Seeking hidden idiom relationship within musical masses of G. P. da Palestrina.

Analysis of Palestrina's work corpus using quantitative methods and Python descriptive and visual statistics

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Abstract

This manuscript aims at giving insight into the theoretical claims about the style of liturgical music by G. P. da Palestrina. By deriving additional data from the scores and assemblying them into a database, we can draw conclusions from the whole corpus of works at once. We try to support the claim, that Palestrina's counterpuntal style is uniform and consistent among the whole corpus of his work. We use Python's PANDAS and PINGOUINS libraries in order to generate graphs, analyze the data.

1 Introduction

Since the XVII century, the entire corpus of sacred musical compositions by Giovanni Pierluigi da Palestrina (* 1525 †1594) has been regarded as the pinnacle of a so-called *stille antico*– a style of polyphonic vocal music appropriate for the liturgical usage in the Roman Catholic Church. Palestrina's style has been imitated and taught by various theoreticians through XVIII (Johannes Fux), and XIX-XX centuries, and to this day his opus is a basis of classical counterpoint curriculum, constituting the basic material for composition and music theory students' practical exercises [2].

The style of Palestrina has been recodified by Knud Jeppesen (1892 — 1974) in his *The Style Of Palestrina and the Dissonance* (1946). Jeppesen was able to confirm, ground, and reject many misconceptions about the style of the Italian master by enlisting all the places in Palestrina's corpus of work to which those ideas concerned.

Jeppesen embraced this gargantuan study much before any digital data science was considered a way to go in musicology. To meet similar tasks using a modernized approach, at the beginning of 90's David Huron created the Humdrum toolkit and database standard for digital score encoding and analysis [5]. The `**kern` file format used in Humdrum is a `.tsv` file containing records representing notes, articulations, dynamics, and a whole plethora of interesting parameters related to the score as well as performance (e.g. timing of note attack on MIDI keyboard).

Having a digitalized Palestrina's corpus of works would have definitely aided not only research in the spirit of Jeppesen but also may help to reveal additional information about the idiomatic, aesthetic, or even hermeneutical aspect of Palestrina's counterpoint – and not only technical and related to voice-leading. Such a database consisting of `**kern` files was prepared within the *Elvis* project [7] (being itself a part of SIMSSA: the *Single Interface for Music Score Searching and Analysis* project [4]). An example of such a study was made by Claire Arthur in his paper *Vicentino versus Palestrina: A computational investigation of voice leading across changing vocal densities* [1], where he dealt with one of the most notorious problems of musicology and music theory: how does a theory of counterpoint at Palestrina's time relate to the musical practice and composition.

We would like to contribute to this paradigm of empirical musicology [3]. Using data derived from an encoded database (rather than being a result of a private inquiry) may reveal surprising correlations or — at least — confirm or reject some popular ideas about Palestinian counterpoint spread widely among pedagogical practices.

2 Research Questions

For the purposes of this assignment, we decided to limit our research question to the investigation of the numerical variables present in our database.

What are the correlations between the total part duration, note density and note-per-syllable ratio within the database of Palestrina masses? The length of a piece (its "duration") might have some consequences for the distribution of other mentioned parameters.

Palestrina's style of sacred music is very often described as uniform: despite the *ethos* of the text or the length of the lyrics, the music itself does not focus on reflecting those kinds of properties, following *decorum* of evenly-balanced polyphony across the voices as strictly as possible. Can descriptive statistics offer any support for this claim?

