[The ambiguity dilemma in procurement projects]

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The ambiguity dilemma in procurement projects

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Abstract:

Ambiguity in the procurement process is a bane for procuring principals and a boon for vendors—for the former, it is an issue to be managed, and for the latter it provides an opportunity to extract extra payments, referred to as insurance rents, from the principals. In this paper, we use a stylized model in which there is a degree of risk and uncertainty (or ambiguity) in the procurement process. We show that, under certain conditions, the contracting principal can be exploited by a rational, rent-extracting vendor. In particular, we show that there is an incentive for a vendor to delay the resolution of ambiguities in the contract until late in the procurement process, when the insurance rents are at a maximum. We then propose ways in which principals might mitigate this conduct of vendors. This study contributes to the current literature by highlighting a problem in the procurement process and describing it in the form of a novel game.

Keywords: Game Theory; Procurement; Uncertainty

1. INTRODUCTION

In every procurement process there are known and unknown risks, generally referred to as ‘risk’ and ‘uncertainty’, respectively (Griffith & Zhao, 2015; Luu, Cadeaux, & Ngo, 2018). ‘Risk’ characterizes those situations that are clearly measurable with respect to probability (Kaplan & Garrick, 1981; Lu & Yan, 2016; Nguyen & Nguyen, 2017), while uncertainty describes those situations where the event space does not come equipped with a ‘natural’ or

an ‘objective’ probability measure although a probability can be subjectively inferred (Geersbro & Ritter, 2010; Glas & Kleemann, 2017). Examples of risky events in the procurement process include: price movements, absences of key staff, changes in the weather, the natural stochastic characteristics of materials, and so on. The nature of these risks is similar to that of fair coin tosses. Examples of uncertain events in procurement are fundamentally related to the R&D component that is embedded in the overall product development and delivery process—will the product deliver the attributes aimed for? It’s in the nature of these phenomena that they’re unknown, though ‘rough’ or ‘approximate’ probability estimates can be made. These unknown risks are often modelled by so-called ‘horse lotteries’ and ‘urn draws’ (Battigalli, Cerreia-Vioglio, Maccheroni, & Marinacci, 2017). In this paper, we utilize coin tosses and urn draws to simulate the different impacts that risk and uncertainty have on the procurement process, with the object of exploring the strategic behaviour of players on both sides of that process. In explaining this behaviour, we aim to add to the existing literature on procurement, which largely deals with the issues raised by (known) risks alone.

The procurement process analysed in this paper goes broadly as follows. Both the vendor and the purchaser are in a situation where there is some risk and some uncertainty. Specifically, we suppose that there is a product development and production process which is subject to both risk and uncertainty (Kreye, Goh, & Newnes, 2017; Yeo & Ning, 2006). The risk and uncertainty apply to the attributes of an artefact which is to be delivered by the seller to the buyer at the end of a well-defined process (Asadabadi, Saberi, & Chang, 2017; Wylie, 2017). Both parties agree on the risks and uncertainties, and must determine some way of resolving them as part of the product development and delivery process. Each party faces different incentives, and this results in each behaving in antagonistic ways with respect to the way the risks and uncertainties are resolved (Ben-David, Brookshire, Burness, McKee, &

Schmidt, 2000). The vendor benefits from delaying the resolution of risk and uncertainty for several reasons. First, on the assumption that *caveat emptor* applies, the vendor can offload the risk of a poor outcome onto the purchaser. The purchaser—who pays the expected value of the artefact—then bears the risk in the product development process of a low-quality artefact being produced. Remediation can be achieved, but at extra cost to the purchaser. In addition to this issue concerning pure risk, the vendor also generally prefers uncertainty to be resolved late in the product development process. The reason for this is that, as time goes by, and as the delivery date nears, the purchaser grows increasingly anxious about the kind of artefact that will ultimately be produced. Accordingly, he will pay a greater amount to have those uncertainties resolved than he is willing to pay early in the procurement process.

In light of these incentives for the vendor to postpone the resolution of risk and uncertainty, the best option that the buyer has is to seek to resolve the risks and ambiguities before the contract is signed (Wakker, Timmermans, & Machielse, 2007). With regards to risk, the solution is straightforward. The vendor—who we suppose is risk neutral—simply assumes the risk for the (presumed) risk-averse buyer, and charges a premium to do so. In effect, the vendor, in return to receiving a reasonable extra payment, namely insurance, insures the buyer against a below-average deliverable. Insurances, referred to as guarantees or warranties, serve this function, and are well understood commercial arrangements. With regards to uncertainty, the situation is more complex. Early in the procurement process, the purchaser is likely to be at least somewhat ambiguity avid; and only, over time, does he become increasingly ambiguity averse. The reason for this is that, early in the process of product development, the purchaser is hopeful that the upside potential of the uncertainties will eventually be realized, and he underemphasizes the potential downsides. As time goes by and the delivery date nears, however, the purchaser begins to worry about the downsides. At

that point, he will be willing to pay more to avoid the uncertainties than he was willing to pay early on.

