Advanced Computational Methods in Economics and Finance

(A Pre-View of the Fall 2018 Class)

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1. Why Economics and Finance Are Important: High-Level Perspective

- The ultimate goal of science and engineering is to make the world a better place.
- Numerous innovations do make our lives better:
  - cell phones and emails make it easier to communicate,
  - commercial websites make buying easier.
- However, in many cases, innovations come with negative side effects: e.g.,
  - fracking makes energy cheaper but can lead to pollution,
  - self-driving cars will probably make travel safer, but they may increase unemployment.
- How to take into account everyone's interests?

2. High-Level Perspective (cont-d)

- Modern economics and finance techniques enable us to formulate such questions in precise numerical terms.
- After this, we need to design and apply computational techniques to solve these problems.
- In this class, we will learn the basic computational ideas and techniques used in solving these problems.
- Of course, we will only learn the basics.
- To really become a *quant*, it is necessary to learn many technical details and tricks.
- It is not possible to cover all this in one semester.
- However, what we will do is cover most basic ideas behind these tricks.

3. Why Economics and Finance Are Important: Pragmatic Perspective

- In the real world, every business needs to ne profitable.
- The need to take economic and financial aspects into account influences decisions about software:
  - when we release it,
  - how much we test it,
  - how much efforts we can afford to spend on optimizing it.
- It is not realistic to expect that every employee understand all the related economic and financial details.
- However, having a basic understanding definitely helps one to become a more productive employee.
- It also improves the chances of moving up the ladder, to leadership positions.

4. Pragmatic Perspective: What We Plan to Do In This Class

- Again, this class is not a substitute for real economics and business classes.
- Basic knowledge from this class will help better understand how companies function.

5. Important Aspects of Decision Making in Economics and Finance

- One of our main objectives is to come up with strategies for group decision making.
- We need strategies that take into account interest of al the people involved.
- In order to make these decisions, we need to have a good understanding of individual people's preferences.
- Once we learn people's preferences, we can help people make decisions which best reflect these preferences.
- It is also important to take into account that:
  - when people actually make decisions,
  - they often do not use complex optimization algorithms,
  - they use their intuition which often leads only to sub-optimal decisions.

6. Decision Making in Economics and Finance (cont-d)

- It is therefore important to learn:
  - not only how people *should* make decisions,
  - but also how they *actually* make decisions.
- Whatever decisions we make, these decisions affect the future; therefore:
  - to make appropriate decisions,
  - we must make reasonable predictions about the future state of economics.
- When we decide which company to work for, we predict which company will survive in the long run.
- When we invest money for retirement, we predict which stock will remain valuable.

7. Decision Making in Economics and Finance (cont-d)

- To predict future values of corresponding quantities, we can use:
  - past values of this quantity and/or
  - current (and past) values of related quantities.
- These are all the problems that we will deal with in this class:
  - prediction,
  - individual decision making, and
  - group decision making.

8. Traditional (Basic) Approach to Prediction and Decision Making

- The simplest predictions models are linear models

$$y \approx a_0 + \sum_{i=1}^{n} a_i \cdot x_i.$$

- In these models, we estimate:
  - the predicted value y as
  - a linear combination of the past and current values x_i of one or several quantities.
- The coefficients of this linear combination must be determined based on the available data

$$\left(x_1^{(k)}, \ldots, x_n^{(k)}, y^{(k)}\right).$$

9. Traditional Approach (cont-d)

- The standard way of finding these coefficients is by minimizing the mean squared error

$$\sum_{k=1}^{K}\left(y^{(k)}-\left(a_0+\sum_{i=1}^{n}a_i\cdot x_i^{(k)}\right)\right)^2.$$

- This *Least Squares* method will be the first thing we study in this class.
- Once we can predict the values of different quantities, the next step is:
  - to make a decision
  - that would maximize the corresponding objective function.