3 Methodology

We aimed at using computational and quantitative methods first to derive and then to analyze the corpus of musical masses by G. P. da Palestrina encoded in `**kern` notation in the spirit of empirical and computer-aided musicology.

```
!!!COM: Palestrina, Giovanni Perluigi da
!!!OPR: Viri Galilaei
!!!OTL: Gloria
**kern   **kern   **kern   **kern   **kern   **kern
*ICvox   *ICvox   *ICvox   *ICvox   *ICvox   *ICvox
*Ibass   *Itenor *Itenor *Icalto *Icalto *Icant
!Bassus !Tenor 2  !Tenor 1  !Altus 2  !Altus 1  !Cantus
*clefF4 *clefGv2  *clefGv2  *clefG2 *clefG2 *clefG2
*k[b-]   *k[b-]   *k[b-]   *k[b-]   *k[b-]   *k[b-]
*G:dor   *G:dor   *G:dor   *G:dor   *G:dor   *G:dor
*M4/2 *M4/2 *M4/2 *M4/2 *M4/2 *M4/2
=1   =1   =1   =1   =1   =1
0r   0r   0r   1.d  1r   0r
. . . . [1a .
. . . 2d   . .
=2   =2   =2   =2   =2   =2
0r   1.d  0r   0f   2a]  1.dd
. . . . 2a   .
. . . . 1a   .
. 2d   . . . 2dd
=3   =3   =3   =3   =3   =3
0r   1B-  0r   1d   1g   1dd
. 1A   . 1e   [1a 1cc
=4   =4   =4   =4   =4   =4
0r   2d   0r   2f   2a]  1.dd
. 2G   . 1b-  2g   .
. 2B-  . . 2f   .
. 2F   . [2a 2f   2cc
=5   =5   =5   =5   =5   =5
0r   1G   0r   4a]  0d   2.b-
```

Figure 1: An example of `**kern` data records from Palestrina's *Gloria* from *Viri Galilæi* (listen at https://www.youtube.com/watch?v=wL3EjnaKKFM)

We obtained the library of Palestrina masses from the `corpus` collection of the Music21 Python module. Music21 is a module for computer-aided musicology. It does not only contain a set of useful analytical methods (like calculating ambitus, estimating key, creating histograms from musical scores etc): it also consists of a vast repository of music scores encoded in various file formats (including the mentioned `**kern`).

A script written by us in Python allowed us to create a `.csv` file populated by records derived from each `**kern` file. The data derives both from the already prepared `**kern` metadata (name of the mass, part of the ordinarium, tone, mode, meter) as well as Python analysis and computation (duration, note-per-syllable and note density). We use statistical tools to study the relationships between the aforementioned information.

The data analysis procedure as well involved the usage of Python programming language platform. In order to perform descriptive statistics and statistical analysis, we adhered to the Pandas and Pingouin modules. For creating graphs, histograms, and other forms of data visualization we used Matplotlib and Seaborn libraries.

For the hypothesis testing, we used Pearson‘s correlation test for normality.

3.1 Limitations

records	masses
683	95

Figure 2: First five records of our database, generated using Python script.

It is important to point several limitations and caveats of our approach, whose main source is the database itself. The Elvis database does not contain the whole corpus of Palestrina‘s work, because the digitalization of his work was not yet completed. Also, since the actual database we use is an adaptation of the mentioned Elvis database, it might contain errors and unpredicted values (the Python script responsible for its population has not been unit-tested).

The biggest issue is of musicological nature. The original work consists of choir partbooks written in late-XVI century mensural notation. As the encoded `**kern` files use the notions of barlines, meter, and rhythm aligning with modern sheet notation practices, it is likely that a lot of information regarding original notation has been lost during transcription (for example original mensuration and ligaturae). Thus, many metadata associated with each mass part and the records of note themselves consist of data, which may be regarded as "anachronistic" (like meter and absolute note rhythm values instead of mensuration sign and corresponding issues).

4 Statistical results

The original Palestrina Elvis database consisted of 683 items (parts of 95 masses — in a form of `.krn` files (standard Humdrum files of musical scores encoded into the `**kern` notation).

The generated database is stored in a `.csv` file, whose each record is generated from one `.krn` file of the Elvis database. Each column represents a different variable:

1. **name**: adapted name of the file consisting of the mass name and part name;

2. **part** of the Roman Catholic mass (*Ordinarium Missæ*): *Kyrie*, *Gloria*, *Credo*, *Sanctus*, *Benedictus* or *Agnus*;

name	mass	part	voices	tone	mode	meter	duration	notePerSyllable	noteDensity
Lauda Sion: Benedictus	Lauda Sion	Benedictus	4	G	mix	3/2	396.0	18.86	88.38
Veni Sancte Spiritus: Sanctus	Veni Sancte Spiritus	Sanctus	5	G	dor	3/2	768.0	22.59	86.91
In te Domine speravi (1599): Credo	In te Domine speravi (1599)	Credo	6	C	ion	4/2	2472.0	6.75	73.86
De Beata Marie Virginis (II): Sanctus	De Beata Marie Virginis (II)	Sanctus	5	G	mix	4/2	90.0	2.65	82.78
In festis Apostolorum (II): Sanctus	In festis Apostolorum (II)	Sanctus	5	D	dor	4/2	1294.0	38.06	81.18

Figure 3: First five records of our database, generated using Python script.

