Homo Heuristicus: From Risk Management to Managing Uncertainty in Large-scale Infrastructure Projects

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***Abstract* –** Large-scale infrastructure projects tend to experience variances between estimated and final costs. Governments, in response, have been using statistical methods (including probabilistic approaches) such as Reference Class Forecasting (RCF) to try and mitigate cost overruns. While helpful in accommodating risk, such statistical methods often fail to account for a project's cost uncertainty. To reduce cost variance under uncertainty, it is necessary to use heuristics when formulating an infrastructure project's cost contingency. This article argues a need to adopt a vision of human nature described as *Homo heuristicus* (heuristics-using-person). We provide awareness and rationale for developing an 'adaptive toolbox' of heuristics for ecologically rational and contextually-aligned cost contingency decision making. However, the selection, recognition, and evaluation heuristics for determining cost uncertainty have yet to be examined. Thus, future research is required to cultivate the heuristics needed to address the uncertainty that surrounds the determination of a cost contingency.

***Index of Terms*:** Contingency, cost, heuristics, infrastructure, probability, risk, uncertainty

I INTRODUCTION

"RISK: If risks are known, good decisions require logic and statistical thinking. UNCERTAINTY: If some risks are unknown, good decisions also require intuition and smart rules of thumb." Gerd Gigerenzer [1:p.23-24]

The cost performance of large-scale infrastructure projects[1] receives regular attention from the media and opposition political parties as they routinely experience variances (+/-) from their original budget. In these instances, a compelling aim is to hold incumbent governments accountable for spending taxpayers' monies and ensure that the expected benefits of projects are realized. Equally, there are no doubt times when opposition parties engage in political point-scoring, and the media create an emotive headline and language, irrespective of the facts, to highlight and persuade people that a project has been the subject of cost overruns and benefit shortfalls [2]. To this end, the rhetorical spin often presented in the media about project mis-performance should be treated with caution and not given credence until the facts are presented objectively to the public [2], [3].

Explanations of infrastructure project cost mis-performance abound [4]-[9]. Despite such explanations, there remains no consensus on causal explanations due to conflicting theoretical stances [8]. Consequently, this conflicting and even contradictory information has hampered the ability to effectively determine the impact that risks and uncertainties can have on project performance, notwithstanding the various complex statistical cost modelling approaches that have been propagated and purport to accurately deal with these issues [10]-[13]. Thus, we aim to redress this imbalance in this article by advancing the value of recognizing uncertainty and employing heuristics (i.e., mental shortcuts that people use to solve problems and make

[1] Hereinafter we use the term infrastructure project. There is no definitive value that defines a large-scale infrastructure project as it varies between countries. But such projects tend to be complex not simply due to their size, length of duration or scope, but the differentiation and interdependency between parties. Additonally, the surrounding context and conflicting stakeholder goals add to this complexity .

judgments quickly and efficiently) as an alternative solution to accommodate variances in project costs.

Part of the challenge in predictive modelling results from our blurring of implications for projects due to two different events: (1) risk, for which the probability can be *known*, and (2) uncertainty, whose probability is *unknown* [1], [14]. Thus, even though many statistical models (including probabilistic approaches) can account for risks in infrastructure projects (e.g., geotechnical, incomplete documentation, scope changes and safety), they cannot accommodate uncertainty (e.g., rework, environment and weather conditions, and pandemics).

Whether the risk or uncertainty of a cost increase is incorporated into specific unit rates of a budget estimate and/or included in a contingency[2] set aside, five out of ten projects tend to experience cost overruns [15], [16]. Suffice to say, regardless of the percentage of project costs conserved to form a contingency as a consequence of statistical modelling (e.g., Expected Value, Monte Carlo simulation and Reference Class Forecasting, RCF) or expert judgement (e.g., intuition, historical evidence, and percentage uplift), the typical mechanism for mitigating exposure to risk and uncertainty is, by and large, inadequate [17].

Repeatedly applying statistical models to accommodate risk and uncertainty when project costs regularly exceed their budgets raises questions about these models' suitability and accuracy. Specifically, two issues come to the fore:

1. Statistical models such as RCF present conceptual and empirical blind spots [18]-[20]. Briefly, the logic of RCF is to examine historical data for entire classes of projects (e.g.,

[2] In its simplest form, a contingency incorporates an exposure to risk and uncertainty. Typically, a contingency refers to costs that will probably occur based on past experiences, often expressed in percentage terms as a proportion of an estimate.

light rail, bridges, tunnels, and roads) and determine their average cost overruns. Then, a similar multiplier value is applied to any new project cost assessment, adjusting the cost under the assumption that it, too, suffers from an inaccurate estimate due to over-optimism and strategic behavior[3] [21]. Simply put, statistically-based models such as RCF seek a *post hoc* 'correction' without prior critical evaluation. They offer, at best, the promise of a 'quick fix' to embedded or systematic error;

2. Information often needed to produce an initial cost contingency is unavailable or unknown [23], [24]. However, as a project's scope is defined and its design progresses, a better estimate of risks can be made and an improved understanding of uncertainty realized.

