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Editorial

There are five items in this issue:

- The first paper, by I.D. Hill, makes the case for using Meek's computer-oriented version of STV for Scotland's STV elections.
- In the second paper, Lee Naish discusses a system of partial disclosure of STV results that can be used to preclude the enforcement of certain coercive voting practices.
- In the third paper, James Green-Armytage reviews software that can be used to count elections by a variety of voting rules, including a number of versions of STV.
- The fourth paper is a response by Thomas Colignatus to the review by Markus Schulze of Colignatus's book, *Voting Theory for Democracy* in the previous issue of *Voting matters*.
- The fifth and final item is Markus Schulze's reply to Thomas Colignatus.

Readers are reminded that views expressed in ***Voting matters*** *by contributors do not necessarily reflect those of the McDougall Trust or its trustees.*

The Case for Meek for STV in Scotland

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Abstract

Using the votes in the STV elections for local government in Glasgow in 2007, this paper argues that the voters' wishes would have been better met, in two wards, if Meek's method had been specified for making the count. The results in the other 19 wards would not have been changed.

Keywords: Glasgow, Gregory method, Meek method, Scotland, STV, WIGM

1 Introduction

Articles about STV in Scotland by Curtice [2] and by Gilmour [3] are both informative and interesting, but it is disappointing that neither of them gives any indication of how and why the particular form of STV now used in Scotland, the Weighted Inclusive Gregory Method, known as WIGM [7], was chosen. However, that is not intended as a criticism of those authors. While accepting that WIGM is better than traditional versions of STV, it is regrettable that WIGM was chosen rather than the Meek method [4, 5]. It is the aim of this paper to show why it is regrettable.

The main differences between the two methods are: (1) WIGM continues the traditional practice of jumping over already-elected candidates when transferring votes while Meek gives new surpluses to such candidates, for further redistribution; (2) WIGM uses a constant quota based on the original number of valid votes while Meek reduces the quota whenever votes become non-transferable, in accordance with the current number of active votes. This reduced quota then applies to all candidates, and those already elected get new surpluses to be transferred.

Those who support any particular version of a voting procedure, rather than an alternative version, are always under a slight disadvantage in trying to prove their point, in that if short simple examples are presented showing their preferred method to be superior, they are told that those examples are too artificial and that real votes are quite different. While it is true that we must never take such artificial examples too seriously, they nevertheless can be useful in showing where and how things can go wrong in rival systems. If, on the other hand, real results are presented, the information is usually voluminous, making it difficult to show in detail what is happening. What is more, real voting patterns are, quite often, regarded as confidential information, not to be published, while such result sheets as are published are useless for detailed analysis.

In the present instance the data for the 21 wards for local government within the City of Glasgow in 2007 have been published in full [1] and, as those results are public knowledge, they have become a precious resource for research purposes. The fact that they are voluminous means that it is not easy to present short reports on them, but the fact that they are real election data is more important than that.

This paper argues that those data provide evidence supporting the proposition that Meek's method is better than other STV methods. There is, of course, no suggestion here that the count was wrongly conducted; every election must be counted in accordance with the rules in force, and that was done.

For the present paper, the voting figures for each of the 21 wards were re-analysed using the Meek method. It was found that in only two of the 21 wards does Meek give a different result from that actually observed. That is not many, but it is very important in those particular cases. If it is thought not worth using a different method for so few changes, it should be noted that, in every single case, WIGM elected the same candidates as would have been elected by more traditional STV methods, such as the current rules of the Electoral Reform Society [6] for example.

Furthermore there were only three wards (Baillieston, Craigton and Partick West) in which those elected by WIGM were different from those who would have been elected had only first preferences been looked at, the transfers making no difference. Such figures are sometimes misrepresented as what would have happened from a "first past the post" election, but that is quite incorrect because these are multi-seat wards and each voter is allowed only one first preference, not one for each available seat. The fact that transfers so rarely made a difference does not make transfers unimportant. It merely means that, in the majority of cases, the result was clear enough anyway. This does not mean that the Single Non-transferable Vote (SNTV) would be almost as good, because it is the knowledge that votes will be transferred when appropriate that gives voters the freedom to express genuine preferences without worry about strategic implications. Under SNTV voters have to worry about wasting their votes on non-elected candidates, or on large surpluses for elected candidates.

In implementing the two methods, a precision of five decimal figures after the decimal point has been used, as laid down in the regulations, for WIGM, but nine figures after the point, as used in New Zealand, for Meek. There is no reason to suppose that this difference alters the results. In the following presentation all figures have been rounded to one decimal for the sake of simplicity.

The two wards where Meek would have given a different result from WIGM are analysed below. The Pollokshields ward is taken first because it involves a slightly simpler analysis.

2 The Pollokshields ward

The actual result using the WIGM rules, as specified in the Scottish regulations, elected Khalil Malik (Scottish National Party), David Meikle (Scottish Conservative and Unionist Party), and Irfan Rabbani (Scottish Labour Party). With the same votes using Meek rules, Malik and Rabbani would still have been elected but Ian A. Ruffell (Scottish Green Party) would have been elected instead of Meikle.

The decision between Meikle and Ruffell could be considered marginal for WIGM but not for Meek. At the point where the decision between them had to be made, using WIGM their votes were 1839.5 and 1835.2 respectively, while using Meek they were 1916.5 and 2007.4 respectively. The Meek result sheet would have been as shown in Table 1.

2.1 Analysis of the Votes

There were 4117 ballot papers that do not mention either Meikle or Ruffell. These can be ignored as contributing nothing, whichever rules are used.

1730 papers that mention Meikle, without mentioning Malik, Rabbani or Ruffell before Meikle, each contribute 1 vote to Meikle whichever rules are used.

1591 papers that mention Ruffell, without mentioning Malik, Meikle or Rabbani before Ruffell, each contribute 1 vote to Ruffell whichever rules are used.

661 papers that mention Meikle, without mentioning Ruffell before Meikle, and may be reduced in value by having contributed to Malik and/or Rabbani, give 186.54 to Meikle by Meek, but 109.53 by WIGM.

1468 papers that mention Ruffell, without mentioning Meikle before Ruffell, and may be reduced in value by having contributed to Malik and/or Rabbani, give 416.39 to Ruffell by Meek, but 244.23 by WIGM.

A few typical cases of the papers that may be reduced in value, and the amount received by Meikle or Ruffell from each, are shown in Table 2. The full information can be obtained from the author on request.

2.2 Discussion

All candidates except Malik, Meikle, Rabbani and Ruffell are excluded by the time the choice between the final two candidates is made.