This phenomenon of shifting attitudes to ambiguity over time is the result of two forces. First, as experimental evidence shows, many decision makers are increasingly ambiguity averse with respect to Expected Value (EV) (Grant, Kline, & Quiggin, 2014; Liu, 2007; Zhu, 2019); which is to say the greater is the expected value of a gamble, the greater is the degree of ambiguity aversion. The second feature is time discounting (Groom, Koundouri, Panopoulou, & Pantelidis, 2007)—the present value of each future dollar is worth less than the present value of each current dollar. Early in the procurement process, the expected value of the artefact is somewhat less than it is as the process plays out, all else being equal. At the initial point, therefore, the buyer is relatively open to ambiguity. As the delivery date gets closer, the expected value increases, and the buyer becomes increasingly ambiguity averse. The combination of both these factors—ambiguity aversion and time discounting—would not be an issue if it were not for the additional fact that ambiguity averse individuals are not, generally, dynamically consistent in their behaviour (Charness, Karni, & Levin, 2013; Miles & LaSalle, 2008). This is to say; decision makers willingly depart from *ex ante* plans over time because they find those plans to no longer be optimal *even though no new information has come to light.* Thus, a purchaser's early plan to bear the uncertainties and to forgo insurance for the duration of the procurement process may be set aside as the delivery date nears and anxieties increase. This dynamic inconsistency is able to be exploited by the vendor, who, we suppose, is ambiguity neutral.

This paper describes the ambiguity problem in the relationship between the purchaser and vendor using decision theory and game theory. It contributes to the current literature by highlighting an existing problem in the procurement process and describing it using decision theory under ambiguity in a game-like setting. Specifically, we employ game theory in a

unique way to deal with imperfect information coupled with ambiguity. In this game, the vendor is subject only to risk—i.e., the vendor knows the objective probabilities that apply to the event space—whereas the buyer is subject to both risk and uncertainty—i.e., he has only incomplete knowledge of the likelihoods of events. Hence, the game is one of asymmetric information. Additionally, we suppose that the supplier manages the bargaining process and has three options: 1. resolving both the ambiguity and the risk upfront, 2. resolving the ambiguity first and the risk later, 3. reducing the risk first and the ambiguity later. As we show in our discussion, the option of resolving both risks and ambiguities in the later stages of the game is suboptimal for the vendor, and so is not a live option. Furthermore, as purchasers do not normally agree to contract unless the risks and ambiguities are resolved at some point over the course of the project, the option of not dealing with risks and ambiguities at all is precluded. For each of these scenarios, a game can be formulated to describe possible situations and remedies. The paper explains the ambiguity problem when the buyer does not have the option of changing the supplier because of the terms and conditions of the contract. The case where the buyer can easily switch supplier is a matter for future discussion and analysis.

The remainder of this paper is organized as follows: in section 2, we look at a stylized static game; in section 3, we look at a stylized dynamic game; in section 4, we further discuss the impact of time-discounting; in section 5, we look at the evolution of ambiguity attitudes over time; in section 6, we recapitulate the foregoing arguments in discursive terms; in section 7, and finally, we propose some solutions to the dilemma that the purchaser faces. These solutions are broadly in accord with those made by the Kinnaird Review (Kinnaird, Early, & Schofield, 2003).

2. RISK AND AMBIGUITY

In this section and the next, we make use of a stylized event space to characterize the differential impacts of risk and uncertainty on the procurement process. Specifically, we use coin tosses to represent risky events, and urn draws to represent uncertain events. Moreover, we assume that there are multiple scenarios where the payoff is zero (these are the no-profit scenarios); whilst there is one scenario that delivers strictly positive profits (in our simple stylization, this amount varies, but is generally a multiple of $50). This payoff structure captures the idea that there is some upside potential in the procurement for the purchaser (otherwise he would not engage in the process), but there are more scenarios where the gains are negligible. Although strikingly simple, this framework of analysis is rich enough to allow for a novel and useful characterization of the event space and payoffs; and it allows us to model the procurement game that purchasers and vendors play in a way that is both revealing and surprising.

In this section, we begin by looking at a domain (event space) of pure risk. Given our chosen stylization, this means that we have two fair coins which divide the event space into four equally likely states, as shown in Figure 1. All the probabilities are known (all states are equally likely with probability ¼), so the situation is one of risk.

