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Transaction Fees, Block Size Limit, and Auctions in Bitcoin: Open Review

Nicola Dimitri*†

Reviewers: Reviewer A, Reviewer B, Reviewer C

Abstract. The final version of the paper "Transaction Fees, Block Size Limit, and Auctions in Bitcoin" can be found in Ledger Vol. 4 (2019) 68-81, DOI 10.5915/LEDGER.2019.145. There were three reviewers involved in the review process, none of whom have requested to waive their anonymity at present, and are thus listed as A, B, and C. After initial review by Reviewers A and B (1A), the Author responded (1B) and submitted a revised manuscript. Because the opinions of Reviewers A and B were split on the revised submission, a third reviewer, Reviewer C, was asked to also review the submission (2). At this point the submission was accepted on condition of revisions in line with the second round of review, after which it was deemed acceptable for publication with minor revisions, thus ending the peer review process. Authors' responses, where included, are bulleted for clarity.

1. Review (First Round)

Reviewer A

Does this paper represent a novel contribution to cryptocurrency or blockchain scholarship?:

Not sure

If you answered "yes" to the previous question, in one sentence, describe in your own words the novel contribution made by this paper:

Is the research framed within its scholarly context and does the paper cite appropriate prior works?:

Important references are missing

* 1N9ukmAq6EhhVigrAHiMMzSHdEwDAcLskP
† Nicola Dimitri (dimitri@unisi.it) is Professor of Economics at the University of Siena, Italy, and Research Associate at the Centre for Blockchain Technologies, University College London.

Please assess the article's level of academic rigor.:

Good (not excellent but a long way from poor)

Please assess the article's quality of presentation.:

Good (not excellent but a long way from poor)

How does the quality of this paper compare to other papers in this field?:

Top 50%

Please provide your free-form review for the author in this section.:

This paper formalizes bitcoin transaction fees as an auction where transactions are "bidding" for space inside a block. The paper then discusses the implications this has on block size and tradeoffs that miners have for adding in an additional transaction.

While I appreciated a simple, yet explanatory model, the paper had some major issues in it which would make me recommend a revision before acceptance.

Highlights:

- This paper presents a simple, elegant model that makes sense. Placing transactions in blocks seems like a natural fit for auction theory.

- The author uses users' willingness to pay to put their transactions on the blockchain as input to how large the blocksize should be. This connection is an interesting one that seems to work out.

- The theoretical parts of this paper are well done and well explained.

Issues:

- This paper gives trivial examples of when transactions fit in blocks. However, this problem reduces to the 0/1 knapsack problem (see https://freedom-to-tinker.com/2014/10/27/bitcoin-mining-is-np-hard/). The author needs to acknowledge and reconcile this with their paper -- how should miners approximate this hard problem?

- The author acknowledges some of their assumptions, but fails to acknowledge others. The assumptions baked into this model were not entirely explicit. There is a fundamental assumption of the competitive nature of Bitcoin mining (not necessarily an assumption that generalizes). For instance, consider an oligopolistic model where the miners demand fees above the market setting level. Or the monopsonistic model where most transactions are placed by a few software implementations that coordinate.

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- The author does not consider nor mention ways of boosting transaction fees, like child pays for parent or opt-in replace by fee.

- The arbitrage model makes many assumptions that may or may not make sense. For acceptance without revision, the author needs to acknowledge some and attempt to quantify the affect on their model. For instance, the volatility of altcoins, the liquidity of altcoins such that a trade won't affect price, etc.

- The author cites a number of papers but doesn't adequately place the work in the literature. The author seems to be missing some relevant citations as well. How does this paper fit in and contribute to the common wisdom about optimal block creation for miners (most similarly Houy's work and Chepurnoy et al. from the Bitcoin workshop at FC 18, but certainly others)?

Nits:

- The format needs to be standardized. This made the paper hard to read.
- Similarly, the bibliography format made it hard to look up references.
- Theta wasn't defined. I imagine it's the standard from the mechanism design literature, but ...
- The author links Bitcoin and Bitcoin cash using their name. In the top 50, there are other currencies that also have this feature. This point would be better made with a less spurious link (or left off).
- The author suggests that block size needs a 51% consensus of miners. Is there a cite for this?
- The use of the word "registration" is confusing and not in line with the Bitcoin literature.