We argue that statistical models fall short in the face of irreducible uncertainty [8], [23]; that is, uncertainty that cannot be reduced to risk [1], [14]. In this instance, a heuristic, which is "a strategy that ignores part of the information, with the goal of making decisions more quickly, frugally, and/or accurately than a more complex method," can be relied upon to assess uncertainty [25: p.454].

It has been demonstrated in other empirical settings where complexity prevails that heuristics are "more accurate than standard statistical models that have the same or more information", with results referred to as the 'less-is-more effects' [25 p.453]. Heuristics have also been defined as: "a plausible or reasonable approach that has often proved to be useful, a rule of thumb" [26] [27:p. 377]. In practice, heuristics are used informally and widely, and while they can be accurate, their precision "may often look like curiosities in the absence of an overarching theory" [25:p.453]. This absence of a theory has hampered their use when determining the risk

[3] In Flyvbjerg and COWI [21], the term strategic behavior is akin to strategic misrepresentation. For a detailed examination of strategic misrepresentation, refer to the work of Jones and Euske [22].

and uncertainty associated with a project's cost mis-performance. Having a theory to draw upon to support the use of heuristics offers critical explanatory evidence of what is seen and experienced, enabling us to bring about the change needed to ensure projects are delivered according to their expected cost.

Todd and Gigerenzer [28] have proposed the theory of ecological rationality, which stipulates that a heuristic is good when it matches the structure of the context where it is applied. In this instance, ecological rationality provides an environmental structure for bounded rationality where simple heuristics, offering the twin advantages of speed and accuracy, can provide a realistic alternative to optimization. Accordingly, Love *et al*. [24] have suggested that ecological rationality can support the use of heuristics in cost contingency determination. Indeed, it provides a framing to help estimators develop and use an 'adaptive toolbox' [1], a set of evolved and learned rules that deliberately and intuitively help undertake sound and robust cost estimates, especially under uncertainty.

Against this backdrop and inspired by the idea that "zero bias is neither possible nor always desirable for a real mind" [29: p.136], we suggest there is a need to engage with *Homo heuristicus* when faced with decision-making under uncertainty and in particular when formulating a large-scale infrastructure project's cost contingency from a public client's perspective (i.e., project sponsor). Homo heuristicus "has a biased mind and ignores part of the available information, yet a biased mind can handle uncertainty more efficiently and robustly than an unbiased mind relying on more resource-intensive and general-purpose processing strategies" [29: p.107].

While there is a theoretical difference between risk and uncertainty, these concepts are often used interchangeably in practice [1], [14]. This conflation, we suggest, hampers decision-making under uncertainty when formulating an infrastructure project's cost contingency, as it has led to ambiguous and ineffective approaches to mitigating project cost mis-performance [8], [24]. Thus, we commence our article by differentiating between risk and uncertainty (Section II). Then, we examine how, when putting together a project's contingency, better judgements in the face of uncertainty can be made using heuristics (Section III) before concluding our article (Section IV).

II RISK VERSUS UNCERTAINTY IN COST CONTINGENCY FORMULATION

We noted that one of the most popular statistical approaches used by governments worldwide to quantify the risk of cost increases in infrastructure projects under uncertainty is RCF [13], [30], [31]. It is assumed that a major explanatory variable of project cost overruns results from initial cost estimates being prone to the Planning Fallacy [35], which includes optimism bias and strategic behavior. Optimism bias is defined by managers and planners making decisions based on delusion [32], [33] and illustrated by the belief on the part of estimators that they are less likely than anyone else to make mistakes in their estimates. Strategic behavior or deception is the "planned, systematic distortion or misstatement of facts [e.g., estimated costs]") [21], [22: p.437], [34].

The upshot is a tendency to underestimate the times, costs, and risks of future actions and simultaneously overestimate the benefits of infrastructure projects and their odds of success [34]. As a result, Flyvbjerg *et al*. [7] maintain that "the root cause of cost overruns is behavioral bias," that is to say, the Planning Fallacy (p.174). Here, the underlying argument rests on the assumption that humans (in our case, decision-makers, managers or cost estimators) make significant errors of inference from data due to: (1) *representativeness* – ignoring the size of the sample from which observations are drawn; (2) *availability* – basing perceptions on high-profile or most recent events; (3) *anchoring* – artificially constraining subsequent assessments based on initial estimates; and (4) *framing* – interpreting information based on how it is presented [36].

