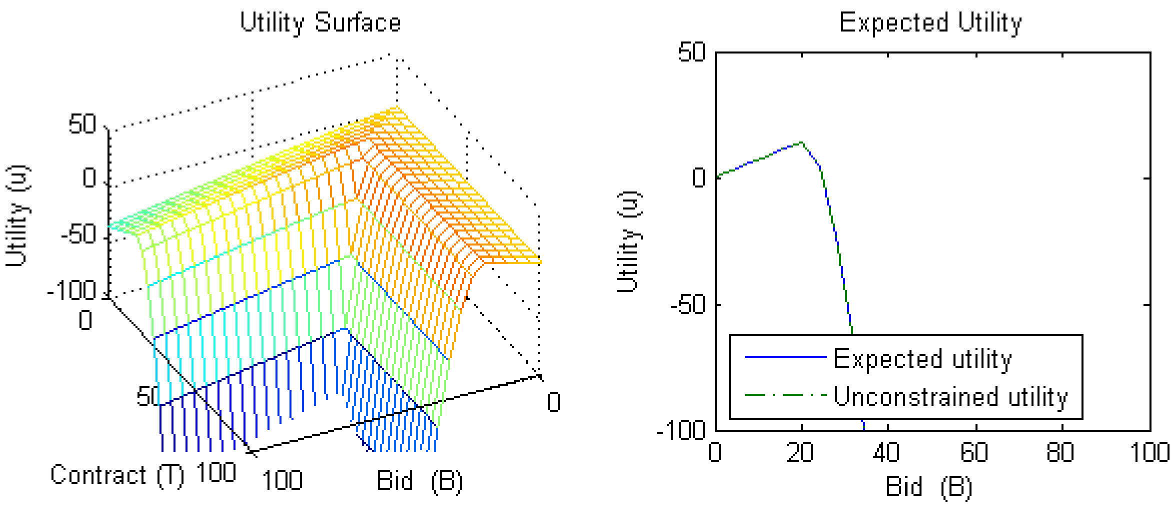

Figure 3.5: *Utility surface and expected utility when the fire threshold is high ($\Omega_j = 80$).*

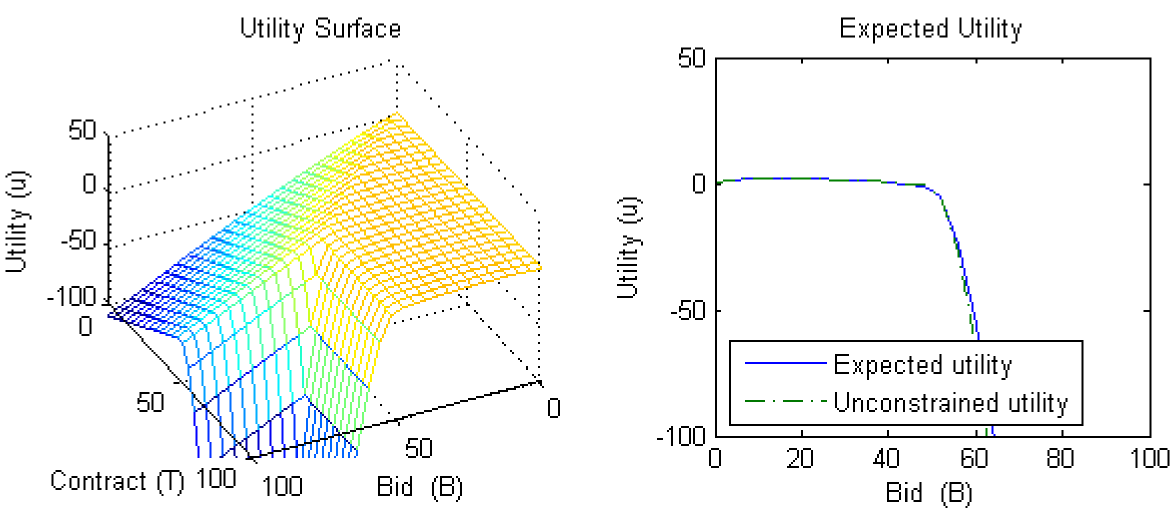

Figure 3.6: *Utility when the search cost is increased to $s(B_j) = 0.6B^{1.136}$. Note the vertical scale on the right has changed.*

Under this policy, the utilities of each agency is still divided into the constrained and unconstrained cases as described in Section 3.2.1, but the conditions are slightly different. For the two-agency case, agency j's utility is unconstrained if $B_j < S_D - B_i$ **or** $B_j > B_i$, and it is constrained if $B_j > S_D - B_j$ **and** $B_j < B_i$. This can be extended to the many-agency case.