Reviewer B

The author of this paper investigates the important problem of how transaction fees are decided, both by miners and those trying to make transactions, using the model of a "transaction fee game" and applying the concepts of Nash Equilibrium.

Although I see a lot of potential in this work, it is in its current form very confusing even for readers well versed in the space. I have made a number of comments below, roughly in the order they appear in the paper. I would be happy to review this work again once these clarifications/revisions are made and where hopefully the paper is easier to follow,

- Quick comment, the citation style doesn't follow the Ledger guidelines

- In the second page there is a sentence about a "fundamental trade-off" regarding fees for transactions. There are two points of confusion here: (1) practically everyone I am aware of in this space uses the word "confirmed" instead of the word "registered" when speaking about transactions being included ina block. The author should certainly use the word "confirmed" otherwise readers will wonder whether "registration" refers to something else entirely. If the author is trying to convey something else, then that needs to be explained early as the word "register" appears throughout the paper. (2) It is confusing to say that "the higher the fee offered... the more expensive... could be the payment." That is like saying "the higher the price

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I pay for this apple, the more expensive it could be." It's both redundant and confusing... what does the author mean by "could be"? Is there a chance that it could not be?

- On the second page, as well, the author says "The block size is decided with the bitcoin community"... throughout the paper the author refers to "block size" without being clear as to whether he is referring to a particular block generated by a miner or a "block size limit". In this sentence, it seems that the author means the "block size limit". Throughout the whole paper, the author *must* be specific as to whether he is referring to the limit, or the size of a particular blocks. Blocks have variable sizes!

- Early on, it is confusing as to what "optimal" means regarding "optimal block size"... is this meant to be "optimal for a miner", or "optimal for a user" or "optimal for the community" etc. (for example, on the 2nd page the 2nd paragraph from the bottom the author writes "If the values' distribution is polarised... ... the optimal size of a block would be small." Optimal in what sense? Even though this becomes more clear later in the paper, the problem statement needs to be articulated clearly on the first or second page, because otherwise the paper is very hard to follow.

- It's unclear in this paper how important fiat/exchange rates are to the conclusions. It seems like a distraction. It would be better to assume 1 bitcoin = 1 dollar (and state that as an assumption) and leave it out of the analysis. Perhaps it can be added in towards the end if it leads to some interesting observation.

- A the top of page 4 a new variable is introduce \theta that is not explained. Although it is not impossible to try to guess why the author introduced it, it would make the paper easier to follow if there were a setence (like with all of the other variables). Here \theta has the meaning of... " ".

- At the top of page 4 there is also language about the i'th "registered" block and "registration" -- again, please use "confirmation" unless it is intended to refer to something different.

- Near the top of page 4 the author says that "the block size S_i = S is constant over time"... does the author mean the limit? The block size is certainly not constant.

- In example 1 at the bottom of page 5, the text reads "Suppose S is the announced block size"? What does this mean? Who is announcing it? A miner? The community? Is it a limit? If it is a miner, they do not PRE announce block sizes... their preferred block size is hidden to the users.

- Example 1 also refers to "occupied bytes" which is confusing. There are no such things as "unocupied bytes" (see also on page 7 where the author says "leave some bytes empty")... if the block size limit is 1 MB and there are only 700 kB of transactions, then the block produced is only 700 kB.

- Section 3 "Nash Equilibrium" refers to a prior "chapter", I think the author means "section" as this is not a book

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- At the top of page 7 the author uses the word "transfers"... is that meant to have the same meaning as "transactions"? If so, please use the word "transactions"

- In section 3.2, it is unclear when the author writes that (in this case) the users have no knowledge about what fees the other users are paying, but then in Example 2 the author writes that in equilibrium users will pay no lower than the highest fee of an excluded transaction. Could the author clarify how they would know this under the assumption that users do not know about each others transaction fees?

- As a general comment, I think showing examples is great and helps make the paper easier to follow. I would strongly suggest the author also consider showing some of the conclusions in the form of simple charts, that depict, for example, how r(S) varies as a function of the block size (or block size limit?) S under different scenarios.