Of note, there exists limited empirical evidence to support the presence of optimism bias when cost estimates are produced, and instances of strategic misrepresentation are notoriously difficult to prove [8], [16], [17], [37]-[39]. We should not discount the existence of behavioral bias at the individual and collective levels and its various guises when formulating a project's budget estimate during a project's appraisal and business case development process. Still, cost estimates tend to be produced by teams and often vetted by third parties (particularly in large-scale or politically-sensitive projects), so the influence of some 'non-collective' form of behavioral bias can only be considered marginal [40]. We also need to point out that decisions are based on limited information, which often requires professional judgements.

However, people's judgments are not always equal and can be prone to variability, which Kahneman *et al*. [41] refer to as *noise* (i.e., irrelevant information). To address the problem of noise, we need to put aside irrelevant information and focus on what is required for decision-making within a given context, not that which is available [42]. In this context, decision-making occurs in an ecologically rational context [42], which manifests "when the structure of boundedly rational decision mechanisms matches the structure of information in the environment" [28: p.3].

In line with an ecologically rational lens, the decision-making process becomes inductive, relying on heuristics and their accuracy relative to prevailing contextual cues. Thus, the "rationality of heuristics is ecological and not logical [29:p.116]. Proponents of logical rationality, when focusing on human cognition [41], [43], ignore the world around them when making decisions. However, according to Simon [44], "ignoring the world around us makes futile any effort to understand human cognition as it is a reflection of subtle dance between mind and environment" [45:p.1]. These proponents also proffer an unfairly negative view of the human mind where people are fundamentally biased in decision-making [1]. In particular, when determining a cost estimate and contingency, four issues remain problematic [8], [16], [39]:

1. Cost estimators are believed to be prone to optimism bias, but research suggests they may be equally subject to pessimism bias [15], [16].
2. The context within which a project is delivered and, in particular, the risk-uncertainty distinction is often overlooked (e.g., risk *versus* uncertainty).
3. Optimism bias, which has been found to prevail at the individual level, especially in laboratory experiments, is assumed to prevail at the collective level.
4. The assumption of bias is itself a biased assumption.

Notably, government agencies and researchers alike have tended to overlook the issues mentioned above, thus hindering our ability to make headway to address the cost mis-performance problem.

A On the Danger of Simple Solutions to Complex Problems

Applying simple solutions to complex problems can often have the opposite of the desired effect, resulting in sub-optimal outcomes and even failure [46]. Accordingly, Mencken [47] wisely stated that "explanations exist; they have existed for all time; there is always a well-known solution to every human problem—neat, plausible, and wrong "(p.155). As part of the solution to addressing inadvertent increases in project costs, we previously noted that Flyvbjerg [48] had proposed the mechanism of RCF to harness new estimates to the collective wisdom and historical performance of other projects of a similar class. In doing so, Flyvbjerg [48] argues that estimates can be based on more realistic and plausible metrics due to previous results. Moreover, some empirical evidence suggests RCF offers better forecasts than alternatives like Monte Carlo simulation or earned value projections [49].

While we are broadly in sympathy with Flyvbjerg's [48] ideas for using RCF as a remedial device, there are also important dangers in assuming that such *post hoc* de-biasing of 'assumed' behavior offers anything more than a stopgap or short-term solution to a recurring problem. In short, RCF fails to address the causes of such cost overruns and attempts to 'smooth' estimates after their development: the equivalent, perhaps, to fixing the problem of a teenager's late arrivals at home by adjusting their watch an hour ahead each evening as they leave the house.

Perhaps demonstrating evidence of their own biases, decision-makers in projects continue to fall victim to the trap of employing the simplest methods for 'corrective action'. That is, despite a lack of empirical evidence, cost estimates still tend to be de-biased by simply adding an uplift to the budget estimate and contingency [21], [31], [48]. In this instance, RCF simply becomes "contingency on a contingency" [24:p.5] and thus does not distinguish between risk and uncertainty, treating them blindly to be synonymous [8]. Moreover, relying on RCF negates motivation for organizational learning and problem-solving.

When a *post hoc* corrective action merely consists of creating an artificial inflator device, government agencies (i.e., project sponsors) avoid the need to uncover the root causes of cost overruns on previous projects by simply adding a corrective adjustment to assumed flawed estimates. Moreover, behavioral research supports the notion that humans quickly determine anticipated corrections and factor those into their initial estimates, further obfuscating the validity of cost estimates at approval [50]. The upshot is that RCF cannot accurately cater to likely cost increases in projects, rendering its use highly questionable [18]-[20], [24]. We identify examples of prominent projects where this has been the case below. However, we first conceptualize the nature of the project mis-performance problem under uncertainty.