----Insert Fig. 1 here---

If $100 is awarded for correctly guessing which combination of heads and tails is realized, then the expected value of the gamble is $25. Moreover, the conditional probability of the first coin turning up heads (or tails) is ½, so that the probability of either of the remaining states occurring is also ½ (i.e., the probability of the second coin turning up heads or tails is 50%). The expected value of the conditional gamble, assuming that the $100 is located in either of the two remaining states, is equal to $50. Consequently, a risk neutral decision maker confronted with this gamble would be willing to pay up to $25 to resolve half the risk early on (i.e., to face the conditional gamble just described). This amount can be understood

as being a kind of insurance payment, as it insures the principal against the partial possibility of loss. In standard terminology, we have:

$$EV\ (v) = \$25$$

$$EV\ (v|v_1, t_1) = \$50$$

$$\text{Insurance payment} = 50 - 25$$

Now, suppose that the game is changed a little. Instead of using two coins, we use one coin and an urn of marbles. As noted earlier, this is a standard device from probability theory and is used to characterize the uncertainty that the decision makers face. The marbles can be white or black. Although the number of white and black marbles in the urn are unknown, the probability of either type of marble being drawn is still 50%. This follows from the application of the Principle of Insufficient Reason (PIR) (White, 2018). The possible situations are as presented below, in Figure 2.

----Insert Fig. 2 here----

If we suppose that the correct choice of the coin toss and the urn draw is rewarded with $100, we see that the game described in Figure 2 (*viz*, game 2) is similar to the game given in Figure 1 (*viz*, game 1). However, there is uncertainty in game 2 which is absent in game 1. Experimental evidence shows that people prefer the first game to the second on account of the first game containing only risk but no uncertainty. Moreover, we observe that this is so, even though their computed expected values are the same for both games. This is the essential insight of the Ellsberg paradox; the first person to make this point that decision makers prefer risky probabilities (coin tosses) to ambiguous probabilities (urn draws) was Ellsberg, 1961 (Ellsberg, 1961). The subsequent literature goes under the rubric of the "Ellsberg paradox".

Focusing now on the second game, we observe that people prefer to gamble on the coin toss (which has known probabilities) rather than the urn draw (which has unknown

probabilities). In other words, given the choice between two conditional gambles—one where the risk (heads or tails) is resolved, and the other where the uncertainty (black or white marbles) is resolved—decision makers prefer that the uncertainty caused by the urn draw is removed rather than the risk associated with the coin-toss being removed. Consequently, they will pay a premium amount, A, in order to remove the ambiguity as per the following equations.

$$EV\ (v) = \sim\$25$$

$$EV\ (v|v_1) = \sim\$50;\ EV\ (v|t_1) = \$50$$

$$\text{Insurance payment} = 50 - 25 + A$$

This gives us some insight into what an ambiguity averse buyer will do in a 'static' procurement process (Grant et al., 2014). The buyer will be willing to pay more to the vendor for the vendor to remove that part of the event space that gives rise to ambiguity than he would pay in order to eliminate an equivalent amount of risk (the 'equivalence' here is measured in terms of expected value).

Now, suppose that the magnitudes of the above gamble are all multiplied by 10, so that the 'prize' is $1,000, and the approximate expected value is initially $250, and the conditional expected value is $500 (assuming that the prize remains in play). We know that humans become *increasingly* ambiguity averse when expected values rise (Machina & Siniscalchi, 2014) – for instance, we don't mind uncertainty when buying a bottle of wine at $10, we might even want to take the risk and try something new, but we do avoid any uncertainty when spending $5000 on a bottle of wine. So, if the decision maker is risk neutral, ambiguity averse, then he will pay an amount *strictly greater* than 10 x A to reduce ambiguity at higher expected values. Thus, an insurer will be able to extract proportionately *more* from this decision maker, the greater is the expected value of the gamble.

This conclusion is reached in a static context. However, the implications for dynamic games are as follows. If the expected value of the outcome increases over time as the due date for delivery draws near and time-discounting is reduced, then the vendor will profit by postponing any offer to insure the purchaser against an adverse *uncertain* outcome for as long as is technically possible. This accords with our earlier discussion, and it is what motivates the vendor in the procurement process to delay the resolution of uncertainty. By doing so, the vendor is able to extract proportionately greater value from the purchaser. In fact, as we shall immediately see, it is possible for differential rents (extra payments) to be extracted from the buyer by the seller even when time discounting is nugatory.

3. TIME AND DYNAMICS

In order to understand the dynamic implications of the ambiguity or uncertainty aversion of decision makers, we can consider the above coin-toss/urn-draw games as sequential games. In that case, it's expedient to represent the games as decision trees rather than as matrices. In what follows, we assume that the decision maker is everywhere risk neutral and is also ambiguity neutral for expected values of $250, but is ambiguity averse at expected values of $500.