- Another general comment: There is an important distinction in these matters between transactions that are broadcase, transactions that are in the mempool, transactions that are put into blocks by miners, and transactions that are in blocks that have been confirmed on the blockchain. I think using the language of the mempool (and being clear about how it is defined in the context of this paper) would add strongly to its readability and relevance.

I look forward to reading a revised version of this work that makes the above clarifications.

1B. Author's Responses

Reviewer A

Does this paper represent a novel contribution to cryptocurrency or blockchain scholarship?:

Not sure

If you answered "yes" to the previous question, in one sentence, describe in your own words the novel contribution made by this paper:

Is the research framed within its scholarly context and does the paper cite appropriate prior works?:

Important references are missing

- I added some further references, specific on transaction fees. However, if in your view some important ones are still missing please let me know.

Please assess the article's level of academic rigor.:

Good (not excellent but a long way from poor)

Please assess the article's quality of presentation.:

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Good (not excellent but a long way from poor)

How does the quality of this paper compare to other papers in this field?:

Top 50%

Please provide your free-form review for the author in this section.:

This paper formalizes bitcoin transaction fees as an auction where transactions are "bidding" for space inside a block. The paper then discusses the implications this has on block size and tradeoffs that miners have for adding in an additional transaction.

- Indeed

While I appreciated a simple, yet explanatory model, the paper had some major issues in it which would make me recommend a revision before acceptance.

- Thanks for this

Highlights:

- This paper presents a simple, elegant model that makes sense. Placing transactions in blocks seems like a natural fit for auction theory.

- I'm pleased that we agree on the approach

- The author uses users' willingness to pay to put their transactions on the blockchain as input to how large the blocksize should be. This connection is an interesting one that seems to work out.

- Willingness to pay is an essential element in most auction theory, and i think in this case too.

- The theoretical parts of this paper are well done and well explained.

- Many thanks for your appreciation

Issues:

- This paper gives trivial examples of when transactions fit in blocks. However, this problem reduces to the 0/1 knapsack problem (see https://freedom-to-tinker.com/2014/10/27/bitcoin-mining-is-np-hard/). The author needs to acknowledge and reconcile this with their paper -- how should miners approximate this hard problem?

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- Many thanks for pointing out the knapsack problem, which i must admit i've only heard of before. There certainly are similarities but also differences between the two problems, which i now briefly discuss, in the introduction.
- To anticipate, (in the language of the rucksack) the main difference between the (my) auction and knapsack approaches is the following. As i discuss in the paper, in the former approach a change in "rucksack volume" (block limit size) could change the weight of the objects (transaction fees) which is not the case in the classical rucksack approach.

- The author acknowledges some of their assumptions, but fails to acknowledge others. The assumptions baked into this model were not entirely explicit. There is a fundamental assumption of the competitive nature of Bitcoin mining (not necessarily an assumption that generalizes). For instance, consider an oligopolistic model where the miners demand fees above the market setting level. Or the monopsonistic model where most transactions are placed by a few software implementations that coordinate.

- Good point which, it is true, I did not consider in the paper. The main reason why is because I wanted to focus on the issue fundamentals and clarify them. I now briefly discuss the point in the introduction.

- The author does not consider nor mention ways of boosting transaction fees, like child pays for parent or opt-in replace by fee.

- True that I do not mention these points. However, I think those elements may affect transaction fees by affecting willingness to pay. That is, since I do not discuss how values are determined their level may also encompass those points.

- The arbitrage model makes many assumptions that may or may not make sense. For acceptance without revision, the author needs to acknowledge some and attempt to quantify the affect on their model. For instance, the volatility of altcoins, the liquidity of altcoins such that a trade won't affect price, etc.

- Thanks for this. To make the paper more homogeneous I decided to eliminate the arbitrage model.

- The author cites a number of papers but doesn't adequately place the work in the literature. The author seems to be missing some relevant citations as well. How does this paper fit in and contribute to the common wisdom about optimal block creation for miners (most similarly Houy's work and Chepurnoy et al. from the Bitcoin workshop at FC 18, but certainly others)?

- Thanks. I now point out and briefly elaborate that, to my knowledge, no existing contribution has an approach similar to mine.

Nits:

- The format needs to be standardized. This made the paper hard to read.

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- Thanks. I worked on this

- Similarly, the bibliography format made it hard to look up references.