B Tame or Wicked Problems: A Matter of Understanding

Trivializing and attributing the causes of an infrastructure project's cost increase to optimism bias and strategic misrepresentation (behavior) and relying on RCF as a definitive solution is akin to treating mis-performance as a 'tame problem'. People prefer simple and alluring explanations when they are understandable and plausible. However, this can result in what Rosling *et al*. [51] refer to as the 'Single Perspective Instinct', where there is a tendency to think there is a single cause (e.g., behavioral bias) behind complex problems and that they can be solved with a single solution (e.g., RCF).

Unquestionably, the project cost mis-performance problem is complex [8]. It is influenced by a combination of factors, including market predisposition (e.g., competition, supply and demand of labor), procurement methods and contractual conditions, environmental and geotechnical conditions, and a variety of social and economic determinants. Recognizing the complexity of delivering infrastructure projects within budgeted and contracted costs and the innumerable links that shape their performance, we should view the problem as 'wicked' [2]. [52]. Often wickedness conjures up notions of complexity. However, Conklin [53] suggests treating it as a different type of problem instead of a new way of solving complex problems. Thus, it is more important to understand the problem rather than immediately seek a solution *per se*. A wicked problem is inherently "illusive or difficult to pin down and influenced by a constellation of complex social and political factors, some of which change during the process of solving a problem" [54:p.445]. In this regard, determining the risk and uncertainty of cost mis-performance is likely to be viewed differently depending on the perspectives, experiences, or biases of those who have a stake in a project.

Applying statistical models based on probabilistic reasoning to determine the cost contingency is unfitting under conditions of irreducible uncertainty. This is not to say statistical models are redundant; quite the contrary. As Knight [14] points out, "the practical difference between the two categories, risk and uncertainty, is that in the former, the distribution of the outcome in a group of instances is known, while in the case of uncertainty, this is not true" [p. 233]. Hence "what appears to be normative under risk, is not always normative under uncertainty" [55:p. 329] or, put more simply, as described by Gigerenzer [1] at our article's outset, " RISK ≠ UNCERTAINTY: The best decision under risk is not the best decision under uncertainty" [p.40].

C Underestimation of Contingency

The Edinburgh Tram System and Airport Link is a well-known example of a transport infrastructure project in the United Kingdom (UK), documented in Love *et al*. [24] and Love and Ahiaga-Dagbui [39], which relied heavily on RCF to debias its cost estimates and the risk of unnecessary cost increases. The project was initially estimated to cost £320 million, including a risk contingency-based estimate [56]. Taking all the available distributional information into account, considering a set of similar rail projects (e.g., London Docklands Light Rail), the reference class estimated an 80th percentile value of £400 million.

The project was completed three years late in 2014 at a reported construction cost of £776 million. Considering claims and contractual disputes partly due to errors and omissions in contract documentation, a revised estimated final cost of over £1 billion was forecasted, including £228 million in interest payments on a 30-year loan to cover the funding shortfall [57]. Thus, even applying an RCF 'intervention' in the project to bring costs into conformance with historical data, contingency was severely underestimated in this case, resulting in massive remediation.

Another high-profile infrastructure project experiencing a cost overrun is the beleaguered National New Children's Hospital (NCH) in Dublin (Republic of Ireland) [2]. The hospital is set to become one of the world's most expensive buildings, with an original budget of €400 million, an approved budget of €1.43 billion, and a staggering final cost of €2.4 billion [58]. An independent review by PwC [59] retrospectively suggested that €294 million (65%) of the cost increase was due to optimism bias, and the contingency allowance was inappropriate. There is no doubt the contingency was insufficient, but retrospectively suggesting the cost estimate had been subjected to optimism bias is laden with its own hindsight bias. Indeed, the Public Spending Code [30], [60] sets out processes for capital projects to address optimism bias and behavioral influences (e.g., confirmation bias, present bias, cognitive limitations and framing) during their business case development, using techniques such as external peer review, benchmarking and RCF.