Table 1. Election result sheet for Pollokshields ward of Glasgow 2007, if the Meek method had been used.

Number to be elected = 3
Total valid vote = 9567

	Count 1 To elect Irfan Rabbani To exclude Ali Ashraf		Count 3 To exclude Fatima Uygun		Count 4 To exclude Karin Currie		Count 5 To elect Khalil Malik To exclude Muhammad Shoaib
Quota	2391.7		2357.1		2333.5		2301.6
Ali Ashraf	184.0	0.0%	0.0		-		-
Karin Currie	438.0	100.0%	454.5	100.0%	471.4	0.0%	0.0
Khalil Malik	2057.0	100.0%	2126.7	100.0%	2247.9	100.0%	2306.1
David Meikle	1435.0	100.0%	1454.2	100.0%	1461.9	100.0%	1594.8
Isabel Nelson	863.0	100.0%	897.1	100.0%	919.6	100.0%	1006.1
Irfan Rabbani	2575.0	91.1%	2362.2	90.9%	2396.2	88.5%	2361.8
Ian A Ruffell	1043.0	100.0%	1100.6	100.0%	1202.9	100.0%	1280.6
Muhammad Shoaib	592.0	100.0%	614.3	100.0%	634.0	100.0%	657.1
Fatima Uygun	380.0	100.0%	419.0	0.0%	0.0		-
Non-transferable	0.0		138.4		233.1		360.4
Total	9567.0		9567.0		9567.0		9567.0

		Count 7 To exclude Isabel Nelson		Count 11 To elect Ian A Ruffell To exclude David Meikle	
Quota		2181.4		1978.8	
Ali Ashraf		-		-	
Karin Currie		-		-	
Khalil Malik	87.5%	2271.5	69.8%	1996.2	Elected
David Meikle	100.0%	1650.4	100.0%	1916.5	
Isabel Nelson	100.0%	1110.5	0.0%	0.0	
Irfan Rabbani	79.7%	2281.2	63.5%	1995.1	Elected
Ian A Ruffell	100.0%	1412.0	100.0%	2007.4	Elected
Muhammad Shoaib	0.0%	0.0		-	
Fatima Uygun		-		-	
Non-transferable		841.3		1651.8	
Total		9567.0		9567.0	

Note: The counts shown are those where an election or exclusion is about to be made—the intervening counts are working towards the solution but cause no immediate action. The percentage figures show the fraction of each vote, or part of a vote, that is kept by the particular candidate at that count, the rest being transferred to the voter's next preference if any, or to "non-transferable" otherwise. The actions mentioned at the head of each column are those to be taken as a result of what appears in the column.

Table 2. Some typical ballot papers in the Pollokshields ward, with the amount of vote received by Meikle or Ruffell at the point where a decision had to be taken between them.

	Amount received by Meikle or Ruffell	
	Meek	WIGM
As **Ra** (Me or Ru)	0.36541	1.00000
Ra *As* (Me or Ru)	0.36541	0.07106
As *Ne* **Ma** *Cu* (Me or Ru)	0.30241	1.00000
As *Cu* **Ma** (Me or Ru)	0.30241	0.08867
Cu *Ne* **Ra** **Ma** (Me or Ru)	0.11050	1.00000
Ma *As* **Ra** *Sh* *Uy* *Ne* (Me or Ru)	0.11050	0.08867
Ra *Ne* *As* *Cu* **Ma** (Me or Ru)	0.11050	0.07106
Ra *As* **Ma** *Cu* (Me or Ru)	0.11050	0.00630

Note: The candidate names are shortened to just the first two letters. The notation *As* **Ra** (Me or Ru), for example, means a vote that gave Ashraf as first preference, Rabbani as second preference, Meikle or Ruffell as third preference. There may have been other preferences beyond those shown but they play no part. Names in bold face are of candidates who have already been elected; names in italics are of candidates who have already been excluded.

Using WIGM, there is distortion caused by the fact that the two candidates already elected would be sure of election on less than the original quota because some votes have become non-transferable, but they have to keep a full original quota nevertheless. This prevents either of the two contenders for the last place from reaching a quota when the decision has to be made. In contrast, using Meek, the decision is made by three of the four candidates having passed the reduced quota while the other one has not—the same quota applies to all and nobody is elected without reaching it.

The amount of vote that passes to Meikle or Ruffell, using Meek, depends only on whether Malik or Rabbani, or both of them, are mentioned earlier on the ballot paper. In comparison the WIGM figures are less consistent. They depend upon whether and where other, now irrelevant, candidates were mentioned. Even if no others at all were mentioned, under WIGM a ballot has to make contributions to both Malik and Rabbani if Rabbani is mentioned before Malik, but a contribution to Malik only if Malik is mentioned before Rabbani.

In the WIGM (official) count, the three winners ended with 2392.0, 2392.0 and 2217.9 votes respectively, while there were 2565.1 non-transferable votes. This appears to indicate that 73% of the votes were used and 27% wasted. In the Meek count, as presented here, the three winners ended with 1995.1, 1996.2 and 2007.4 votes respectively, while the runner-up had 1916.5 votes and 1651.8 were non-transferable. This appears to indicate that 63% of the votes were used and 37% wasted. It might be claimed that this indicates better usage of votes by WIGM.

However it is a standard part of the case for STV that votes are wasted not only when they end not assigned to an elected candidate but also when they end as part of an elected candidate's votes but in excess of those needed to be sure of election. If it is accepted that, as Meek demonstrates, a quota of only 1978.8 votes is, in the end, necessary, then it can be said that the wasted votes from WIGM are 413.2, 413.2 and 239.1 from the elected candidates plus the 2565.1 non-transferable, giving a total of 3630.6. Similarly the wasted votes from Meek are 16.3, 17.4 and 28.6 from the elected candidates plus 1916.5 and 1651.8 from the runner-up and non-transferable, also giving a total of 3630.6. What Meek wastes on unused votes WIGM wastes on keeping the quota unnecessarily high, so this particular argument does not help in making a judgement.

3 The Craigton Ward

The actual result using the WIGM rules, as specified in the Scottish regulations, elected

Ruth Black (Solidarity—Tommy Sheridan), Iris Gibson (Scottish National Party), Matthew John Kerr (Scottish Labour Party), and Alistair Watson (Scottish Labour Party). With the same votes using Meek rules, Gibson, Kerr and Watson would still have been elected but Gordon Macdiarmid (Scottish Labour Party) would have been elected in place of Black.

In neither case was the decision marginal. At the point where the decision between Black and Macdiarmid had to be made, using WIGM their votes were 1641.7 and 1493.1 respectively, using Meek they were 1821.5 and 1906.3 respectively.