- I worked on this too

- Theta wasn't defined. I imagine it's the standard from the mechanism design literature, but ...

- I now better define theta. It typically stands for a share of the amount of bitcoin transacted

- The author links Bitcoin and Bitcoin cash using their name. In the top 50, there are other currencies that also have this feature. This point would be better made with a less spurious link (or left off).

- Thanks. I now do this, listing the 6 of them

- The author suggests that block size needs a 51% consensus of miners. Is there a cite for this?

- As the issue is still somewhat controversial, to avoid dwelling too long on the point, with no harm for the paper I decided to eliminate the reference to 51%

- The use of the word "registration" is confusing and not in line with the Bitcoin literature.

- Sorry you are right. Everywhere I now use “confirmation” rather than “registration”

Reviewer B

The author of this paper investigates the important problem of how transaction fees are decided, both by miners and those trying to make transactions, using the model of a "transaction fee game" and applying the concepts of Nash Equilibrium.

- Indeed. Transaction fees analysis is then instrumental to discuss the optimal block size (revenue maximizing) for the miner.

Although I see a lot of potential in this work, it is in its current form very confusing even for readers well versed in the space. I have made a number of comments below, roughly in the order they appear in the paper. I would be happy to review this work again once these clarifications/revisions are made and where hopefully the paper is easier to follow,

- Many thanks for all your interest in the work and the detailed comments

- Quick comment, the citation style doesn't follow the Ledger guidelines

- I now take care of this

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- In the second page there is a sentence about a "fundamental trade-off" regarding fees for transactions. There are two points of confusion here: (1) practically everyone I am aware of in this space uses the word "confirmed" instead of the word "registered" when speaking about transactions being included ina block. The author should certainly use the word "confirmed" otherwise readers will wonder whether "registration" refers to something else entirely. If the author is trying to convey something else, then that needs to be explained early as the word "register" appears throughout the paper.

- Sorry you are right. Everywhere i now use “confirmation” rather than “registration”

(2) It is confusing to say that "the higher the fee offered... the more expensive... could be the payment." That is like saying "the higher the price I pay for this apple, the more expensive it could be." It's both redundant and confusing... what does the author mean by "could be"? Is there a chance that it could not be?

- Thanks for this. I used the “…could be..” To intend that if confirmation does not take place then there is no payment. But since this caused confusion i now amended the expression

- On the second page, as well, the author says "The block size is decided with the bitcoin community"... throughout the paper the author refers to "block size" without being clear as to whether he is referring to a particular block generated by a miner or a "block size limit". In this sentence, it seems that the author means the "block size limit". Throughout the whole paper, the author *must* be specific as to whether he is referring to the limit, or the size of a particular blocks. Blocks have variable sizes!

- Thanks for this too. Yes I meant “block size limit” and I now specify this in the paper

- Early on, it is confusing as to what "optimal" means regarding "optimal block size"... is this meant to be "optimal for a miner", or "optimal for a user" or "optimal for the community" etc. (for example, on the 2nd page the 2nd paragraph from the bottom the author writes "If the values' distribution is polarised... ... the optimal size of a block would be small." Optimal in what sense? Even though this becomes more clear later in the paper, the problem statement needs to be articulated clearly on the first or second page, because otherwise the paper is very hard to follow.

- The paper specified this already (optimal for the miner) but I now emphasise the point even more.

- It's unclear in this paper how important fiat/exchange rates are to the conclusions. It seems like a distraction. It would be better to assume 1 bitcoin = 1 dollar (and state that as an assumption) and leave it out of the analysis. Perhaps it can be added in towards the end if it leads to some interesting observation.

- Thanks. I now elaborate shortly on the point in the introducton. On a related matter, notice that to increase the paper homogeneity, the last section on the arbitrage model has now been eliminated

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- A the top of page 4 a new variable is introduce \theta that is not explained. Although it is not impossible to try to guess why the author introduced it, it would make the paper easier to follow if there were a setence (like with all of the other variables). Here \theta has the meaning of... " ".

- Thanks, I now make its meaning more explicit.

- At the top of page 4 there is also language about the i'th "registered" block and "registration" -- again, please use "confirmation" unless it is intended to refer to something different.

- I do now

- Near the top of page 4 the author says that "the block size S_i = S is constant over time"... does the author mean the limit? The block size is certainly not constant.