Even though the business case for the NCH was prepared in 2013 and finalized in 2014, there was no specific allocation within the contingency for de-biasing estimates due to optimism bias. As a result, this led PwC [59] to make the following remark: "on a project of the scale and complexity of the NPH [National Paediatric Hospital], we would expect to see a quantified risk assessment or a detailed and separate optimism bias allocation" (p.27). Here, it is assumed that optimism bias is akin to being a 'known-unknown' in determining cost contingency, though the project was confronted with irreducible uncertainty. However, as we mentioned above, such optimism bias has not been demonstrated to exist in cost estimates that have been collectively and professionally produced. More importantly, the wicked problem of cost deviation should not be considered a risk but instead placed in the realm of uncertainty (i.e., 'unknown-unknown') [2]. Nonetheless, Shine *et al*. [61] – rather simplistically, we would argue – responded with the call to use RCF as an approach to mitigate cost variances in healthcare capital projects despite it providing what Gigerenzer [1] calls an "illusion of certainty" (p.17)

D Something is Wrong: A Case of Oversimplification

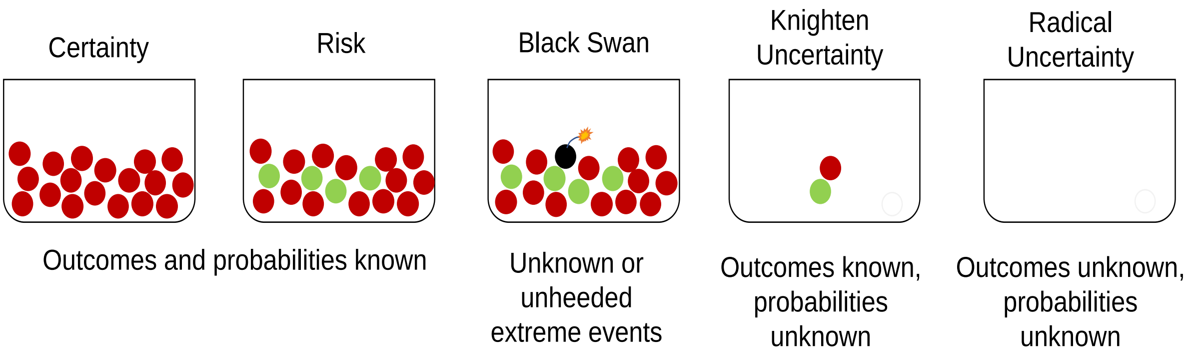
In the two cases we identified above, there has been an inability to mitigate project cost variances, which raises two important questions. First, what is wrong with the cost contingency approaches used by many government agencies? With infrastructure projects regularly exceeding their budget estimates and considering the two high-profile cases noted above, it seems clear that contingency approaches have failed to mitigate their cost variances [2], [24]. Second, governments regularly undertake audits and public inquiries into projects that experience cost variances, so why have they not learned from them and amended their procurement practices accordingly?

Complexity presents decision-makers with wicked problems, with cost mis-performance vexing governments due to multiple and interrelated causes and influencing factors being indeterminable *ex-ante*. Moreover, because of mutually adaptive behaviors and the resulting 'indeterminacy' of project performance, it may not be possible to determine how much the project will cost [8]. While governments routinely face challenging situations characterized by multi-causality and ambiguity, they have been unable to adapt and respond to potential cost uncertainties. Instead, they have responded by embracing a seductive process *oversimplification* by adopting RCF or deterministic approaches (e.g., percentage uplift or expert judgement) to mitigate project cost variances [8], [62:p.2]. The often-poor results are generally predictable and demonstrate the failure of *post hoc* cost adjustments to original estimates.

E Not all Project Contexts are Equal: The Need for Realistic Assumptions

Undisputedly, determining likely cost variances is a difficult task as the complexity of the context within which projects are procured "incorporate dynamic feedback loops and exhibit chaotic tendencies that exacerbate minute variations in initial conditions" [23:p.135], [63]. However, the problem when formulating a contingency does not only lay with the "circular and chaotic nature" of a project's context but also the approaches used to generate the estimates under risk and uncertainty [23:p.136]. In short, not all project contexts are equal. A mismatch, however, exists between these contexts (e.g., Alliances and Private Participation in Infrastructure project delivery methods) and the contingency approaches used to respond to risk and uncertainty. We see this mismatch when governments use RCF during their infrastructure procurement, as it is underpinned by unrealistic assumptions that do not reflect the reality of cost estimation practices.

Essentially, RCF attempts to de-bias risk by deriving outcome probabilities (*a priori*). Here, decision-making under risk refers to situations in which probabilities can be known (or are knowable) [64]. However, as mentioned above, there is no evidence to suggest that these probabilities are 'knowable' in the reference class used to calculate the proposed uplift to a project's cost estimate. Furthermore, in this case, "outcome probabilities are not logically deductible and cannot be inferred from the data" [23: p.136]. Hence, in this situation, we are faced with decision-making under what has been called either 'Knighten Uncertainty' or 'Radical Uncertainty', as shown in Figure 1 [14].