The Meek result sheet would have been as shown in Table 3.

3.1 Analysis of the Votes

There were 3920 ballot papers that do not mention either Black or Macdiarmid. These can be ignored as contributing nothing whichever rules are used.

1439 papers that mention Black, but not Gibson, Kerr, Macdiarmid or Watson before Black, each contribute 1 vote to Black whichever rules are used.

1413 papers that mention Macdiarmid, but not Black, Gibson, Kerr or Watson before Macdiarmid, each contribute 1 vote to Macdiarmid whichever rules are used.

1259 papers that mention Black, but not Macdiarmid before Black, and may be reduced in value by having contributed to Gibson, Kerr and/or Watson, give 382.5 to Black by Meek, but 202.7 by WIGM.

3021 papers that mention Macdiarmid, but not Black before Macdiarmid, and may be reduced in value by having contributed to Gibson, Kerr and/or Watson, give 493.3 to Macdiarmid by Meek, but 80.1 by WIGM.

A few typical cases of the papers that may be reduced in value, and the amount received by Black or Macdiarmid from each, are shown in Table 4. The full information can be obtained from the author on request.

3.2 Discussion

The main reason for the different result seems to be that, at the time of the decision to exclude Black or Macdiarmid, Meek had already elected Kerr and redistributed his surplus, whereas WIGM had Kerr as still unelected and hence no votes come through from him. As a result the WIGM amount, as shown in Table 4, is sometimes zero.

Secondly, the fact that the WIGM quota stays at 2211.0, whereas the Meek quota has been reduced by this stage to 1881.1, means that Gibson and Watson are each keeping more votes under WIGM than they need, to be certain of election. Meanwhile Black was elected by WIGM not only without quota, but still short of even the reduced quota of the Meek method.

Thirdly, the values arriving at the two candidates under Meek depend only on which of Gibson, Kerr and Watson they have mentioned earlier, whereas the values arriving under WIGM can be changed by which excluded candidates they mentioned and where in the sequence they did so. For example for a voter with preferences starting Watson, Macdiarmid, under WIGM Macdiarmid receives only 0.00682 of a vote, whereas with preferences starting Petty, Watson, Macdiarmid he receives a full 1.0. Under Meek either of those voting patterns receives 0.21613, a much fairer result when Petty has been excluded and is thus totally irrelevant.

Other points are similar to those already mentioned above for the Pollokshields ward.

4. Conclusion

It is a great pity that the Scots should have adopted WIGM when Meek system was available, but the good features in WIGM are, of course, to be welcomed.

At least the chosen system is a good version of STV, and even the crudest form of STV is better than anything other than STV. The English still suffer from the grossly inferior multiple X-vote for their local elections.

5 Acknowledgement

An earlier version of this paper was offered to *Representation* but rejected by that journal. An anonymous referee, however, made many detailed suggestions for improvements. I am

Table 3. Election result sheet for Craigton ward of Glasgow 2007, if the Meek method had been used.

Number to be elected = 4
Total valid vote = 11052

	Count 1 To elect Iris Gibson		Count 3 To exclude Mark Dingwall		Count 4 To exclude Wullie McGartland		Count 5 To exclude Gordon Masterton
Quota	2210.4		2176.1		2167.1		2149.2
Ruth Black	1220.0	100.0%	1321.7	100.0%	1329.7	100.0%	1385.3
Scott R Coghill	457.0	100.0%	503.4	100.0%	511.2	100.0%	525.8
Mark Dingwall	225.0	100.0%	234.9	0.0%	0.0		-
Iris Gibson	2729.0	79.8%	2178.1	79.7%	2184.9	79.1%	2200.3
Matthew John Kerr	1920.0	100.0%	1976.3	100.0%	1995.1	100.0%	2012.6
Gordon Macdiarmid	1328.0	100.0%	1351.8	100.0%	1359.5	100.0%	1371.3
Gordon Masterton	315.0	100.0%	370.1	100.0%	392.5	100.0%	414.5
Wullie McGartland	224.0	100.0%	249.0	100.0%	258.1	0.0%	0.0
Scott Alexander Petty	569.0	100.0%	596.5	100.0%	699.0	100.0%	704.0
Alistair Watson	2065.0	100.0%	2098.7	100.0%	2105.2	100.0%	2132.1
Non-transferable	0.0		171.4		216.6		360.4
Total	11052.0		11052.0		11052.0		11052.0

		Count 6 To elect Alistair Watson		Count 7 To exclude Scott R Coghill		Count 8 To elect Matthew John Kerr To exclude Scott Alexander Petty		Count 12 To elect Gordon Macdiarmid To exclude Ruth Black	
Quota		2121.5		2114.1		2067.9		1881.1	
Ruth Black	100.0%	1465.4	100.0%	1485.7	100.0%	1573.5	100.0%	1821.5	
Scott R Coghill	100.0%	624.9	100.0%	635.8	0.0%	0.0		-	
Mark Dingwall		-		-		-		-	
Iris Gibson	77.3%	2196.3	74.6%	2123.4	74.3%	2214.4	59.8%	1889.7	Elec.
Matthew John Kerr	100.0%	2039.5	100.0%	2056.8	100.0%	2133.2	81.7%	1895.4	Elec.
Gordon Macdiarmid	100.0%	1389.3	100.0%	1406.4	100.0%	1445.2	100.0%	1906.3	Elec.
Gordon Masterton	0.0%	0.0		-		-		-	
Wullie McGartland		-		-		-		-	
Scott Alexander Petty	100.0%	730.2	100.0%	736.0	100.0%	803.1	0.0%	0.0	
Alistair Watson	100.0%	2161.7	98.1%	2126.6	97.6%	2170.2	78.4%	1892.5	Elec.
Non-transferable		444.7		481.3		712.3		1646.7	
Total		11052.0		11052.0		11052.0		11052.0	

Note: The counts shown are those where an election or exclusion is about to be made—the intervening counts are working towards the solution but cause no immediate action. The percentage figures show the fraction of each vote, or part of a vote, that is kept by the particular candidate at that count, the rest being transferred to the voter's next preference if any, or to "non-transferable" otherwise. The actions mentioned at the head of each column are those to be taken as a result of what appears in the column.

Table 4. Some typical ballot papers in the Craigton ward, with the amount of vote received by Black or Macdiarmid at the point where a decision had to be taken between them.