3. **voices**: number of independent choir voices.

4. **tone**: the main pitch (C, D, E, F, G, A);

5. **mode** of the part (dorian, phrygian, lydian, mixolydian, eolian);

6. **meter**: *anachronistic* approximation of the Renaissance MENSURA): 4/2 or 3/2;

7. **duration**: a relative measurement of time in quarter note (♩);

8. **note-per-syllable**: how many notes are there for one syllables of the text;

9. **note**/polyphony **density**: how much of all the voices consist of sounding music (notes) and not silence (rests).

voices	count	part	count	mode	count	tone	count	meter	count
5	255.0	Agnus	176.0	dor	195.0	G	297	4/2	622.0
4	233.0	Kyrie	124.0	mix	164.0	F	113	3/2	61.0
6	152.0	Sanctus	99.0	ion	150.0	D	69		
8	32.0	Benedictus	95.0	aeo	76.0	A	69		
3	6.0	Gloria	95.0	phr	63.0	E	63		
7	5.0	Credo	94.0	?	35.0	C	37		
						?	35		

Figure 4: Numbers of records within each category of metadata.

4.1 Descriptive statistics

Based on the summary statistics provided, we can see that:

- The duration of parts in the dataset ranges from 90 to 3056 crotchets, with a mean of 800.82 crotchets and a standard deviation of 550.89 crotchets.

- The note-per-syllable variable ranges from 2.62 to 85.5, with a mean of 14.58 and a standard deviation of 11.23.

- The note density variable ranges from 49% to 91%, with a mean of 81pp and a standard deviation of 5pp.

We provided additional boxplots for each of the mass part (7), which turned out to be very revealing. For example, the note density seems to be very uniform for each of the mass part – a feature often postulated for the music of Palestrina [6].

index	duration	notePerSyllable	noteDensity
count	683.00	683.00	683.00
mean	800.82	14.58	80.64
std	550.89	11.23	5.12
min	90.00	2.62	48.71
25%	410.00	6.32	78.31
50%	565.00	9.68	81.13
75%	1050.00	19.90	83.84
max	3056.00	85.50	90.69

Figure 5: Information generated using PANDAS `DataFrame.description()` method.

index	0
duration	1.369143
notePerSyllable	1.518972
noteDensity	-1.566813

Figure 6: Skewness of duration, note-per-syllable and note density.

4.2 Outliers

We used interquartile range method (IQR) to identify outliers. However, there are two issues with outlier identification. First, the data itself is very skewed (6). Second, outliers are most interesting part of the research. We then conclude to always include outliers in our considerations.

4.3 Visualisation statistics

By pairploting, we could observe the distribution and possible correlations between the note density and note-per-syllable or duration.

By looking at the **histograms** (7), we observe:

1. not a normal distribution

2. a negative correspondence between note-per-syllable and duration

3. higher note density in low and medium duration

4. higher note density on 5 - 40 note-per-syllable interval

By analyzing the **pairplots** (8), we notice that:

1. Note-per-density and duration has a linear correspondence for every part due to the dependence, part being the main factor deciding on graph's slope.