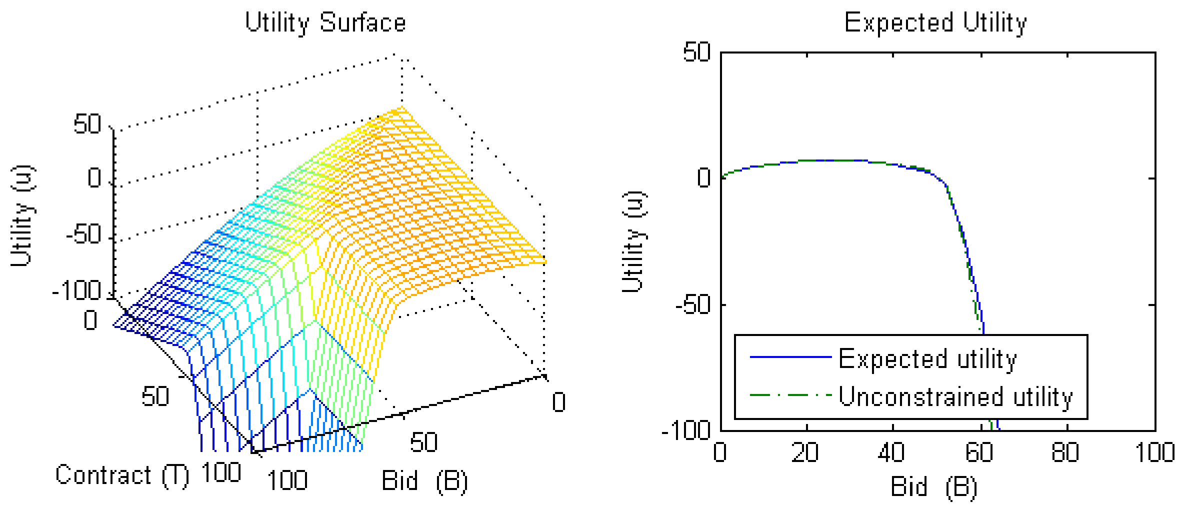

Figure 3.7: *Utility when there are high search costs,* $s_j(B) = 0.2B^{1.4}$.

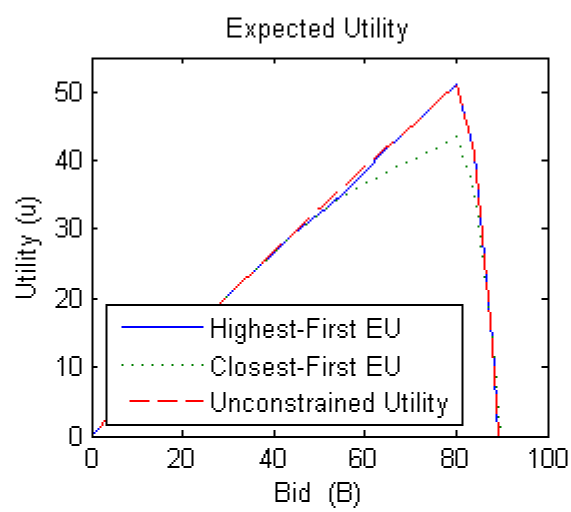

Figure 3.8: *Comparison of two selection policies.*

The net result of this change is that agencies more distant from D are less likely to become constrained at high bids. Analysing the examples using this new policy shows that it tends to bring the expected utility curve closer to the unconstrained utility curve. This is illustrated in Figure 3.8, which shows the case where the fire threshold is set at 20 resource units (all other parameters are set at the default values described in Section 3.4).