	Amount received by Black or Macdiarmid	
	Meek	WIGM
Co *Di* **Gi** *Mc* *Ms* (Bl or Md)	0.40220	1.00000
Gi (Bl or Md)	0.40220	0.18981
Pe **Wa** (Bl or Md)	0.21613	1.00000
Wa (Bl or Md)	0.21613	0.00682
Co **Ke** (Bl or Md)	0.18345	0.00000
Co *Di* **Gi** *Ms* *Pe* *Mc* **Wa** (Bl or Md)	0.08693	1.00000
Gi *Ms* *Mc* *Pe* **Wa** *Di* *Co* (Bl or Md)	0.08693	0.18981
Wa *Co* **Gi** (Bl or Md)	0.08693	0.00682
Gi **Wa** (Bl or Md)	0.08693	0.00129
Co **Gi** *Di* **Ke** (Bl or Md)	0.07378	0.00000
Wa **Ke** (Bl or Md)	0.03965	0.00000
Wa **Gi** **Ke** (Bl or Md)	0.01595	0.00000

Note: The candidate names are shortened to just the first two letters but, to avoid ambiguity, Macdiarmid and Masterton become Md and *Ms*. The notation *Pe* **Wa** (Bl or Md), for example, means a vote that gave Petty as first preference, Watson as second preference, Black or Macdiarmid as third preference. There may have been other preferences beyond those shown but they play no part. Names in bold face are of candidates who have already been elected; names in italics are of candidates who have already been excluded.

extremely grateful to that referee, most of whose suggestions have been incorporated in the above text. Any remaining deficiencies are, of course, entirely my own fault.

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About the Author

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Partial Disclosure of Votes in STV Elections

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Abstract

Full disclosure of votes in STV elections can allow coercion of voters by the use of "signature attacks", but limiting disclosure can make independent verification of results impossible. We propose disclosure of a subset of the preferences in each vote, namely those that are actually used in the count. This scheme is easy to implement, permits verification of the tally, and combats signature attacks to a large degree.

Keywords: signature attack, STV, voter coercion, verification

1 Introduction

It has been noted that full disclosure of votes in STV elections with a reasonably large number of candidates provides a means for coercing voters. With proposed methods of limited disclosure it may be impossible to independently verify from the disclosed information that the votes have been counted correctly and/or verification may be impractically complex. Here we propose a new method of limited disclosure that combats coercion but allows independent verification of the tally and does not add significant complexity to the counting process. We first discuss the coercion method and two proposed solutions. We then present our method and discuss the difficulty of coercion if it is used.

2 The Italian attack

Otten [4] has noted the potential for coercion of voters in STV elections with a reasonably large number of candidates. This method of coercion is known as "the Italian attack" after its apparent use by the Mafia in Italy in the 1970s and 1980s. To elect members of the Italian parliament, voters would choose a party and had the option of expressing numeric preferences for several candidates within the list for that party, and lists of 40 or more candidates were not uncommon [4].

More technically, this form of coerced voting is known as a signature attack. A coercer tells each coerced voter precisely how to vote. Typically, a first preference for the coercer's preferred candidate is followed by some permutation of the other candidates that is very unlikely to be chosen by any other voter. This is the "signature" that, with high probability, uniquely identifies the voter. Each coerced voter is told a different permutation. The number of permutations of N candidates is N factorial, so with a reasonably large number of candidates it is easy enough to find many permutations that can identify coerced voters with a high degree of confidence. If votes are disclosed after the election, the coercer can reward or punish each coerced voter depending on whether or not a vote with their particular signature was cast.

It is possible to guard against this kind of attack by disclosing less information. However, it is desirable to disclose enough information to permit verification that the result of the tally is correct. For example, the Electoral Commission of the Australian Federal State of Victoria currently has a project underway for a computerised voting system, motivated by privacy concerns for visually impaired voters [2]. The use of computers makes the process less transparent, but by using cryptographic methods it is possible to create a completely verifiable system. Ideally, the result would be verifiable while coercion would not be facilitated. Although we do not discuss cryptography in detail here, the method proposed is designed with complete verifiability in mind.

3 Otten's proposal

Otten [4] suggests not disclosing some later preferences in order to prevent unique identification of a ballot after disclosure. He suggests that later preferences be removed until there are at least three copies of each reported permutation. For example, "if there is 1 vote of BCDEFGA, 1 of BCDEFAG and 1 of BCDEGAF then the fact that there were 3 votes of BCDExxx would be published". Unfortunately, this proposal does not guarantee that the tally can be verified, as it is possible that the result depends on the later preferences of some of these ballots. Also, it is not clear that there will be a sufficiently large "crowd" to hide in. Choosing a larger number improves anonymity but decreases the chance of being able to verify the tally.

4 The Shuffle-sum proposal

Benaloh et al. [1] describe a scheme where votes are encrypted in such a way that each stage of the tally can be verified. For example, the fact that there were 100 first preferences for candidate A, say, would be revealed, but the other preferences of those ballots would not be revealed. When ballots were transferred, for example, when a candidate was excluded, they would be shuffled and re-encrypted. For example, if B and then A were excluded, the shuffling and re-encryption would make it impossible to distinguish between ballots of the form BAxxx and Axxxx. While this avoids signature attacks to the greatest possible extent, it is costly. With several dozen candidates, an encrypted ballot can take a megabyte or more of space. Verifying a tally requires the (re)encrypted version of each ballot at each stage of the count. Complex algorithms must be run on potentially many gigabytes of data. These practical considerations make it infeasible for the Victorian Electoral Commission to use the shuffle-sum proposal, despite some concern over signature attacks [2]

5 Properties of STV counting algorithms

Before moving on to our proposal, we discuss some key properties of STV counting algorithms that our proposal relies on. These properties hold for "traditional" STV counting rules that do not prescribe restarting after an exclusion. For rules that do prescribe a restarting after an exclusion, such as Meek and Warren, not all the properties hold. Our methods can be adapted to such rules, but more information will be disclosed, and hence signature attacks will be not as certainly prevented. Here we concentrate on traditional counting rules. There are four key properties of interest to us:

1) The counting procedure is sequential, punctuated by points where candidates are declared elected or excluded. No candidate is declared elected or excluded more than once, so the sequence of candidates declared elected or excluded defines a permutation of a subset of the candidates. It may be a strict subset of the candidates because some candidates may be excluded by default when the tally ends with the last candidate declared elected. We will call this permutation of a subset of the candidates, specified by the order in which candidates are either elected or excluded, the *tally sequence*. For example, with two vacancies, if B is excluded, D is elected, A excluded then E elected, the tally sequence would be BDAE.

2) After a candidate is declared elected or excluded, all preferences for that candidate on ballots are ignored in the counting process.