Consider the sequential form of game as shown in Figure 3. In this version of the game, the coin toss occurs before the urn draw. The payoff for a 'Win' is $1,000, and for a 'Loss' the payoff is 0.

---Insert Fig. 3 here---

If the player 'wins' the first coin toss, then he confronts an uncertain urn draw. This is analogous to a procurement situation where progress is good, so far, but some uncertainties remain. At the point of the urn draw, the expected value is approximately $500. Since the principal is ambiguity averse at that value, there is some positive amount, B, that he will pay to insure against the uncertain possibility of losing the urn draw. By analogy, there is some

amount that he will pay to stop the procurement process going awry in the latter phases. In the terms of our stylized model, the decision maker would take an amount 500 – B, which is insured, rather than face the urn draw, and this is so even though he is risk neutral. Seen from the point of view of the insurer, he will make an amount B from selling insurance at this late stage in the game to the 'buyer'. In a procurement process, the insurance would be in the form of a product-performance guarantee.

Now, suppose that the coin and marbles sequence changes as shown in Figure 4. In this variation of the dynamic game, the urn draw occurs first, and the coin toss follows. If the player 'wins' the urn draw, then he confronts an uncertain coin toss. At that point, the expected value is $500. However, there is no ambiguity left in the game, that having been resolved in the first round. Only risk remains. As the decision maker is risk neutral he will not pay anything extra to insure against the possibility of loss, so there are no rents to be extracted from him.

---Insert Fig. 4 here---

Comparing these two games, we see that sequence matters in two ways. First, insurance 'rents' can be extracted in the former situation (per Figure 3), whereas they cannot be extracted in the second (per Figure 4). Secondly, it's not worth offering insurance in the first stage of the game in either case—at that stage, the expected value is only $250, at which point the decision maker is both risk neutral and ambiguity neutral, so he is not in the market for insurance of any kind.

Given this stylized model of interaction we can draw the following implications for procurement strategies. To start with, we see why it benefits a supplying contractor to defer the resolution of uncertainty to the latter stage(s) of the procurement process—it is at that stage that rents can be extracted from increasingly nervous—meaning, increasingly ambiguity averse—purchasers. Thus, it is at the latter stages of that process at which

‘insurance’ in the form of guaranteed product performance should be expected to be proffered to purchasers by profit maximizing vendors. This is to say that the optimal procurement structure from the vendor’s point of view is to shift uncertainty to the latter stage of the bargaining process, with insurance being offered in this latter stage. This structure beats both the forward-shifting of uncertainty in a dynamic framework, as well as the offering of all-in-one (‘static’) insurance. Both of these alternative strategies are dominated as they lower the expected value of the game by bundling risk and uncertainty together; and, consequently, they undercut the motivation to take out insurance by a purchaser whose ambiguity aversion increases with expected value.

Incidentally, we note that this implication of the model is based on the fact that decision makers have a definitely negative attitude to ambiguity. If decision makers were ambiguity neutral, and were consistently and constantly risk averse, as in standard models, then there would be no benefit to structuring the game and the offers of insurance in a dynamic way—buyers and sellers would be able to bargain in the standard way to resolve any issues with their contracts. This is to say; risk neutral vendors would indemnify buyers against loss for a premium, and it wouldn’t matter when the offer to insure was made. Alternatively, if purchasers were decreasingly risk averse, it would pay to offer to insure them *earlier* in the procurement process, rather than later. However, this is not what we typically observe. Consider, for example, the case of Brexit, where we may take Britain as attempting to procure access to the European Union, and the EU can be seen as offering various options. In that case, the EU has been adamant that the so-called ‘divorce’ settlement—where the ambiguities are relatively minor—are resolved in a first stage, before the more ambiguous issues around the ‘ongoing relationship’ are resolved. Moreover, the EU is committed to this dynamic structure over and against the wishes of the United Kingdom, which would prefer to deal with both matters simultaneously. In the terms of our model, the behavior of the EU is a

classic, rational ploy to extract the greatest possible rents from an increasingly nervous negotiating partner over time (Carmona, Cîrlig, & Sgueo, 2017; Pisani-Ferry, Röttgen, Sapir, Tucker, & Wolff, 2016). Another example of the phenomenon we are discussing is the current state of negotiations between the Naval Group of France and the Australian government over the building of the new class of conventional attack submarines for the Royal Australian Navy, labelled as Shortfin Class Submarines (Stewart, 2016). This contract valued at AUD 50 bn over the next three decades is one of the largest naval contracts in the world. As it currently stands, the negotiations are at an impasse at least in part over disagreements concerning the sharing of burdens in managing unforeseeable ambiguities in the product delivery process. Reports suggest that the Naval Group is seeking to place the full burden of those ambiguities on the Australian government, whilst the government wishes those burdens to be more equitably shared.