3.8. Assumptions on Fire Damage

We make the implicit assumption that as the amount of resources exported increases, the severity of fire damage exceeds any benefit gained from exporting. In other words, for any agency i,

$$\lim_{H_i \to +\infty} \frac{d}{dH_i} f(\Omega, R_i - H_i) - \frac{d}{dH_i} sg(H_i) - \frac{d}{dH_i} cb(H_i) < 0.$$

Note that in practice, H_i is bounded above by R_i, though we expect this limit to reach negative values well before R_i (or else the agency will be tempted to export all of its resources, search costs aside).

3.9. Model Summary

In this section we proposed a mathematical model for resource sharing and analyzed it.

- Based on the results of our interviews, we modeled the value (utility) an agency receives from exporting resources as depending on its own resource requirements, the social goodwill it generates from exporting, any cost recovery it achieves and the logistical overhead of finding and organizing the resources to be exported.
- Based on our model, we concluded that there is a strategic aspect to the export decisions being made by agencies. In particular, agencies need to reason about the amount of resources other agencies may be offering for export. In particular, in the model agencies needed to balance the logistical costs of determining whether resources could be made available given their own requirements against the likelihood that their resources would be assigned by CIFFC.
- The fact that the export decisions of one agency influences the export decisions of another agency does have an impact on the utility obtained by the agencies. We compared the achievable utility of an agency in the case where it was not constrained by the actions of other ("unconstrained utility" in our analysis and graphs) with the expected utility of an agency when its export decision was constrained by the choices of others. We noted a decrease in the utility of agencies when there was this interaction.
- Through a series of small simulations, we noted that it appeared that the CIFFC policy on how resources should be selected and assigned had a notable influence on the strategies and utility of agencies.

4. Conclusion

In this report we presented the results of a series of interviews on resource sharing conducted with agencies across the country and CIFFC. We also proposed a model aiming to capture some of the issues which arose during the interviews. Some key conclusions which can be drawn are:

- Overall, there was great respect and strong support for the way CIFFC organizes resource sharing across agencies in Canada.
- There is a strategic aspect to resource sharing, which became clear during the interviews. Interestingly, the strategic aspect seems to involve gauging the amount of effort to put into guaranteeing how much resources are available for export, as opposed to strategizing when reporting information.
- How CIFFC decides which agencies will export resources is important. During the interviews, a number of agencies mentioned they wished that some of CIFFC's decisions were more transparent, and in our model, even under strong assumptions, we did notice a difference in expected utility and (implicitly) the strategies followed by agencies under different assumptions about the resource allocation process.

Finally, we view this work to be preliminary in nature. While we believe that our model captures some key aspects of resource sharing, our numerical examples are small and were computed using simple parameters. A next step could be a larger scale numerical simulation, using more realistic data. We also think further study into how different CIFFC allocation policies influence agencies decisions would be interesting and important.

5. Acknowledgements

We would like to thank the following people for taking time out of their schedules to talk to us about resource sharing. Charles Beaulieu, Jeff Betts, John Brewer, Jed Cochrane, Steve Cone, Luc Dugas, Howard Dupuis, Mike Etches, Walter Fanning, Duane Feely, John Flinn, Marie-Eve Foisy, Gary Friesen, Leo Gillich, Tim Greer, Grahame Gordon, Bruce Hamilton, Murray Henry, Jonathan Large, Curits Lee, Dean MacDonald, Kara McCurdy, Chris McGinty, Blair McTavish, Jacquie Nixdorf, Daniel Normand, Lakmal Ratnayake, Steve Roberts, John Ross, Quentin Spila, Brian Terrene, Al Tithecott, Steve Tull, Cordy Tymstra, Scott Wasylenchuk, Bruce Young

A. Notation

The following table summarizes the symbols used in our model:

D	Distressed agency
S_D	Amount of resources requested by D
E	Set of exporting agencies which may offer resources
i, j, k	Indices for any particular exporting agency from E
σ_i	Pure strategy adopted by i
Ω_i	Fire load indicating amount of resources that must be retained in province to avoid incurring fire damage
R_i	Amount of resources controlled by i
B_i	Amount of available resources reported to CIFFC by i in response to an export request
H_i	Amount of resources actually exported by i
$u_i(R_i, \Omega_i, B_i, H_i)$	Utility for i
$f_i(\Omega_i, R_i - H_i)$	Fire damage, amount of utility lost due to having less resources ($R_i - H_i$ after exporting) than the fire load Ω_i
$sg_i(H_i)$	Social goodwill, amount of utility gained from social benefits from exporting H_i
$cb_i(H_i)$	Cost recovery, amount of utility gained from cost recovery after exporting H_i
$s_i(B_i)$	Search cost, amount of utility paid to guarantee availability of B_i resources
$u_i^{(1)}$	Unconstrained utility, calculating i's utility assuming i's ability to export is not limited by available contract
$u_i^{(2)}$	i's utility when constrained by the amount of contract remaining after higher priority bids

B. Additional Numerical Examples

This appendix extends Section 3.4 with additional examples describing the utility of agency j under different scenarios. As before, we used the following parameters, unless explicitly stated.

- $S_D = 100$
- $R_i, R_j = 100$
- $sg_j(B) + cb_j(B) = B$
- $f_j(\Omega_j, B) = 0$ if $B \leq 50$ and $f_j(\Omega_j, B) = -(\Omega - B)^{1.8}$ if $B > 50$
- $s_j(B) = 0.2B^{1.136}$
- Agency j's beliefs about the size of $T = S_D - B_i$ follow a Poisson distribution with $\lambda = 50$.

B.1. Scaling Available Contract

In Figure B.1, we consider situations where the size of the contract is significantly different from the amount of resources available to the agency. Figure B.1 (left) shows the expected utility of agency j where expected contract availability is only $\lambda = 5$. Notice that, for the default search costs, j still has incentive to report values much higher than 5 (up to their fire threshold), due to the probability (however small) that it can be used.

Figure B.1 (right) shows the situation where the available contract is expected to be far in excess of the maximum exporting capacity of j ($\lambda = 200$). As with Figure 3.3, the plentiful contract the agency is unlikely to be constrained, and the expected utility almost coincides with the unconstrained utility.

B.2. Stepwise Search Costs

Figure B.2 shows the situation where an agency maintains an accurate inventory of available resources, and the search cost for the first $B_j^* = 25$ units of resources is 0. However, additional resources beyond the first B_j^* has increased cost equal to $s_j(B) = 0.4(B - B_j^*)^{1.136}$. The knee caused by the search costs is visible in the utility surface and expected utility curve, but does not significantly impact decision making in this case; the concern for fire damage determines where the expected utility is maximized .

Figure B.3 shows the same situation, but with fire threshold set at 20. With lower fire levels, more resources could potentially be safely exported. However, this means the impact of higher search costs becomes the limiting factor for export decisions.