- Yes I mean the “block size limit” and further clarify this now

- In example 1 at the bottom of page 5, the text reads "Suppose S is the announced block size"? What does this mean? Who is announcing it? A miner? The community? Is it a limit? If it is a miner, they do not PRE announce block sizes... their preferred block size is hidden to the users.

- Thanks. I now make it clear what I meant by that.
- It is agreed upon by the *community*

- Example 1 also refers to "occupied bytes" which is confusing. There are no such things as "unocupied bytes" (see also on page 7 where the author says "leave some bytes empty")... if the block size limit is 1 MB and there are only 700 kB of transactions, then the block produced is only 700 kB.

- Thanks again, this point is now clarified -

- Section 3 "Nash Equilibrium" refers to a prior "chapter", I think the author means "section" as this is not a book

- Indeed. I now corrected this

- At the top of page 7 the author uses the word "transfers"... is that meant to have the same meaning as "transactions"? If so, please use the word "transactions"

- Replacement done

- In section 3.2, it is unclear when the author writes that (in this case) the users have no knowledge about what fees the other users are paying, but then in Example 2 the author writes that in equilibrium users will pay no lower than the highest fee of an excluded transaction.

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Could the author clarify how they would know this under the assumption that users do not know about each others transaction fees?

- Good point which is even further emphasised in the last section. Admittedly, the model is very simple also because its underlying assumptions are demanding. Indeed, the model that I use is an auction game with *complete information*.
- Following standard game theory, in this context *complete information* means that users know each other *willigness to pay* for a transaction fee. Though, literally taken, this can not be considered as a realistic assumption, observaton of past transaction fees can provide a proxy of users' values and an estimate of their distribution in the population (this discussion is in the last section)
- If this is acceptable, in principle or at least as a first approximation, then what is assumed in the model is not so much that users' know each other transaction fees, when they propose theirs, but rather that they know each other values. It is such knowledge that drives the offer of transaction fees.

- As a general comment, I think showing examples is great and helps make the paper easier to follow. I would strongly suggest the author also consider showing some of the conclusions in the form of simple charts, that depict, for example, how r(S) varies as a function of the block size (or block size limit?) S under different scenarios.

- I now inserted tables 1,2,3 to summarize the examples

- Another general comment: There is an important distinction in these matters between transactions that are broadcase, transactions that are in the mempool, transactions that are put into blocks by miners, and transactions that are in blocks that have been confirmed on the blockchain. I think using the language of the mempool (and being clear about how it is defined in the context of this paper) would add strongly to its readability and relevance.

- Thanks for this suggestion which I have embodied

I look forward to reading a revised version of this work that makes the above clarifications.

- Thanks for your interest

2A. Review (Second Round)

Reviewer A:

This is the second time I've reviewed this paper.

Last review I made the following comments which weren't fully addressed:

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- The format needs to be standardized. This made the paper hard to read. I didn't notice a substantive change here.

- Theta wasn't defined before it was used. The author described this in his review, but it still wasn't in the paper. This is a major issue in readability of the paper.

I appreciated the addition of the comparison to the rucksack problem. However, the major issue with the rucksack problem is that it's not possible to compute an optimal answer in a reasonable amount of time. Would this affect the implementation? While an implementation of this is clearly outside of the scope of this paper, a discussion about the potential to be implemented would add greatly to the paper.

The work has been improved, but I am still concerned about the changes that were addressed only in the feedback but not in the actual paper.

Reviewer B

Does this paper represent a novel contribution to cryptocurrency or blockchain scholarship?:

Yes

If you answered "yes" to the previous question, in one sentence, describe in your own words the novel contribution made by this paper::

This paper uses game theory to make observations about optimal block size limits and also optimal transaction fees

Is the research framed within its scholarly context and does the paper cite appropriate prior works?:

Yes

Please assess the article's level of academic rigor.:

Excellent (terms are well defined, proofs/derivations are included for theoretical work, statistical tests are included for empirical studies, etc.)

Please assess the article's quality of presentation.:

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Excellent (the motivation for the work is clear, the prose is fluid and correct grammar is used, the main ideas are communicated concisely, and highly-technical details are relegated to appendixes).