4. TIME DISCOUNTING

So far in our analysis we have not adverted to the importance of time discounting, which we mentioned in section 1 of the paper. There are two points to be made here, one fairly simple, the other subtler. The first point is simply that, if the buyer discounts the present value of a future prize, and if this discount increases with time, then the expected present value of the prize will be even less than it would be in the absence of such discounting. Accordingly, the arguments given in the preceding section as to the optimal structure of the bargaining process apply *a fortiori* in the case of time-discounting.

The second, more subtle point, arises if the vendor also time-discounts the future. In situations where the vendor's rate of time discount is less than that of the buyer, nothing changes in the above arguments. However, if the vendor discounts the future more heavily than the buyer, then this weakens the case for deferring uncertainty until near-delivery date in order to maximize insurance rents. The vendor/insurer will wish to bring forward some of the

rent-extraction since the present-value of an earlier payment of a smaller rent may be greater than the present-value of a later payment of a larger rent. Depending on the circumstances, this may be an important point of leverage for the buyer when confronting a rent-extracting vendor. We pick up on this point below in section 7.

5. BUYER'S ATTITUDE TOWARD AMBIGUITY

So far in our discussion, we have supposed a simple partition of the event space into risk and uncertainty. This has allowed us to make the fundamental point that vendors can exploit buyers' ambiguity aversion, and, moreover, this implies a very definite dynamic structure to the contracting/bargaining arrangements between the parties. In this section, we want to add an extra dimension of uncertainty in order to canvass an issue that often arises in the public sector—and especially defense—procurement. This issue is the one in which decision makers seem to be ambiguity avid in the first instance (Grant, Kline, & Quiggin, 2018; Machina & Siniscalchi, 2014), and then become increasingly ambiguity averse as time goes by. We have already discussed the reasons for the latter phenomenon (that ambiguity aversion increases over time). We want, now, to look at the issue of why decision makers might be ambiguity seeking early in the bargaining process, and what implications this has. As we have done throughout, we utilize a stylized model based on coin tosses and urn draws. Specifically, consider the situation described in Figure 5.

---Insert Fig. 5 here---

In this game, an urn draw precedes two subsequent urn draws and coin tosses, where each of these subsequent sub-games delivers a different prize, as shown. The (approximate) expected value at the first stage is $18.75; if a red marble is drawn, the conditional expected value is $12.50; and if a blue marble is drawn, it is $25. Suppose that the decision maker is offered a sure $20 at the initial period. He can then choose to proceed with the gamble or take the $20. A risk neutral, ambiguity neutral decision maker would surely take the money. A risk neutral,

ambiguity avid decision maker, however, may well feel that the chance of obtaining $100 or $50 is worth the risk. Interestingly, if he takes the gamble and a blue ball is drawn, he may well be subject to the kind of gamesmanship described earlier if he is ambiguity averse for expected values over $20. Conversely, if a red ball is drawn, he will *continue* to be ambiguity seeking in the conditional domain. This accords with what we often see in practice: if an uncertain situation turns out well, the decision maker becomes ambiguity averse and 'banks the gains'; however, if things go badly, he may double down and continue seeking potential upsides even as the uncertainties mount.

We obtain a further insight into the nature of the negotiation process if we slightly tweak this model. Suppose that the decision maker is ambiguity avid at the expected value of $20, but is not quite sufficiently so to take the gamble (which has an approximate expected value of $18.75) rather than the sure $20. Since the vendor in our model is presumed to know the true distribution of marbles in the urn, the vendor then has an incentive to reveal at least some of information to the 'buyer' in order to try to motivate him to take the gamble. Now, suppose that in the initial situation, the buyer believes that the minimum number of red marbles might be 0, and the minimum number of blue marbles might also be 0. In the absence of any further information, the buyer believes blue and red are equally likely to be drawn. Let it be the case that, if the buyer knows that at least ¼ of the marbles in the initial urn are blue, and at least ¼ of the marbles are red, then the uncertainty will be sufficiently reduced for him to prefer the gamble to the sure amount. This information can then be revealed by the vendor. Once the buyer has taken the gamble, he may then be subject to the gamesmanship we have described earlier.

We thus see that there are circumstances where the vendor has an incentive to reveal information and lower the uncertainties faced by the buyer. This revelation of information is in the vendor's interests, but it does diminish the vendor's ability to extract rents from the

buyer. This observation brings us to our general discussion of potential solutions to the bargaining/procurement problem.