3) For each ballot paper, preferences are examined in order. It is possible that not all preferences, particularly later preferences, will be examined, and some earlier ones may be examined but ignored, due to 2). We will call the sequence of preferences examined and not ignored a ballot sequence. With the example tally in 1) above, the ballot ABCDE would have the ballot sequence AC. The first preference, A, is used and later when A has been excluded, B is ignored (since B has also been excluded at that point) and C is used. In a manual count, the ballot sequence is the path the ballot paper takes as it moves from candidate to candidate in the count. The ballot

DABCE could have the ballot sequence DAC (if the ballot was transferred as part of the surplus of D) or D (if D obtained exactly one quota of votes or if D had a surplus but the rules specified that only BDxxx ballots should be transferred, for example).

4) Each ballot sequence is a (not necessarily contiguous) subsequence of the tally sequence, possibly followed by a single candidate who is not in the tally sequence. If B appears before A in the tally sequence, for example, A cannot appear before B in any ballot sequence (if the ballot ever leaves candidate A, any preference for B will be ignored, since B will already have been declared elected or excluded). The last candidate on a ballot sequence may be a continuing candidate at the point the last candidate is declared elected, so they are not on the tally sequence. Other candidates in the ballot sequence must be in the tally sequence since the only trigger for moving a ballot to another (later) preference is when the candidate to whom the ballot is currently assigned is declared elected or excluded.

6 Our proposal

Our proposal is to disclose just the ballot sequence for each ballot.

The ballot sequences can be determined by very simple modifications to the counting method. We simply need a flag for each preference on each ballot. When the preference is used, it is flagged, and at the end of the count the ballot sequences can be output along with the successful candidates and tally sequence and/or detailed tally. For Meek and other more complex rules, the same method can be used; typically more preferences will be flagged and so ballot sequences will be longer.

Verification of the tally is straightforward—we can simply redo the count with the ballot sequences rather than the original ballots. This will result in an identical tally since the only difference in the two sets of ballots is that preferences which were never used have been removed.

7 Resilience against signature attacks

We now discuss how well our proposal guards against the standard form of the Italian attack and an alternative signature attack. However, we first make an observation about the maximum information content in ballot sequences.

Suppose we have N candidates and K are continuing candidates at the end of the tally. If complete ballots are disclosed, there are $N!$ possibilities for each one. If only ballot sequences are disclosed there are $(K + 1)2^{N-K}$ possibilities for each one. This is due to 4) above: The $K + 1$ factor comes from the choice of continuing candidates at the end of the ballot sequence (the +1 for the case where there is no continuing candidate at the end). The tally sequence has length $N - K$, and each candidate in the sequence may or may not be in the ballot sequence.

8 The standard Italian attack

Although $(K + 1)2^{N-K}$ is much less than $N!$, it is still likely to be large enough for sufficient unique “signatures” to be found. However, the possible ballot sequences depend on the tally sequence, which is only known after the tally has been computed. A coercer would have to be able to accurately predict the tally sequence in order to use this number of ballot sequences for an attack, and for each candidate whose stage of election/exclusion cannot be reliably predicted, the number of ballot sequences that can be used is halved.

Furthermore, the standard form of the Italian attack relies on the “signature” appearing in preferences after the choice of the coercer. Suppose the coercer wants candidate C elected. In the standard Italian attack, coerced voters would be told to mark C as their first preference. The signature could not contain any candidate declared elected or excluded before C, since those preferences would not appear in the ballot sequence. Furthermore, if C is the last candidate declared elected, no signature is revealed at all, and if C is the last candidate excluded, not enough information is revealed to identify significant numbers of voters.

In most situations, attempting to coerce voters is risky, and the greater the number of voters coerced, the greater the risk—there are severe consequences if you are caught. It is only worthwhile if the risk is outweighed by the increased chance of C being elected. In general, coercing significantly more voters than necessary is not a good strategy. For example, if C is already a popular candidate, likely to be elected, coercion is unwise. The situations favouring coercion as a strategy are precisely those where C is the last candidate declared elected (or excluded if the strategy doesn't quite work). These are exactly the situations where revealing only ballot sequences reveals minimal signature information. We thus conclude that our proposal should be very effective at guarding against the standard form of Italian attack.

9 Using early preferences as a signature

Ballot sequences for votes that elect candidate C can contain information encoded in the sequence of candidates elected or excluded before C. A coercer who had some knowledge of this sequence could thus use a form of signature attack. If the coercer had enough loyal supporters who would vote as instructed (without any coercion and the need for signatures on ballots), these supporters could influence the order of exclusion of several "dummy" candidates who stand at the behest of the coercer. These dummy candidates could be used for signatures in votes which eventually deliver a preference to candidate C. We now briefly analyse such an attack. We assume the best case scenario for the coercer, where only their loyal supporters and coerced voters vote for the dummy candidates.

With N dummy candidates, $D_1, \ldots, D_N$, up to $2^N - 1$ signatures can be encoded. Assuming they are excluded in that order, 2^{N-1} of the coerced votes will have D_1 as the first preference, 2^{N-2} will have D_2 as the first preference, and so on. To ensure D_1 is excluded first, there must therefore be at least $2^{N-1} - 2^{N-2}$ loyal supporters with a first preference for D_2, $2^{N-1} - 2^{N-3}$ loyal supporters with a first preference for D_3, and so on. Thus, approximately $(N - 2)2^{N-1}$ votes from loyal supporters are required to ensure D_1 is excluded first.

Furthermore, when D_1 is excluded, half the preferences from coerced votes will go to D_2, a quarter to D_3 and so on. Thus the totals for the coerced votes at this stage of the count will be 2^{N-1} for D_2, 2^{N-2} for D_3, and so on. Similarly, after D_2 is excluded, D_3 will have 2^{N-1} coerced votes and D_4 will have 2^{N-2} coerced votes. The votes from loyal supporters must be sufficient to ensure the correct exclusion at each stage. It would be sufficient to have $2^{N-2} + 1$ first preferences for D_2, $2(2^{N-2} + 1)$ first preferences for D_3, $3(2^{N-2} + 1)$ first preferences for D_4, and so on, a total of about $2^{N-3}N^2$ votes from loyal supporters. Somewhat fewer than this number is sufficient in theory, since the first preference votes for D_2 can be re-used after D_2 is excluded, to help top up the totals of D_4 etc. (so that D_3 is excluded next). However, additional votes are advisable to combat the possibility that some voters who are neither loyal nor coerced may cast votes for the dummy candidates. In addition, the number of coerced voters must be somewhat less than 2^N to account for the permutations of preferences used by the loyal supporters.