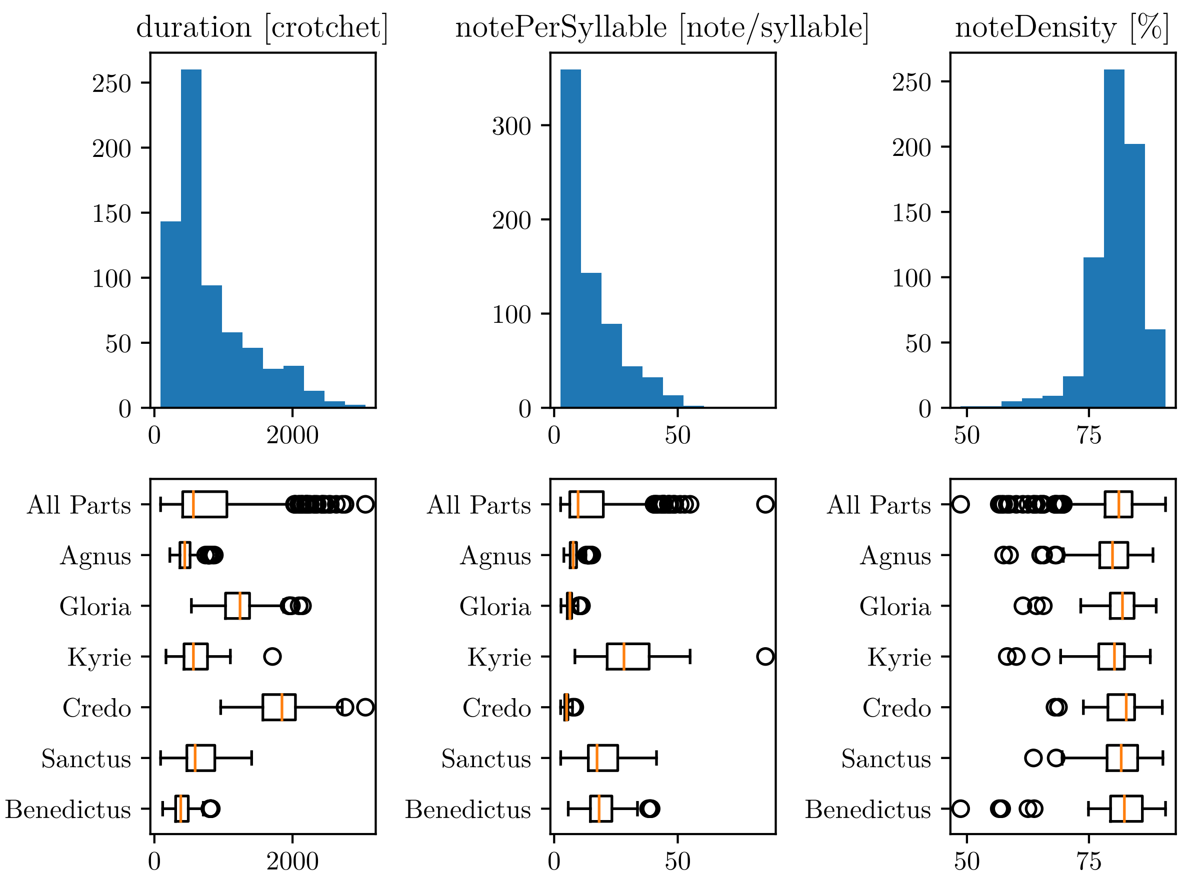

Figure 7: Histogram and box plots for each of the mass part.

2. Note density and duration cover a specific interval for Credo.

3. There is no influence according to mode on either duration per note-per-syllable, duration and note-desitiy or note-per-syllable and note-density.

4. Distributions of duration, note-per-syllable and note density do not seem to by specific for any mode.

5. The distribution of note-per-syllable is almost identical for tone D and A.

6. The distribution for duration is almost the same for tone D, A, and E

7. There is no influence according to tone on either duration per note-per-syllable, duration per and note-desitiy or note-per-syllable per note-density.

4.4 Normality

The normality assumption is violated for all variables. It may be due to the high skewness 6.

A higher value of W indicates that the values in one of the samples tend to be larger than the values in the other sample.

All p-values are very small, which suggests that there is a strong evidence to reject the null hypothesis of equal distributions in favor of the alternative hypothesis that the distributions are different.

4.5 Correlation, Pearson‘s coefficient

Having in mind the uniformity of polyphonic style in Palestrina’s artistic output, strong correlations between numerical variables are not to be expected. However, their positivity or negativity itself might be of a value when confronted with musicological intuitions. Thus, it is important if the calculated correlation lands within the confidence interval CI for the dataset.

4.5.1 Note-per-syllable and duration

Because note-per-syllable is calculated from duration, those two numerical variables are dependent. This result in a characteristic strokes on the graph (8), revealing a full positive correlation within each mass part.