Adapted from Meder *et al*., [64: p. 259]

Figure 1. Examples of decision-making scenarios

The 'black and white' approach (i.e., Knight's dichotomous formulation) to differentiating between risk and uncertainty, while straightforward in the case of determining the presence of optimism bias, does not reflect the real-world situations embedded in the broader context of infrastructure projects. As Neth *et al*. [23] note: "Whereas Knight's original distinction was dichotomous and qualitative, most real-world situations are embedded in wider contexts and lie somewhere in-between. Thus, Knight’s risk and uncertainty categories constitute the extremes of a continuum of varying degrees of uncertainty” (p. 136).

Decision-making scenarios in their various guises influencing the development of a project’s cost variance can be seen in Figure 1. Indeed, there are shades of grey when delineating between risk and uncertainty, which impact our ability to make accurate predictions as they are dependent on the availability of data, the type of model used and the structure of the decision-making context [23] [64] [65]. Instead of reducing uncertainty to risk by assigning perceptions of probability, as in the case of RCF, for example, we should embrace uncertainty. In particular, we suggest that attention focus *not* on developing overly simple yet information-intensive probability-based solutions but instead on fast and frugal heuristic-based strategies to help solve the complex cost-variance problem that faces infrastructure procurement [23].

III MANAGING COST UNCERTAINTY WITH HEURISTICS

As we have put forward, heuristics are the rules of thumb that ignore irrelevant information to draw inferences and exploit core psychological capacities to make fast and frugal judgments, which can yield efficient and effective results, notably in the face of uncertainty [66]. Equally, as Gigerenzer [67] succinctly points out, “heuristics are meant to explain what does not exist” (p.102). A popular heuristic, underpinned by the core capacity of memory recognition, is the *recognition heuristic*. In this instance, when “inferring which two options have a higher value on some criterion, people often choose a recognized option over an unrecognized one” [23:p.137], [66], [68]. There are also many other high performing heuristics, such as the [42]:

- *Fluency heuristic*: If one alternative is recognized faster than another, infer that it has a higher value on the criterion. 'Less is more', and forgetting is beneficial [69].
- *Take-the-best*: To infer which of two alternatives has higher value: (1) search through cues in order of validity; (2) stop the search as soon as a cue discriminates; and (3) choose the alternative this cue favors. Can predict as or more accurately than linear regression [66].
- *Tallying/unit-weight linear model*: To estimate a criterion, do not estimate weights but simply count the number of favoring cues. Can predict as or more accurately than multiple regression [70].

Such heuristics have been widely studied in disciplines as diverse as finance [23], psychology [42], economics [55], biology [71], and marketing [72], to name only a few contexts. However, in the context of judgement and decision-making of infrastructure cost estimates and contingency formulation, where there has been an overarching reliance on the axioms of probability theory, we only see heuristics being drawn upon offhandedly in practice [24] or associated with bias and thus considered liabilities [7].

As a case in point, the Planning Fallacy promoters maintain that the use of heuristics in estimating results in systematic errors and judgmental bias in their decision-making under uncertainty, therefore, leading to cost overruns in infrastructure projects [34], [35], [43], [48], [73]. Consequently, we have seen governments advocate and legitimize *post hoc* RCF in lieu of heuristics to de-risk infrastructure project cost estimates. Nevertheless, this represents a biased view of human nature, which is construed as "pathologically biased and fundamentally flawed" [23: p. 137]. It is also a biased view of heuristics, which are considered "second-best", compared to statistical models that assume that "more information and computation are always better" [1:p. 270]. Indeed, Homo heuristicus possesses "a rational mind" that "needs both sets of tools" and "heuristics are indispensable in a world where not all risks are known ("uncertainty"), while probability theory is sufficient in a world where all risks are known ("risk")" [1: p. 270].

It is fair to say that heuristics offer no guarantees for arriving at a correct (accurate) or optimal solution of cost certainty. However, they can provide a more reasonable estimate as "homo heuristicus exhibits bounded rationality by embracing the benefits of satisfactory solutions and avoiding the excess demands of optimal ones" [23: p.138]. Markedly, Todd and Gigerenzer [28] state that heuristics demonstrate successful results in contexts where the conditions of ecological rationality prevail. Again, the essence of ecological rationality is to match a heuristic to the structure of the context of its application. Such heuristics do not need to be sophisticated to produce successful outcomes in a complex context, quite the contrary. However, while heuristics have been shown to "yield more robust results in an uncertain world" in fields such as finance, we have yet to realize their benefits while formulating an infrastructure project's cost estimate [23:p.138], [24], [74].