How does the quality of this paper compare to other papers in this field?:

Top 5%

Please provide your free-form review for the author in this section.:

The author has addressed my prior critiques. The paper is much more clear and easy to follow now. I recommend publishing with only very minor revisions, listed below:

- In the abstract in the first sentence, remove the word "currency" before blockchain (it does not add anything useful to use the word currency here).

- The second paragraph of the introduction makes reference to various forks of Bitcoin. I don't think this is necessary, and makes the paper seem unnecessarily dated (the majority of the results of the paper should still be true in 20 years, but Bitcoin Gold may likely be long forgotten). The author could instead just mention that the paper is relevant for all cryptocurrencies that follow the protocol originally described in Satoshi's paper.

- On the second page the Author refers to some related literature but the sentence is written "... the existing literature being perhaps 9". This sentence would be ended with something like "...being perhaps the work of ???? et al.9"

- I very much appreciate that the Author replaced "block size" with "block size limit" in most places in the paper. However, in a few places it still says "size" and it is not clear if that's what the Author really intends. For example in the middle of page 4 after defining \theta, the Author writes "Si stands for the size of the next ith block". Does the Author really mean "size" here or is it the "block size limit of the next block"? Perhaps the Author thinks I am splitting hairs, but they have important and distinct meanings!

- This is just my opinion, but right before Section 2.2 I don't think the Author needs to write "less realistic" when writing "That is in a more general, though less realistic, scenario...". Many people in the community think that that is in fact the inevitable future. However, that is admittedly speculative, I just wanted to share my thoughts.

I look forward to seeing this published!

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Reviewer C

Does this paper represent a novel contribution to cryptocurrency or blockchain scholarship?:

Yes

If you answered "yes" to the previous question, in one sentence, describe in your own words the novel contribution made by this paper::

The first attempt to model the optimal block size limit considering the _value_ of transactions to bitcoin users.

Is the research framed within its scholarly context and does the paper cite appropriate prior works?:

Yes

Please assess the article's level of academic rigor.:

Excellent (terms are well defined, proofs/derivations are included for theoretical work, statistical tests are included for empirical studies, etc.)

Please assess the article's quality of presentation.:

Good (not excellent but a long way from poor)

How does the quality of this paper compare to other papers in this field?:

Top 20%

Please provide your free-form review for the author in this section.:

In this paper, author Nicola Dimitri models the optimal block size limit from the perspective of miner revenue (he considers the block size limit that maximizes miners' revenue from transaction fees) by considering the _value_ that transactions have to users. Too high a block size limit, and users who might otherwise pay a high fee will pay a low fee instead, knowing they will be included in the next block. Too low a block size limit, and although miners will obtain large fees from the most motivated transactors, they will lose out overall by not included transactions from people paying slightly lower fees. Dimitri attempts to create a framework for modelling and understanding the question of what block size limit _actually_ results in the most revenue for the miners.

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I think the paper's topic is an important one, and the author's treatment is sensible and meets Ledger's standards for rigor. However, I do not find the results particularly exciting or insightful. Regardless, I think the paper should be accepted. It represents an advancement of knowledge.

Some minor comments:

- "currency blockchain" in the abstract sounds funny. Maybe just say "blockchain"

- the author spent a lot of time talking about the "rucksack problem" but from my perspective this isn't particularly interesting because the block size limit is normally much larger than the size of the individual transactions such that simple sorting the transactions by fee density results in _close to_ to optimal block. I think it's OK to leave the discussion in place, as I suppose it would be relevant if the block size limit remain at 1 MB and the average transaction size increased, or God-forbid, the block size limit were decreased. But maybe the author could make a comment that all this complexity around the rucksack problem is only a minor detail within the larger revenue-optimization problem for _most_ sets of transactions and blocks in practice.

- The following wasn't clear to me:

“Equation (6) implies that the optimal block size S^* in general may not coincide with the one maximizing the per byte expected revenue $r(S)$, since it must be $r'(S^*) < 0$.”

Is this the case purely due to the rucksack problem? What I mean by this is, does this condition vanish if the block size limit is large compared to the byte-size of transactions? If the answer is “yes” (and I think it is), then I would state this explicitly. If the answer is “no,” it means I missed an interesting result from your paper.

Other than that, and some typesetting improvements, I think the paper looks good.

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