Although we have not established the precise optimal relationship between the number of dummy candidates, the number of loyal supporters and the number of coerced votes, it seems this strategy may be plausible for very small elections, but is unlikely to be successful for larger elections that have careful oversight from electoral authorities. For example, to obtain an extra 1,000 votes through coercion, about 12,000 loyal supporters must be instructed to vote in the right ways and 10 dummy candidates must stand.

10 Conclusions

To verify the correctness of a tally in STV elections, some voting information must be disclosed. If all information is disclosed, signature attacks such as the Italian attack can be used to enable coercion of voters. Previous work proposed a cryptographic method that minimises the information disclosed and allows verification in theory but makes it difficult in practice due to the size of the data produced and the complexity of the algorithms used. This paper proposes an alternative scheme for less than full disclosure. It entails disclosure of more information than the cryptographic method but is much simpler to implement and makes verification much easier. It combats the standard Italian attack effectively. There are other possible attacks that involve standing dummy candidates and using the votes of loyal supporters to attempt to ensure that these candidates are excluded in a particular order. However, particularly for larger scale elections, our proposal seems to provide a reasonable compromise between the ease of verifying the correctness of the tally and the risk of signature attacks being used to coerce voters.

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About the Author

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Software Review: OpenSTV and OpaVote

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Abstract

OpenSTV is a software application that implements several STV rules, as well as a number of other single winner and multi-winner voting rules. OpaVote is an online tally service with similar capabilities.

1 OpenSTV overview and pricing

OpenSTV[1] is a software application that can be used to compute the results of elections, using a variety of voting rules. These rules include a very large number of STV variants, as well as plurality, Borda, a few Condorcet methods, and some others. OpaVote is an online counterpart to OpenSTV, which provides the same menu of voting rules. Both OpenSTV and OpaVote were created by Jeffrey O'Neill,[2] who holds a Ph.D. in engineering from the University of Michigan and a J.D. from Cornell Law School.

OpenSTV was first released in 2003 and has been updated several times since, in a careful process of development and improvement. From the web site http://www.openstv.org, one can download OpenSTV as a self-installing program for either Windows or Mac; the installation program is quick and straightforward.

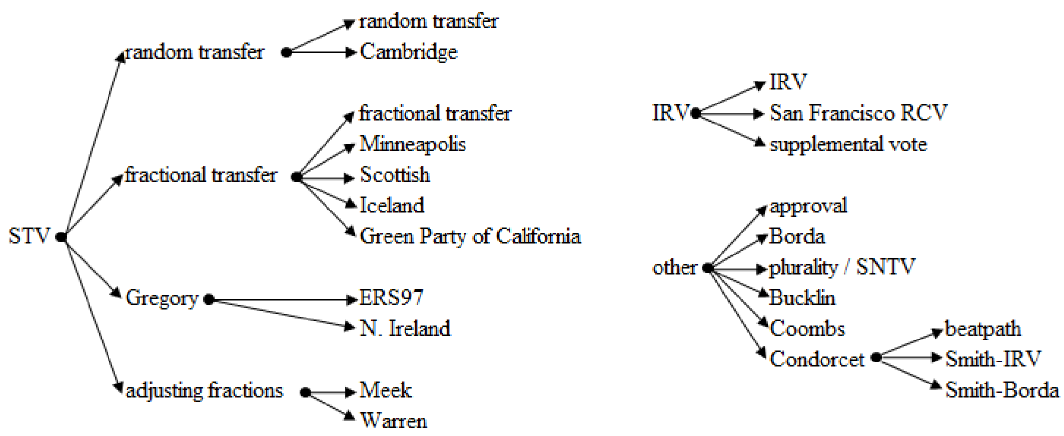
The primary command in OpenSTV is 'Run Election'. After selecting this command one is prompted to choose a file containing ballot information and a voting rule. Next, one encounters a submenu screen that permits customization of the voting rule, for example by deciding the number of seats to be filled, the type of quota (Droop or Hare), etc. (The options in this second menu depend on your primary voting rule, and often allow a very high degree of customization.) Once these choices have been made, the program calculates the result, produces a text-based printout that names the winner(s), and provides relevant details about the counting process. For example, in the case of STV rules this includes vote totals as of each round, reports on when candidates are elected or eliminated, etc.

The program allows one to create and edit ballot files, which have .blt file extensions and can also be read with simple text-editing programs. For example, for an election in which paper ballots have been cast, one can enter the information from these ballots one at a time using the menu that follows from the 'New Ballot File' command, save the file, and then apply the desired voting rule using the 'Run Election' command. The ballot file creation/editing process permits ballots with either complete or incomplete rankings of the candidates, and review or alteration of the ballots that have already been entered.

OpenSTV was an open source program from 2003 to 2010 (hence the name), but Dr. O'Neill decided thereafter to change to closed source distribution, in part because of free-riding and a lack of outside contribution to development of the software. Currently, OpenSTV licenses are available on a yearly basis according to a three-tiered pricing structure: Individuals and small non-profits (with 0-3 employees) may buy a license for the minimum price of $5, medium-sized non-profits (with 4-30 employees) are asked to pay the intermediate price of $40, and other users (including large non-profits, businesses, and governments) are asked to pay $400.

[1] The version of OpenSTV examined is 2.1.0.
[2] Jonathan Lundell and Dan Keshet assisted Dr. O'Neill with the development of the software.

Figure 1: Taxonomy of voting rules implemented in OpenSTV



2 OpaVote overview and pricing

To use OpaVote, one goes to www.opavote.org, logs in with a Google account, and then chooses the 'My Elections' tab, where one can create a new election or poll. The difference between these is that voting in an election is by invitation only; when creating the election, one supplies a list of email addresses, and each person on this list receives a link that allows them to vote once. On the other hand, a poll allows anyone to vote; it is possible to restrict people to one vote each (e.g. by using tracking cookies) or simply let them vote as many times as they wish.

Use of OpaVote on a small scale, i.e. with 400 or fewer voters, and 20 or fewer candidates is free; this seems like a good option for people who are interested in familiarizing themselves with the software before making a commitment. Some of OpenSTV's options for voting rule customization are not available in OpaVote, but the number of choices is still quite large, and thus sufficient for most casual purposes.

An OpaVote election or poll costs five cents for each additional voter beyond 400, and one dollar for each additional candidate beyond 20. Also, if an election or poll remains online for more than two weeks, this costs five dollars per additional two weeks.

