Examination Report

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Title: Investigation of Market Mechanisms for Distribution Level Energy Managment

Summary

The thesis consists of 2 main technical contributions. The first part, presented in Chapter 4, is a novel approach for computing the disagreement point in cooperative games which is termed GNK value. It is an extension of an existing approach but for settings where the action space is restricted and depends on the actions on other players. This approach for computing the "value" is then applied to compute payments in a DC powerflow market. However, the computation of the GNK value proves to be a major obstacle in applying this in practice. Hence the author has come up with several modifications to make it computationally more tractable. One approach is sampling. Another approach is to change the problem from its initial two-stage min-max optimisation like in a Stackelberg game, to a "flattened" version. The approaches are compared to others payments such as VCG and LMP. In addition, different sampling approaches are compared. It is shown that JOIN outperforms or is similar to other methods, including SEBM which is the approach produced by the author. GNK is shown to have some good properties. However, it turns out it violates one of the main properties which is individual rationality.

The second technical contribution is a novel approach for stratified sampling which is covered in Chapter 5. New theoretical bounds are derived for this approach, and it is also evaluated empirically both on distributions and for approximating the Shapley Value, which is the part of the GNK value from the prior chapter. Empirical results show that the new sampling approach outperforms the other approaches compared to for several different games. In addition, the bounds are also tighter compared to many other approaches.

Comments

The thesis covers a breadth of topics, from mechanism design and energy markets, to cooperative games and stratified sampling. This shows an excellent and impressive knowledge of the domain. In terms of contributions, I found Chapters 2 and 3 did not seem to contain any novel contributions and gave the required background needed for the remainder of the thesis and to frame the discussion around fairness of allocations. The main contributions are chapter 3 and 4. I will comment on each chapter separately in more detail.

Chapter 2. This chapter is very much philosophical and presents some of the early arguments around fairness and equality. While interesting I did not really see that much benefit of this chapter to the narrative of the rest of the thesis. First of all, important contemporary concepts around fairness that are discussed in the social choice literature were missing from this. I'm referring mainly to the concept of envy freeness, which is very relevant to the discussion since it is about how to fairly allocate resources. This is not mentioned and seems to be an obvious omission. Another issue is that, in the end, it runs out that the allocation of resources is decided by using the utilitarian social welfare approach (i.e. maximising the social welfare or sum of utilities). This has many issues especially when utilities cannot be directly compared/transferred. This should probably need some discussion in this chapter.

Chapter 3. This chapter gives an excellent introductory background to the concepts needed to understand the remainder of the thesis, and shows very good knowledge of the topics. However, what is missing is a proper and thorough review of the related work and gap analysis. Although relevant work is cited in Chapter 4 and 5, even in those chapters there is no sense that a proper literature review has been conducted. Novelty claims are made in Chapters 4 and 5, but because there is no literature review and gap analysis, this has not been properly situated within the existing literature, and so the significance of the results is not clear. This is not something that necessarily should be addressed in Chapter 3, and might be better placed to address in Chapter 4 or 5.

Chapter 4 This chapter is the first technical contribution chapter and contains many interesting results. However, there are several issues. First, the structure is confusing and is presented using a "story telling" approach where the reader is unprepared for what comes next. Everything is a surprise. Whereas a chapter in a scientific thesis needs introductory paragraphs which describe how the chapter is structured so there are no surprises and the reader knows what to expect at every turn. This is especially an issue here since a lot of ground is being covered with many diverse topics. Perhaps even splitting this into multiple chapters might be better. There are also many issues with punctuation and capitalisation (more details below).

On the more fundamental level, by the end of the chapter I was left confused by how the notion of Nash bargaining solution (NBS) is actually relevant here. In the thesis, the GNK value has been presented as an extension of the NBS and particular for the computation of the disagreement point. However, in the DC powerflows application the NBS is not used at all. Instead the allocation is determined by maximising the sum of utilities (i.e. the social welfare) whereas in NBS the product of utilities minus disagreement value is maximised. The GNK is instead used to compute the payment, not the allocation, and so at this point the connection between NBS and the energy application seems lost. This is not to say that the GNK is not, on its own accord, a viable solution for the NBS. However, it then does beg the question whether such a complex solution is actually required to merely compute the payments when there are many equally good or even better solutions with similar if not more theoretical properties. In particular it turns out that the NBS is not individually rational, which is quite a significant negative result since individual rationality is an important property. If individual rationality can be sacrificed then there are budget balanced (BB) Groves mechanisms which could be used instead, since they at least have BB+Incentive compatibility (IC), whereas GNK is not even IC. Another thought is why the candidate did not apply Shapley value directly to compute the payment. This would be budget balanced if scaled properly. How would it compare to NBS?

The chapter is largely empirical but there are some theoretical properties. However, these are hidden in the appendix and not really discussed in the chapter itself. The ones that are discussed, either the significance is not clear (e.g. continuity, why is this important) or trivial (e.g. the fact that GNK is not IC).