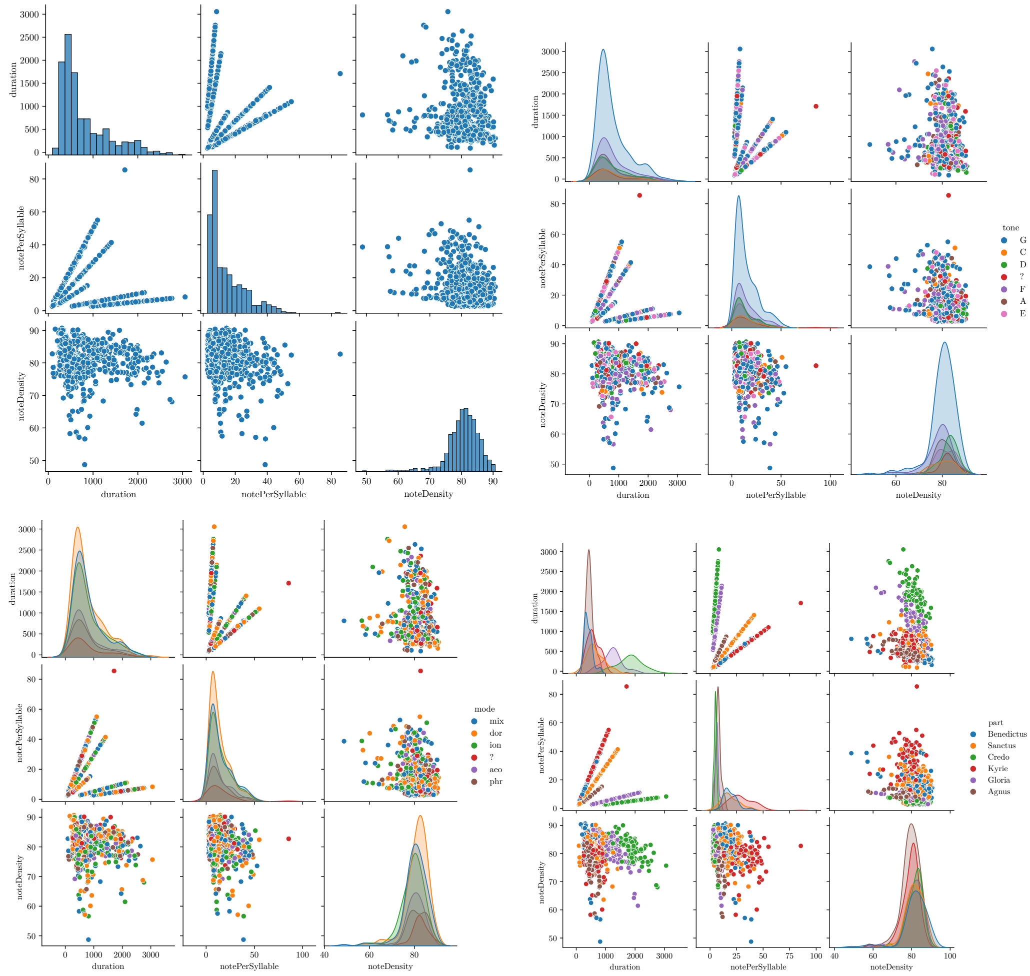

Figure 8: Pairplots of the database according to tone, mode and part.

index	W	pval	normal
duration	0.838365	9.484203e-26	False
notePerSyllable	0.837328	8.048434e-26	False
noteDensity	0.904243	2.857085e-20	False

Figure 9: Shapiro-Wilk tests on the numerical data.

However, looking globally on the whole databes, the result is surprising. For every parts altogether, the correlation is small (-0.157), which means that note-per-syllable factor is little influenced by the duration of the piece (adding an empirical evidence to the uniformity of polyphonic style across texts of various ethos and length). This result is statistically significant.

4.5.2 Duration and note density

Encoutering a negative correlation between duration of a part and its note density might reveal if the longer pieces tend to be less "dense" in the sense of all voices singing at all time. This effect is somewhat observed, but very weakly. With the result of r approaching 0 from the negative domain is statistically significant: not only Bayes factor indicates weak evidence in favour for the alternative hypothesis, but also — according to r^2 — the study has a moderate likelihood of detecting a true correlation (if it exists in the population) and such a correlation falls into the right interval (with a 95% level of confidence) (refer to 10).