3 Voting rules implemented

OpenSTV has an initial menu of twelve rules: approval, Borda, Cambridge STV, Condorcet, ERS97 STV, instant runoff voting, Meek STV, Minneapolis STV, N. Ireland STV, plurality/FPTP/SNTV, San Francisco RCV, and Scottish STV. However, ticking the 'Show All Methods' box in the options menu yields eight more choices: Bucklin, Coombs, fractional transfer STV, Green Party of California STV, Iceland STV, random transfer STV, supplementary vote, and Warren STV. So, there are twenty rules to choose from altogether.

Figure 1 arranges OpenSTV's voting rules by category. The program implements eleven different STV rules, which can be divided into four sub-categories: random transfer, fractional transfer, Gregory, and adjusting fractions.

When a candidate reaches the quota, the random transfer STV rules (Cambridge, and a generic, customizable random transfer rule) transfer the surplus in the form of whole ballots, while leaving the remainder with the original candidate. Which votes are transferred and which votes remain depends on the order in which the votes are entered into the system; therefore, to make the process truly random, the ballots should be shuffled before being input.

Instead of transferring some votes at full value when a candidate has a surplus, the fractional transfer STV rules (Minneapolis, Scottish, Iceland, Green Party of California, and a generic, customizable fractional transfer rule) transfer all votes at a fractional value. The Gregory STV rules (ERS97 and N. Ireland) operate in much the same manner, except that when one candidate's elimination or surplus transfer brings another candidate above the quota, only these last-received votes are transferred again (which is convenient for hand-counting purposes).

In the adjusting fractions STV methods, Meek and Warren, the fractional part of votes that elected candidates retain is updated throughout the count. Under one of the other STV rules, a tactical voter might indicate a hopeless candidate for his first choice, so that once this candidate is eliminated, his vote will be transferred with its full weight to his favourite candidate who has not yet been elected, as opposed to being reduced in value during the process of being transferred from his sincere favourite candidate(s). Meek and Warren thwart this tactic by bringing this vote to the elected sincere favourite after the hopeless candidate has been eliminated, and recalculating the share of votes that the elected candidate must retain, thus decreasing the weight of the tactical ballot and increasing the weight of the ballots already transferred from that candidate, so that they have the same value. These rules are difficult to implement with a hand count, so their inclusion in OpenSTV should be counted as a major virtue.

In its single-winner case, STV is known as instant runoff voting (IRV), the alternative vote, ranked choice voting, etc. The primary difference between the IRV and STV rules as implemented here is that the former do not allow for the transfer of surplus votes. (That is, OpenSTV does allow one to use IRV to elect more than one seat; this works as a series of elimination-and-transfer rounds that continue until the number of remaining candidates is equal to the number of seats.) OpenSTV gives the user a choice of a generic customizable IRV rule, the San Francisco RCV rule, and the supplemental vote rule, which uses only the first two rankings on the ballot and allows for only two rounds of counting.

In addition to these several STV and IRV rules, OpenSTV gives six additional choices: approval, Borda, plurality, Bucklin, Coombs, and Condorcet. Of these, all except Bucklin and Condorcet can be used for multi-winner elections.

Approval counts all rankings as 'approvals'; to indicate 'disapproval' of a candidate, a voter should leave that candidate unranked. Each approval earns a candidate one point. Given C candidates, Borda gives a candidate C points for each ballot on which it is ranked first, 0 points for each ballot on which it is ranked last or not ranked at all, and $C - n + 1$ points for each ballot on which it is ranked as the voter's nth choice. Plurality, also known as 'first past the post' (FPTP), or 'single non-transferable vote' (SNTV) when used for multi-winner elections, gives a candidate one point for each ballot on which the candidate is ranked first. For approval, Borda, or plurality, with S seats to be filled, the winners are the S candidates with the most points.

Coombs works like IRV, except that it eliminates the candidate with the most last-choice votes instead of the fewest first-choice votes (with unranked candidates being treated as tied for last place). As with the IRV implementation here, Coombs continues with its eliminations until the number of remaining candidates matches the number of seats. Bucklin first checks to see whether a majority of voters rank any candidate in first place, then checks whether a majority of voters rank any candidate in first or second place, and so on, until such a candidate is found.

Finally, the 'Condorcet Voting' option provides the choice of three interesting Condorcet-efficient rules, all of which choose a candidate from the Smith set (also known as the minimal dominant set, i.e. the smallest set of candidates such that every candidate inside the set is ranked above every candidate outside the set by a majority of voters). The first of these is referred to as 'Schwartz sequential dropping', and is also known as 'beatpath' or 'Schulze'. (See Markus Schulze's article in issue 17 of *Voting matters*.) Since the OpenSTV version of this rule calculates and explains the results using a beatpath matrix, the second of these names seems most descriptive to me. The second Condorcet-efficient rule that one may choose eliminates candidates not in the Smith set, and then performs an IRV tally on the remaining candidates. (My article in issue 29 of *Voting matters* examines this along with three other very similar methods, and concludes that they share attractive qualities, such as an unusually high resistance to both strategic voting and strategic nomination.) The third Condorcet-efficient rule eliminates candidates not in the Smith set, and then performs a Borda tally on the remaining candidates. (This is similar to the 'Black' rule, except that it eliminates candidates outside the Smith set before performing its Borda tally in the case of a majority rule cycle.)

4 Other features and remarks

4.1 Graphing election results

While OpenSTV presents election results in a primarily text-based form, OpaVote includes colour-coded bar charts showing the vote totals for each candidate as of each round of counting. The latter presentation can also be generated by OpenSTV using the following steps: First, run an election, proceeding through to the text-based display of the results. Second, from the file menu, choose to 'Save Results as HTML…', indicate a file name, and hit 'Save'. Third, add an extension of '.html' or '.htm' to the name of the resulting file. Now, it should open in a web browser and display the results as OpaVote does.

4.2 Generating illustrative examples

In order to better understand the properties of different voting rules, it's often helpful to devise ballot profiles that illustrate how their results diverge in particular cases. Usually these examples are described in a manner such as '6 voters prefer D, then A, then B, then C; 5 voters prefer B, then C, then A, then D; 4 voters prefer C, then A, then B, then D.' Happily, it is very easy to create examples like this in such a way that they can be tallied by OpenSTV. For example, the situation above can be captured by simply creating a text (.txt) file with nothing but the following content:

```
6: D A B C
5: B C A D
4: C A B D
```

OpenSTV will recognize this as a valid ballot file, and count an election using this set of votes.

4.3 Ballot files from public elections

At present, the OpenSTV web site houses ballot files for about fifty public elections that have used ranked ballots and taken place over the last several years, e.g. in San Francisco, Scotland, Minneapolis, etc. These can be found via the Ranked-Choice Voting' tab, saved, and then run with OpenSTV.