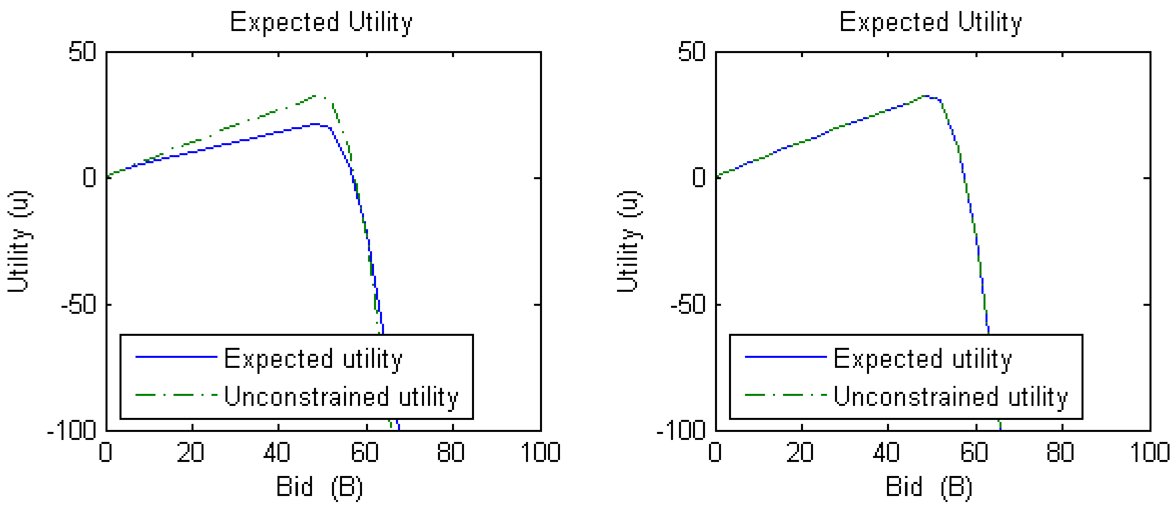

Figure B.1: *Expected utility with* $\lambda = 5$ *(left) and* $\lambda = 200$ *(right).*

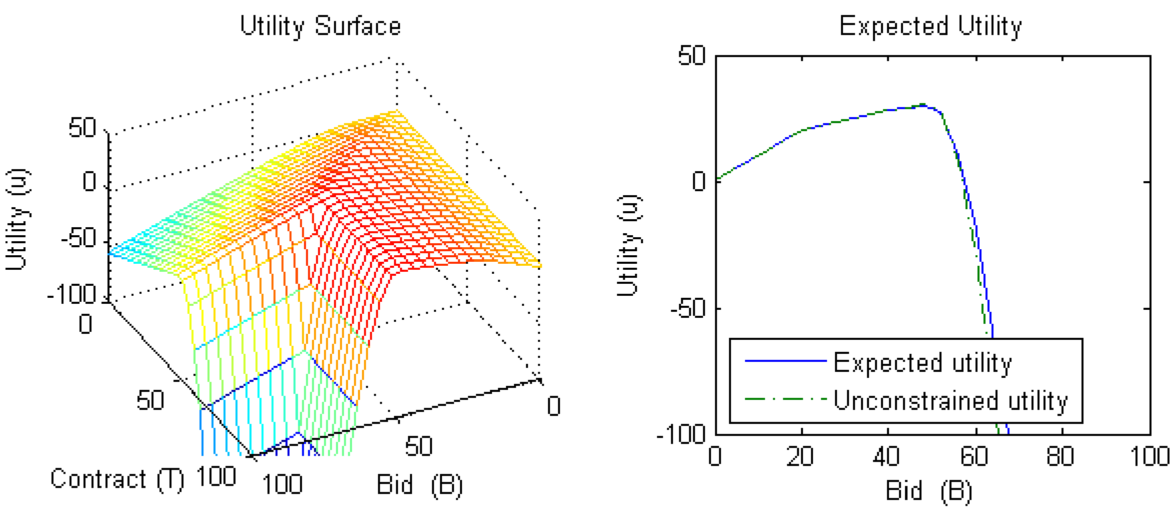

Figure B.2: *Utility when there is a stepwise search function* ($B_j^* = 25$).