4.5.3 Note-per-syllable and note density

The music of Palestrina is often said to focus on the clear prononciation of the liturgical text (according to standards of XVI-century Europe). Measuring the correlation between note-per-syllable and note density might bring some insight to this opinion. The longer and musically less ornamented texts should tend to have lower note density in order to allow various and non-overlapping voice configurations to pronounce the text clearly. This time as well the prediction is confirmed: the correlation is negative, small yet stronger (almost -0.2) and statistically well significant when compared the previous one.

index	n	r	CI95%	p-val	BF10	power
note perSyllable/density	683	-0.196240	[-0.27, -0.12]	2.346739e-07	2.958e+04	0.999377
notePerSyllable/duration	683	-0.157415	[-0.23, -0.08]	3.593314e-05	240.082	0.985451
duration/noteDensity	683	-0.098326	[-0.17, -0.02]	1.013464e-02	1.298	0.730412

Figure 10: Correlations for all numerical variables.

5 Musicological results and Synthesis

Creation of the dataset and its analysis revealed several interesting features about Palestrina's style.

Certain supports have been found for the alleged Palestrinian *uniformity* of the style and consistency in voice leading. The noteDensity factor (**??**) has similar mean values for all of the parts. Together with Lack of correlation between note-per-syllable ratio and duration of the piece *in toto* is one of the strongest evidence in this matter. Other correlations turned out to be too weak in order to provide definitive conclusions, however their polarity lined up with the predictions.

The biggest peculiarity of the database is its skewness. This results mostly from the fact, that we made the analysis of the whole database at once, instead of considering each part of the Catholic Mass alone. Such an approach from the one hand might result in missing important insights. From the other hand, it shows that nevertheless the note-per-syllable ratio tends to be rather small and is skewed to the lower values — an alignment with the common opinion about Palestrina's style that it is rather not the most ornamental one within the musical landscape of XVI-century.

All of the outliers detected when assembling the database represent cases, which are worthwhile to focus on when conducting more historical and hermeneutical research. What kind of opportunity let Palestrina to compose unusually long or short masses?

Most of the mass parts turned out to have G as their tonic. This is as well very symptomatic for the XVI-century polyphonic music. Taking into account notational aspects of that time (e. g. the case of the so-called *b quadratum et molle*, i. e. a specific chromatic interchange allowed for all the modes) it would be worthwile to investigate it even further on the level of music score itself — why was it the most popular choice?

6 Discussion and the future work

Critical Evaluation (200-400 words)

The issues related to this project may be categorized into ones related to database, statistics, programming, paper-writing.

In the field of musicology and music theory, statistics is rarely adressed due to the fact, that the "classical" music theory focuses mostly on the analyses of single works and comparisons between them and tends to avoid generalizations. This is definitely an opportunity for statistics, ceased by the notions of empirical musicology and digital humanities.

Already after writing the script creating the database, we discovered Music21 Python library, which might have covered most of the custom code written for our purposes. Regarding Pandas, we managed to provide a code staying within the operations done on DataFrame and NumPy arrays, supporting a good coding practice of not converting between those types and lists back and forth.

We took some important steps toward a better automatization and integration with document-formatting environmnents like LaTeX. Our Python script generates graphs in .pgf format. Those files are much more lightweight and take shorter time to generate. We still need to find a way to optimize file generation by Seaborn. The tables generated from DataFrame are already saved as a LaTeX tabulars, allowing for direct input. Unfortunately, this approach doesn't allow for the direct output of graphs (they have to be compiled in LaTeX first), which (un)surprisingly slows down the process of taking right conclusions from the data. From the other hand, due to the fact that the database itself is derived from the other database (which may cause bugs), this approach allows for the data automatically update already within the final document.

Regarding statistics, we are quite surprised how effectively they can be used to support (or reject) the sound musicological claims. At the same time, we have only scratched the surface. We aimed at implementing Prince's Correspondance Analysis, which we wanted to apply for the modes analysis, however it turned out to be problematic to use (and install. Already getting the contingency table was hard enough for us). We had to restrict ourselves to the basic Pearson's correlation. Also, we provided little tests and assumptions check.

6.1 Future Work

This project was for us the first big dive into Numpy, DataFrame and other tools related to do statistics in Python as well as utilizing the knowledge in practice. We have built the foundation for the future work.

Patterns applied in this document can be used with extended databases of scores of different composers of Palestrina time in order to do more comparative work.

PRINCE package should be embraced again in order to progress with the Correspondance Analysis.

All the issues related to packages tempt us to nevertheless try R.

List of Figures

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