To perhaps put this latter point another way, the absence of evidence of heuristic validation is not the same as evidence of its absence in such determinations, partially due to the paucity of research that directly investigates the role of heuristics as an explanatory variable in estimation. In sum, we need to move away from a 'biased' view of human nature and heuristics to an alternative view of Homo heuristicus, where collective intuition and mutual experiences are perceived positively and considered in cost estimation. On this account, a way forward in better understanding cost overruns and benefit shortfalls is moving away from dualisms (the tyranny of "*or*") and entertaining dualities (the power of "*and*"). Put differently, in true complexity thinking tradition, we should seek to reconcile, in theory, and practice, the issues of risk and uncertainty and the tensions between biases and heuristics [8], [24].

A Toward an Adaptive Toolbox

Models of heuristic cognition focus on situations where people need to act fast when probabilities are unknown and "multiple goals and ill-defined problems prevent logic or probability theory from finding the optimal solution" [42: p.20]. This situation arises during the strategic justification process, and the business case realization of an infrastructure project's cost estimate may continue until a government client awards a contract[4]. Various heuristics tailored to particular aspects of the project's contingency to mitigate cost variances may be called upon in this instance. So, relying on the use of heuristics in the absence of information, the "mind resembles an adaptive toolbox with various heuristics tailored for specific classes of problems—much like the hammers and screwdrivers in a handyman's toolbox [42: p.20].

Creating an adaptive toolbox and determining the contextual structures in which a given and matched heuristic is successful (i.e., ecological rationality) and ensuring the results can be used to help mitigate cost variances in infrastructure provides a much-needed scientific underpinning to mitigate project cost variances. Having a well-equipped adaptive toolbox to draw upon provides an alternative to over-reliance on simple, *post hoc* corrective devices like RCF. It will also stimulate a new line of inquiry to address the cost mis-performance problem. In addition to the popular heuristics mentioned above, other types that can be found to exist empirically can be seen in Table I, which may be consciously and unconsciously drawn upon and likely to be in the adaptive toolbox of humans. The selection of an existing heuristic from

[4] Equally, construction organizations also develop cost estimates and contingencies and the use of heuristics is relevant to them.

the adaptive toolbox or constructing a new one based on its building blocks[5] provides a fertile line of inquiry, which we believe will yield results that improve the cost estimation practices for infrastructure procurement. In particular, two overarching questions come to mind: (1) What heuristics are needed in an adaptative toolbox? and (2) In what context does a heuristic work? [1].

Typically, heuristic selection arises from [75]: (1) reinforcement learning (i.e., learning from heuristics instead of behavior); (2) social learning (i.e., observing, modelling, and imitating the behaviors, attitudes, and emotional reactions of others) and (3) evolutionary learning (i.e., learning from heuristics developed through the process of natural selection). Indeed, inasmuch as bias to a degree can be beneficial for the intelligent mind of Homo heuristicus (that is, to ignore part of the available information), flexibility, or variance (e.g., small *versus* large samples), to a degree, in the context where the heuristic is applied, can be beneficial and thus promote learning to a degree.

As noted earlier, we suggest a more positive view of human nature and heuristics, described as Homo heuristicus. By engaging with a Homo heuristicus view, heuristics are not considered liabilities but assets for developing a robust cost contingency. Moreover, in line with the current prevailing bias paradigm, risks and uncertainties are presented as probabilities. These probabilities, derived from Monte Carlo evaluations (P50 or P90), present a statistical level of confidence in a project's cost estimate that helps determine the level of 'bias uplift' with RCF. However, bias may be eliminated when risks and uncertainties are presented as natural frequencies [67]. So, estimators need to reframe the way they ask questions about risk and

[5] Heuristics are based on building blocks, which can be adjusted and adapted to new situations. There are typically three building blocks [42: p.25]: (1) search rules (look up cues in order of validity); (2) stopping rules (stop search after the first cue discriminates between alternatives); and decision rules (choose the alternative the cue favors).

uncertainty in their projects when developing a contingency. Instead of asking, "what is the probability of a road project exceeding its budget?" the biased mind of Homo heurisiticus would ask, "How many road projects of this type procured using a given delivery method exceed their funding and do we expect this to occur?"

The context within which infrastructure projects are delivered varies, and, as such, practitioners will tend to deliberately or intuitively select heuristics, evaluating their ecological rationality (Table 1) [25]. Prior to applying a heuristic, two judgements are required [76]: (1) recognition (i.e., identifying whether it can be used in a given situation); and (2) evaluation (i.e., assessing its ecological rationality for the situation). Not all heuristics are applicable in a given situation, and thus the context within which they are being framed needs to be given due consideration [77]. Hence, research is needed to determine those heuristics that are most suitable. However, possible scenarios that can be utilized during the formulation of a cost estimate and its contingency are identified in Table 1.