Organizations using OpenSTV and OpaVote: At http://www.openstv.org/openstv-users, there is a long list of forty or so organizations that have used OpenSTV or OpaVote, including several non-profits, universities/student unions, etc.

5 Conclusion

Dr. O'Neill has an impressive, scholarly knowledge of the different STV variants, and he has clearly taken great care in applying this knowledge to the creation of a program that is accessible and user-friendly. The result is a valuable contribution for those who are interested in studying ranked ballot voting rules, and implementing them in practice.

A Short Response to a 'Review', with a Comment on Arrow's Impossibility Theorem

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Abstract

Voting matters published a so-called 'review' of *Voting Theory for Democracy* that is unscientific. The place where a more complete response can be found is specified. The 'review' misrepresents a new ranking-based procedure (the Borda Fixed Point procedure) and neglects the important new result that Arrow's Impossibility Theorem is either incomplete or inconsistent.

Keywords: voting theory, democracy, Borda Fixed Point, Arrow's theorem

1 Statement

Voting matters is a journal whose focus is the mechanics of voting procedures in which voters rank candidates. My book *Voting Theory for Democracy* (VTFD) (Colignatus 2011a) deals with many procedures that employ such rankings and also introduces the *Borda Fixed Point* procedure. Given the purposes of *Voting matters* it was fitting that Professor Nicolaus Tideman, the editor, accepted the idea of a review, but it is unfortunate that Schulze (2011) is not a true review because it is unscientific (see Colignatus, 2011b).

In my experience voting theorists tend to understand 99% of the standard issues in voting and not understand 1%, but for each theorist it is a different 1%, so that the literature abounds with confusion. I found it necessary to reconstruct voting theory from the bottom up and then introduce the corrections along the way. VTFD thus sets the record straight and it is the only book in the world that properly explains voting theory as of the year 2011. Routines in *Mathematica* help the new student avoid the tough mathematics and vague language that block understanding in common expositions of voting theory.

Unfortunately, again, Schulze and Tideman go off course with respect to the 1% that they do not understand. They may have been tired by the repetition of the 99% that they do understand, then failed to study sufficiently the 1%, and then dismissed VTFD as inadequate.

The only way to proceed is the scientific process. It happens that the world still has grossly non-democratic ways even in countries like the USA, UK and France (see Stavrou, 2011). Unscientific behaviour in the academic world is an important explanatory factor for this dismal situation. One might hope that more people will study the relevant arguments.

VTFD p. 3 clearly states its purpose: 'This book has two agendas: First to develop voting theory from the bottom up, referring to cheating and sensitivity to the budget. Secondly, to solve the confusions generated by Arrow's theorem.' And p. 22: 'This book allows for both beginner and advanced readers. Section 1.2 starts for beginning readers. Advanced readers would tend to start with section 1.3. If you have done the beginner chapters and have become interested in voting theory, then you should study some of the serious textbooks in the field (advised are Mueller (1989) and Sen (1970)). After that, you would benefit from section 1.3 as well.… Once you have mastered these issues, you will find the more complex Chapters 9 and 10 of the book that may require more work and some additional study using the library. This part of the book would be directly interesting for advanced students. But even if you are an advanced student, then you are still advised to work your way up, since some points are rather subtle and easily overlooked, particularly in relation to the new programs that are presented here.'

Schulze misrepresents my new *Borda Fixed Point* procedure and desultorily calls it my 'pet theory' which seems to suggest that nobody can develop a new procedure. My novel result from treating Arrow's Theorem within deontic logic (the logic of morals), that shows that Arrow's framework is either incomplete or inconsistent, receives another desultory designation of 'mumbo-jumbo'. The 'review' makes lightning mistakes but to correct them takes tedious pages. Unfortunately Professor Tideman did not accept my full response for *Voting matters*, on the ground that such a discussion was not within its objectives. Hence I refer the reader to Colignatus (2011b) for that full response. It is somewhat curious that an unscientific article is published in a journal but the correction is not.

The editor wanted more reassurance with respect to this 'mumbo-jumbo' regarding Arrow's Impossibility Theorem, not from Schulze but from me. My report on this can be found in Colignatus (2011c). In my evaluation of Professor Tideman's approach to Arrow's Theorem I have found that he is inconsistent. This will not be printed in *Voting matters* either since the editor holds that the journal is not about Arrow's Theorem.

In an email of 25/11 Professor Tideman writes: 'I have read sections 9.1 and 9.2. I can see that there is a significant overlap between your view of Arrow and mine, but there are also vast differences.' Instead of 'mumbo-jumbo' he finds: 'I think that anyone with a background in logic or mathematics is unlikely to find your writing to be helpful to their understanding of Arrow, because of your use of idiosyncratic definitions and numerous acronyms. So it seems to me unlikely that your discussion of Arrow will have the productive impact that you hope for.'

I am sorry. These are not idiosyncrasies. Rather, they form a carefully designed didactic approach and new foundation for voting theory. The book also shows that Arrow is either incomplete or inconsistent. I have met two mathematicians who found sections 9.1 and 9.2 enlightening. I hold that the name of the axiom of 'independence of irrelevant alternatives' (AIIA) is highly misleading and that the proper name is 'pairwise decision making' (APDM). Forgive me those acronyms and look at the content, I would say. Allow me to refer also to Gamboa (2011) who reviewed another book of mine and who also had this kind of struggle but fortunately had the openness of mind to see what I intend to do when re-engineering a subject. Another review of said book plus another one is by Richard Gill (2012) and also he shows an open mind for my re-engineering of a subject. Voting theory needs re-engineering too plus an openness of mind for what that generates.

I thank Tideman and Schulze for their time on this, and in particular Professor Tideman for the greater openness of mind than I have met with from others.

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About the Author

Thomas Colignatus is the scientific name of Thomas Cool, econometrician and teacher of mathematics in Scheveningen, The Netherlands.

Short Reply to "A Short Response to a 'Review', with a Comment on Arrow's Impossibility Theorem" by Thomas Colignatus

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In his Short Response to my Review, Thomas Colignatus claims that I misrepresented his Borda Fixed Point (BFP) method. However in another response (Colignatus, 2011), he acknowledged that I interpreted his BFP method correctly in my Review and that I have shown that his BFP method violates the majority criterion. It would have been advantageous if Colignatus had acknowledged this in his Short Response.

Reference

[1] Thomas Colignatus (2011), "Erratum on Voting Theory for Democracy",11 November 2011, http://thomascool.eu/Papers/VTFD/2011-11-11-Erratum-VTFD.pdf