6. A DISCURSIVE LOOK AT THE ISSUE

Before proceeding to discuss solutions, we take a diversion to connect our arguments with certain stylized facts about real world procurement processes. We are here concerned, in particular, with governments as procuring principals. We start by asking: why might the level of ambiguity seeking for some governmental departments be unusually high? The reasons for this are twofold. First, the public servants engaged in the negotiations are agents of the government; and, consequently, they may be less motivated to care about the amount of ambiguous 'gambling' involved in the procurement process than is optimal from the government's point of view. This is to say that the high degree of ambiguity preference in government procurement processes is an instance of the principal-agent problem (Petersen & Østergaard, 2018; Yang, Cao, Lu, & Zhang, 2017). The principal-agent problem generally arises when the principal – the purchaser in our case – has distinct and partly conflicting aims from the agent – the vendor in our case – and this difference motivates the vendor to try to 'game' the principal. The consequence is that, in the absence of remedial action, the strategies of the two players are not aligned. This is why the principal must develop a strategy to manage the agent (Grant et al., 2018). Secondly, government projects are typically built over a long period of time, and the future consequences of the ambiguity is time-discounted. In other words, the public servants negotiating today tend to undervalue the costs of potential failure in the future, when the project is due to be delivered.

As we have seen, this tendency for ambiguity aversion to increase over time creates gaming opportunities for vendors. This issue is exacerbated by the fact that the power of a government purchaser to force the supplier to cooperate and resolve ambiguities once a contract is signed diminishes over time. The reason for this diminution in power is twofold.

The investments that governments make tend to be of the 'putty-clay' type—prior to the contract being awarded, there is flexibility as to what form the artefact will take and who will build it; but, once awarded that flexibility is lost. The artefacts—particularly in defense—are lumpy (i.e. large and expensive) and are company-specific, so once engaged, it is costly to disengage. The other reason for the government's diminished power once a contract is well underway has to do with reputation. Often the government itself, or individuals within it, are tied to a project, and 'walking away' or 'shelving' it can impose unacceptable reputational damage to those involved. In many instances, the government would prefer to pay to solve the problem rather than accept failure, even if a cost-benefit analysis were to indicate that the latter was the optimal course. This way of proceeding is especially likely if the true costs of remediation are not publicly available.

A stylized depiction of the buyer's power reduction is shown in Figure 6.

---Insert Fig. 6 here---

This decrease in power occurs simultaneously with the rise over time in the purchaser's degree of ambiguity aversion for the reasons discussed above. This rise in ambiguity aversion or anxiety is depicted in Figure 7, along with the diminution in power.

---Insert Fig. 7 here---

Thus, over time, a wedge is driven between the anxiety of the purchaser and the purchaser's ability to deal with the causes of that anxiety. This wedge is exploited by the vendor in ways that we have already discussed.

7. POTENTIAL SOLUTIONS TO THE PROCUREMENT DILEMMA

The fundamental structure of the procurement process when ambiguity is in play naturally favors the vendor for the reasons discussed in sections 2-6. In this section, we propose several actions that the purchaser can take to ameliorate the issues he faces.

There are four 'solutions' that the above analysis suggests as follows.

1. Use competitive tender processes wherever possible.
2. Use early outside options to incentivize information revelation by the tenderers.
3. Employ ambiguity neutral negotiators.
4. Exploit differences in time-discounting preferences to delay payments to motivate contractors.

The solutions are detailed as follows.

1. Use competitive tender processes

The use of competitive tender processes is implied by the above analysis, but is not made explicit there. The argument applies when the purchaser is ambiguity averse in the early stages of the procurement process and when there is a high degree of competition amongst potential vendors. In that case, each potential vendor has an incentive to undercut the others to secure the contract, and this competitive process continues in the standard way until the one with the lowest possible cost wins. In addition to its being the lowest cost contract, the winning contract will also be the least ambiguous. The reason for this is that, if ambiguity can be decreased further at the same cost for a contract, then others have an incentive to reduce the ambiguity or to indemnify the purchaser against ambiguity at the same cost, thereby winning the contract. Consequently, the successful contract will minimize both the amount of ambiguity facing the purchaser as well as the costs of supply. The maximum amount of indemnity will be provided by the successful vendor to the purchaser.

Unfortunately, for many government contracts, there are often only a few potential vendors, so the situation is one of oligopoly rather than competition, and this undercuts the incentive to offer best-value contracts. In addition, as we have argued, the government or its agents may be ambiguity seeking in the first instance, and this mitigates against their seeking to resolve ambiguities early. Consequently, the potential vendors are not requested to reveal information or to indemnify the government against the failure to supply the artefact to a

well-defined specification. Thus, in situations where the tender process is not as competitive as is optimal, or where the negotiators are initially inclined to be ambiguity avid, other solutions are needed.