Unfortunately, another issue with this chapter is that the empirical evaluation is not reproducible. The description of the setting is incomplete. For example, on p.66, the paragraph "Using this algorithm we considered..with randomly generated consumption/generation limits.". None of the parameters for e.g. the graph generation or the distributions are given, making it impossible to reproduce. The essence of science is reproducibility. For the settings that are given, these are scattered between explaining the algorithm and the results, and are hard to find. For someone wishing to reproduce this, it would be difficult to find and it would be better to present he settings in a table.

The structure of providing a model and algorithms, results, more models, more results, another model and more results, makes it very difficult to keep up. It would be much better to put the results together, or split the contributions across different chapters. The 3d graphs in section 4.7 don't seem to add much. It would be better to have clearer, 2d graphs, comparing different methods.

Chapter 5. After reading chapter 4 I got quite worried about the contribution. Luckily then for chapter 5. This seems to be in much better shape in terms of structure and writing, and also has a clearer purpose and contributions. The results seem significant. Even so, there is still no proper literature review and gap analysis. Some works are discussed, but there is no sense whether this is all related work, or just a subset, and whether works are missing. In some cases it's also not clear what is a new contribution, and what is from others. For example, is Algorithm 2 new? In some cases, e.g. Theorem 9, proofs are provided for existing theorems. This seems highly unusual. Is the proof different from the original? Is there another reason for including it? If so, it might be good to add a brief sentence saying "Proof has been restated here to..". The comment in the para of section 5.3.2 "which, we note, appears to be novel" is simply not convincing without a proper lit review. Anything can appear novel if you have not done a proper literature search (I am not saying here that this was the case, but there is simply no evidence of this). Overall, however, the approach seems solid and the results significant.

Some minor issue:

- In Section 5.4.2, one of the assumptions is that each stratum has a mean and variance. How does this apply in the cases of the games described in Section 5.6 or the energy setting from Chapter 4? These seem to be deterministic settings.
- In Section 5.5.1, why is JOIN not included as part of the benchmarks? This one seemed to perform the best in the preceding chapter.

To summarise, there are very solid contributions but parts of the thesis seem to have been rushed and don't come together completely, especially in chapter 4. I recommend some changes are made before submitting the final version. In particular:

Chapter 2:

- Consider whether envy freeness would be appropriate to discuss here
- Consider whether you would want to discuss the issues with maximising the collective utility function, especially when the utility is not an "objective" measure but can be sensitive to affine transformations

Chapter 3:

- P. 40. Unusual definition of Pareto optimality. Consider revising.

Chapter 4

- Give overview of how chapter is organised. Consider reorganising.
- Consider adding more of a lit review
- Clarify relevance of the NBS, make clear this is somehow separate (i.e. can be used for NBS but also to compute payments), or remove the reference to it

- 4.2/4.3 Explain why restricted games are important to consider. Give examples of restricted games.
- Section 4.4: not clear what DC approximation is. Can't assume reader is familiar with DC powerflows. E.g. what is "Line susceptance"
- 4.4.1: linear power consumption assumption not motivated
- Provide table with overview of the settings
- Discuss theoretical results from appendix. Clarify why some of these properties are significant
- 4.6.2: first time that "stratified sampling" is mentioned here. Needs more explaining of what it is, with forward referencing to Ch 5.
- 4.6: Provide enough detail of the settings to reproduce experimental results
- Consider adding vanilla Shapley value as another payment mechanism (or explain why this is not trivial/unnecessary)
- 4.7: "50-50 split of small consumers and small generators of electricity". Again needs more detail to allow reproducibility. Parameters could go to appendix if it makes the chapter too long.

Chapter 5:

- Consider adding a proper literature review
- Clarify where proofs are reproduced/restated from another paper and why
- Clarify if Alg 2 is novel
- See "minor issues" comments above
- 5.6 first para seems to have some repetition from Chapter 4. Instead use referencing

Textual errors

There are many instances where punctuation is incorrect and other issues. Please check the grammar rules on hyphens and commas. Some examples (incomplete):

- Typo in the title: "managment"
- P 7: "begin applicable" -> "being"?
- P. 20. Walk-away -> Walk away (no hypen)
- P. 26 Mechanism Design – don't capitalise. Only names should have capitals
- P. 26 Nash-equilibria -> Nash equilibria (several occurrences)
- P 27 players valuation -> players' valuation
- P28 One of the most features -> most notable features??
- P. 29: "Additionally, that selling" not a complete sentence
- P. 38: Shapley Value -> Shapley value
- P 39. "markets, however" -> "markets. However," same mistake occurs many times
- P. 48: pareto-optimal -> Pareto optimal
- P. 48: three-or-more -> three or more
- P. 52: sentence "the pricing the immeditate" needs fixing
- P. 52: "And then give". Needs fixing
- P. 58: disjunnctive
- P. 76 "whether-or-not" -> remove hyphens
- P. 78 "less less"

- P. 89: "Since the aggregated.." not a complete sentence
- P. 93: "sharpened" -> "improved"
- P. 100 "- and in this section is created an empirical (" consider rephrasing
- P. 102 "But that this form.." subsentence used as new sentence
- P. 106 Proof of Theorem 12 "In a similar was as per" fix
- P. 117 is gamma function -> is the gamma function
- P. 122: "apon"
- P. 124 "infact" should be 2 words