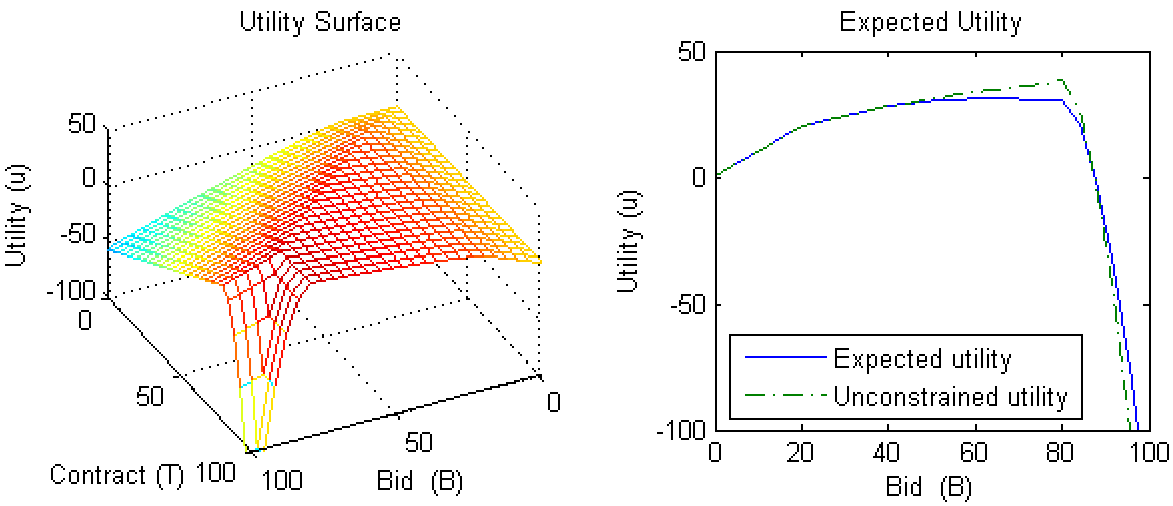

Figure B.3: *Utility with stepwise search function, with low fire threshold (set at 20 units).*

B.3. Effects of Varying Contract Availability under Alternate Selection Policies

Section 3.4 investigated the effects of changing contract availability (by adjusting the parameter λ) on the expected utility of agency j while using "Closest First" selection policy. The follow graphs compare the expected utility of agency j under the two selection policies, with varying contract availability. Note that expected utility under the "Highest First" policy depends on the size of the original contract in addition to expected availability λ. In each case below, we set the size of the original contract $S_D = 2\lambda$. As with Figure 3.8, we set fire threshold to 20.

As mentioned in Section 3.4, the expected utility under the "Highest First" policy follows the unconstrained utility closely. However, this benefit of this policy is diminished when contract availability is plentiful (higher values of λ and S_D), when the expected utility under "Closest First" also approach the unconstrained curve.

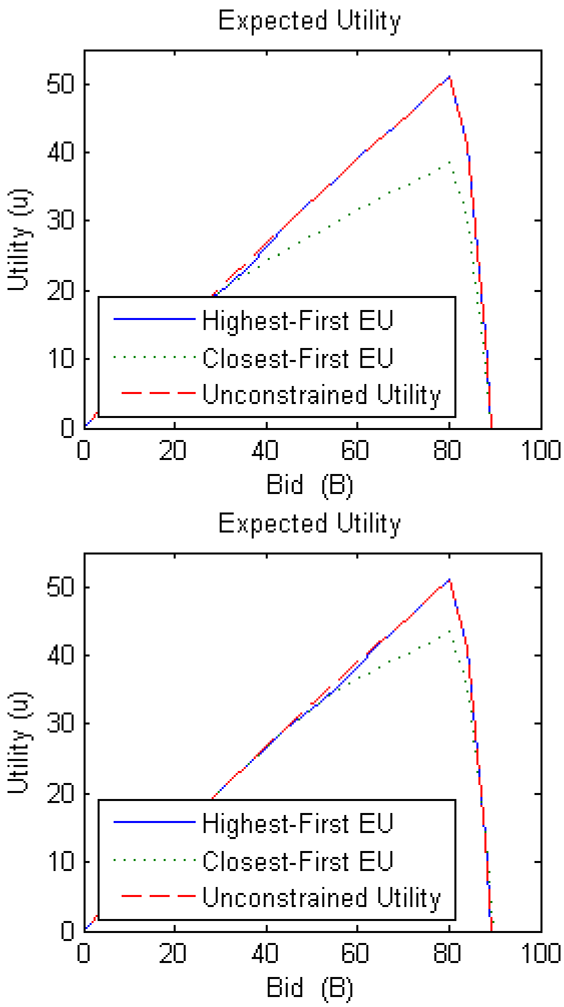

Figure B.4: *Expected utility under two selection policies, with varying contract availability:* $\lambda = 30, S_D = 60$ *(top left)*, $\lambda = 40, S_D = 80$ *(top right)*, $\lambda = 50, S_D = 100$ *(bottom left)*, $\lambda = 60, S_D = 120$ *(bottom right)*