2. Use early outside options

The idea of using early outside options is motivated by our discussion in section 5. In that section, we observed that it may pay the vendor to increase the information he reveals to the purchaser to incentivize the purchaser to take on greater levels of ambiguity. This situation occurs when the purchaser is somewhat ambiguity avid. In this case, the existence of an early outside option—such as a sure-thing bet—is the fulcrum that leverages the information out of the vendor.

This insight of the model we have outlined is not original. The Kinnaird Review (Kinnaird et al., 2003) recommended the use of military-off-the-shelf (MOTS) options to benchmark proposed, higher risk/more uncertain alternatives in the early stage of the tender process (pp19-20) (Kinnaird et al., 2003). The Kinnaird Review investigated major procurement processes in the Australian Department of Defence. The Review recommended several changes to the tender process and the management of vendors which correspond to the conclusions we arrived at as a result of our discussion. The issues addressed in that Review are shared by departments of defence across the world; and in fact, they are issues shared by any major contracting organization that deals with ambiguity. The major contribution of this paper is to put those empirically inferred solutions on sound theoretical foundations. The model described in this paper supports Kinnaird's view. Moreover, it identifies when this approach applies—namely, when the negotiators are ambiguity-seeking, but the ambiguity of initial proposals is too high even for those negotiators.

There is a word of warning with this approach, however. The reason it works is that the potential vendor hopes that extra information will be just enough to tip the purchaser into

selecting the more ambiguous option. Once the purchaser has chosen this option, the vendor intends to secure monopoly rents from the purchaser over time by exploiting the bargaining wedge described in section 6. So, this 'solution' is only a partial one, and points to the next proposal.

3. Employ ambiguity neutral negotiators

An additional way of avoiding some of the pitfalls in the procurement process is to employ consistently ambiguity neutral negotiators over the course of the procurement process. The upside of this approach is that the purchaser behaves in a dynamically consistent manner over time—he does not become increasingly anxious as time goes by. This cuts the wedge in half; and, as a result, the purchaser is less susceptible to the gamesmanship described earlier. The downside of this approach is that it is a conservative one—it forgoes the potential upsides that R&D and innovation can bring. As always, it is a matter of judgment as to how ambitious or conservative the purchaser wishes to be. It may be that ambition and the embrace of ambiguity are optimal in one situation; but conservatism and ambiguity-neutrality are optimal in another.

In either situation, however, it might generally be suggested that a 'red team' of ambiguity neutral analysts review the decision making of the blue team. Again, this approach—or something like it—is proposed in the Kinnaird Review (2001, pp17-18) (Kinnaird et al., 2003).

4. Defer payments for non-delivery

In section 5, we mentioned that differing rates of time preference between the purchaser and vendor may present options to the former when attempting to mitigate exploitation by the latter. Specifically, if the buyer discounts the future less than the vendor, he may be able to defer payments for unresolved issues until a future date, whereas the vendor will seek a relatively speedier resolution in order to bring forward contractual payments. Thus, for

contracts with protracted delivery schedules and where delivery is somewhat piecemeal, the buyer may motivate the remediation of an intermediate deliverable that manifests unrealized upside by deferring payment.

In addition to motivating the remediation of deliverables, the deferment of payment can be tied to the revelation of information about the event space. This is to say; a buyer might construct the contract so that, at each stage, the vendor is required to provide more guidance on the likelihood of certain product attributes being delivered before payment for the deliverables up to that point. This approach increases the reliability of data that the purchaser confronts for the duration of the procurement process, and thereby reduces the ambiguity that is the cause of the dilemma that the purchaser faces.

5. Co-opt the vendor

At this point, it is worth enquiring: might the purchaser co-opt the vendor by forming an alliance with him or, indeed buying out the vendor so that production and contract delivery is 'in house'? The *dirigiste* arrangements in France—for example, the government having a majority shareholding of Naval Group—is an instance of just such an organizational arrangement in the defense sector. Another example along similar lines was the ownership by the Australian government of the submarine shipbuilder, Australian Submarine Corporation (ASC) (Schank et al., 2011), which had the explicit aim of managing the uncertainties of the production process to the benefit of the ultimate purchaser, the Australian government. Although this is a form of solution to the principal-agent problem that we have discussed in this paper, it raises complex issues of its own. Rather than address those—which would take another paper—we have chosen to limit ourselves to answering the more limited query: how might a purchaser resolve issues of bargaining related to ambiguity aversion that arise in the procurement process? In answering this question, we have limited ourselves to situations where the vendor and purchaser are and remain distinct entities.