However, beyond specific classes of a project that drive the model, the context is largely ignored when RCF is applied to de-bias cost estimates using probabilistic reasoning. Thus, the mis-performance problem is treated as content-blind, and the experiences and inferences from a practitioner's worldview of projects go abated. A wealth of evidence suggests that heuristics can work, especially under uncertainty where 'best-fit-to-context' responses may trump 'best-practice' solutions such as RCF. In the face of uncertainty, heuristics can be customized to solve diverse problems as well as provide different responses that can usefully complement those that emerge from applying logic and probability, which in principle should work under risk. Moreover, by "understanding the ecological rationality of a heuristic, we can predict when it fails and succeeds" [42: p.27].

Table I. Examples of heuristics that may exist in an adaptive toolbox

Heuristic	**Definition**	**Ecologically rational if:**	**Bold predictions**	**Scenario of use**
Satisficing	Search through alternatives and choose the first one that exceeds your aspiration level	Decreasing populations, such as those in seasonal mating pools	Unknown	Drawing on costs of previous projects to establish an allowance in a contingency
1/N; equality	Allocate resources equally to each of *N* alternatives	High unpredictability, small learning sample, large N.	Can outperform optimal asset allocation models.	Apportion a nominal allowance for a contingency across projects of a similar ilk
Default	If there is a default, do nothing about it	Values of those who set defaults match with those of decision maker, consequences of choice hard to predict.	Can predict behavior when trait and preference theories fail.	Usually, an allowance of 10% is allowed for a contingency by a client. However, the type of project is novel to the client. Thus, the estimator adopts the client's default of 10%
Tit-for-tat	Cooperate first, keep a memory of Size I, and then imitate your partner's past behavior	If other players also play tit-for-tat; if the rules of the game allow only defection or cooperation, but not divorce.	Can earn more money than optimization (backward induction).	The client's team and estimators work together to determine items to be included in a contingency and assess their frequency of occurrence based on past experiences.
Imitate the majority	Look at a majority of people in your peer group, and imitate their behavior	Environment is not or only slowly changing, info search is costly or time-consuming.	Mass phenomena, cultural evolution.	For example, in the context of an alliance, the owner-participants and non-participants jointly prepare target outturn cost and target adjustment events. Optimism bias, amongst others, can be thus mitigated. Working collaboratively enables behaviors to be imitated and experiences to be drawn upon.

Adapted from Gigerenzer [42: p.24]

IV CONCLUSION

Infrastructure project cost mis-performance has received widespread attention in the normative literature. Within the context of a compelling series of studies by Flyvbjerg and associates, the argument of decision bias through the Planning Fallacy was advanced as a key cause of cost overruns in projects. One solution proposed was the use of RCF as an 'inflator device' or 'de-biasing technique' to inject greater realism into these initial estimates. While perhaps simply a temporary stopgap, initially, RCF use has gained in popularity and broader acceptance, thus drawing attention to its own inherent limitations. Specifically, despite this attention and the promulgation of statistical or probabilistic methods such as RCF by governments worldwide, we are none the wiser about mitigating cost variances from occurring in infrastructure projects.

Our article has aimed to raise readers' curiosity about the science of heuristics, those mental shortcuts that people use to solve problems and make judgments quickly and efficiently. We have argued for a need to adopt a vision of human nature described as *Homo heuristicus* (heuristics-using-person). In doing so, we have provided awareness and rationale to develop an adaptive toolbox of decision-making that draws on heuristics that are ecologically rational and thus fit within a project's given context.

We have exposed the blind spots of RCF and suggested that its use by governments to mitigate cost variances may be of questionable utility. In sum, we submit that RCF has not been empirically validated; it treats cost mis-performance as a 'tame' instead of a 'wicked' problem and is content-blind. Accordingly, RCF cannot accommodate uncertainty, a significant component of a modern infrastructure project's cost estimate.

Considering these limitations, we suggest the cost mis-performance problem should be treated as wicked, rendering statistical methods for predicting a project's cost variance unfit in situations where risk and uncertainty are undifferentiated. In the case of decision-making under uncertainty in the context of a project's contingency, we submit that the view of human nature characterized as Homo heuristicus offers a theoretical lens that can be used to make headway in reducing a project's cost variance. While heuristics are widely used in decision-making in an array of fields, they have yet to penetrate the mainstream cost estimation practice of infrastructure projects in a formal manner. The absence of a scientific underpinning for their use has contributed to this situation.

Empirical research is required to cultivate the heuristics needed to address the uncertainty that surrounds the determination of a cost contingency. Thus, we hope this article provides the impetus to actively engage with Homo heuristicus during the decision-making process of infrastructure cost estimation. Finally, we draw readers' attention to the wise words of Knight [14], who cogently stated that "the results of human activity cannot be anticipated and then only in so far as even a probability calculation in regard to them is impossible and meaningless" (p.311).

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