CONCLUSION

In this paper, we have aimed to describe the way that non-neutral attitudes to ambiguity can give rise to strategic behaviour in the procurement process. In exploring that issue, we've shown two things. First, we've shown that ambiguity attitude is distinct from risk attitude, and the former gives rise to different issues from the latter for procuring principals. This is a matter that has not, to our knowledge, been thoroughly discussed in the literature. Secondly, we have shown that the dynamics of ambiguity attitude give rise to strategic interactions that cannot be accounted for in the standard, risk-only literature. In particular, we've shown that there is a definite incentive for the vendor to resolve uncertainty late in the procurement process, rather than early, as this allows greater rents to be extracted from the purchaser whose ambiguity attitude follows a typical trajectory. This prediction of the model is distinct from that made by models in which decision makers are characterized by constant or diminishing risk aversion attitudes. We suggest that the Brexit negotiations follow the pattern that our model predicts, *pace* the standard model.

In addition to exploring the dynamic impacts of ambiguity, we've proposed several strategies that procuring principals can deploy to mitigate the gaming behaviour of their suppliers. These suggestions are natural implications of our model, and they concur with principles inducted by practitioners. In particular, we've adverted to the Kinnaird Review of procurement in the Australian Defence Forces as an example of how our deductions agree with practitioners' inferences.

Of course, the current work is an early effort to understand the role that ambiguity plays in the procurement process, and more work remains to be done. It remains to be determined how ambiguity affects the *dirigiste* model of purchaser-supplier relations, and whether that model might not be a better solution to the issues raised. The possibility of substituting suppliers late in the contract process is another matter for further exploration. Both matters

are amenable to being discussed within the mixed risk/uncertainty framework we've outlined in this paper.

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	Head	Tail
Head	1: H and H	2: H and T
Tail	3: T and H	4: T and T

Fig. 1. Two coins

	Black	White
Head	1: H and B	2: H and W
Tail	3: T and B	4: T and W

Fig.2. a coin and an urn draw

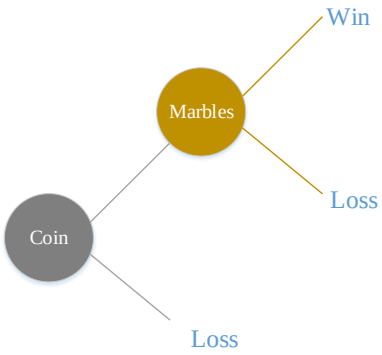

Figure 3. The sequential structure of marble coin game

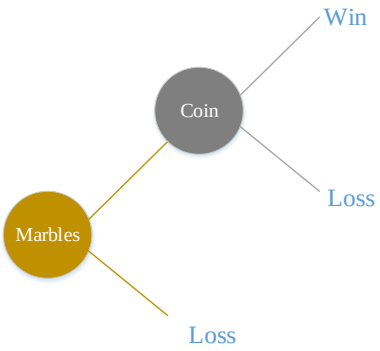

Figure 4. The changed sequence

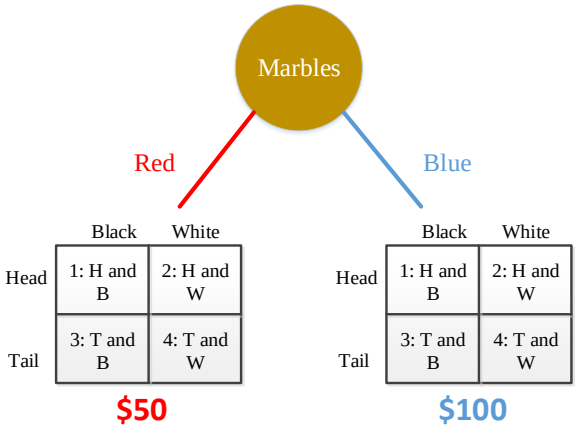

Figure 5: The initial ambiguity of the procurement process

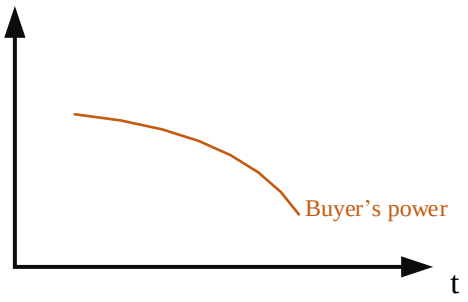

Figure 6: Buyer's power over time

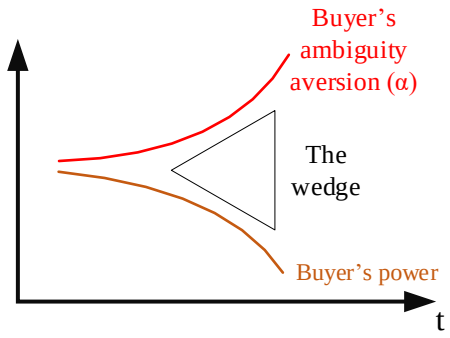

Figure 7: The growing wedge as time goes by