10. Traditional (Basic) Approach to Prediction and Decision Making

- The simplest objective functions are quadratic

$$J(v_1, \ldots, v_m) = j_0 + \sum_{i=1}^{m} j_i \cdot v_i + \sum_{i=1}^{m} \sum_{j=k}^{m} j_{ik} \cdot v_i \cdot v_k.$$

- So, we will study how to optimize quadratic functions.
- Our first example will be on how to best invest money.
- It is based on the 1950s portfolio optimization work of the Nobelist Harry Markowitz.
- We will also discuss how Markowitz theory helps:
  - decrease medicines' side effects and
  - speed up machine learning.

11. Need to Go Beyond Traditional Techniques

- Traditional techniques assume:
  - that the dependencies are linear,
  - that we have full information about all the data, and
  - that the optimization function is quadratic.
- All these assumptions are simplifying: in real life,
  - dependencies are often non-linear,
  - we usually have only partial information, and
  - objective functions are more complex.
- To deal with real-life situations, we need to use advanced computational techniques.
- This is what we will study in this class.

12. Beyond Traditional Techniques (cont-d)

- In dealing with such complex problems, it is important:
  - not just to come up with an optimal solution;
  - but also to have reasonably *simple* solutions, which can be easily used in the real company.
- In view of the uncertainty, to have *robust* solutions, i.e., solutions that work
  - not just for some specific values of the corresponding coefficients,
  - but also under possible deviations from these values.

13. Main Ideas Behind Advanced Economic and Financial Techniques

- Sometimes, to select a proper model or a proper algorithm, it is important to compare
  - similar situations
  - and/or similar representations of the same situation.
- For example, in physics, many fundamental equations can be derived from the natural requirement that:
  - the corresponding formulas not change
  - if we simply change the measuring unit (e.g., from minutes to seconds).
- This *symmetry* approach is productive not only in physics.
- We will see that it is also productive in economics and finance.

14. Main Ideas (cont-d)

- Symmetry ideas can help to find the models if we already know the objective function.
- When we do not yet have a clear expression for the objective function, symmetry ideas can help.
- In some cases, it helps to consider three or more different situations and to require *consistency*.
- A good example of such consistency is *additivity*.
- E.g, formulas for trade with EU should lead to similar results whether:
  - we consider EU as a single economic entity or
  - as several different countries.

15. Main Ideas (cont-d)

- It also often helps to compare economic and financial situations with situations from other areas.
- For example, there are many similarities between physical and economic processes.
- There is a whole direction in economics, known as *econophysics*.
- Its latest trend to borrow ideas and techniques from quantum physics.
- This is known as *quantum econometrics*.
- We will show how these ideas help with prediction and decision making in economics and finance.

16. Specific Topics Covered in This Class: General Idea

- Let us list specific topics covered in this class.
- Of course, this list is approximate.
- We may not have enough time to cover all of this.
- In this case, we will follow the wise advise of one of my Russian colleagues:
  - It is better not to have time for everything
  - than not to understand anything.
- In all these topics, the emphasis will be on the main ideas.
- However, we will also write some code – usually, for simplified situations and simplified techniques.

17. Specific Topics Covered in This Class: Prediction

- How prediction works?
- We need to select a prediction model.
- Such models usually comes with parameters that need to be determined from the data.
- Based on the data, we need to find the values of these parameters which fit the data the best.
- For that, we need:
  - to describe fitness in precise terms, and then
  - to come up with efficient algorithms for finding the best-fit parameters.

18. Topics Related to Selecting a Model

- Why linear models?
- Which non-linear models should we choose: symmetry-motivated approach.
- First application: gravity model of trade.
- Second application: how to predict production.
- State-of-the-art: main ideas behind quantum econometrics.

19. Topics Related to Selecting a Probability Distribution

- Symmetry-motivated distribution functions and their symmetry-motivated combinations.
- Case study: heavy-tailed Student distributions.
- Another case study: Matern covariance model.
- Skew normal distributions.
- Distributions of extreme values.
- Copulas.
- Symmetry-motivated objective functions:
  - from Laplace indeterminacy principle
  - to maximum entropy and generalized entropy.

20. Algorithms

- Depending on what information we have, we need different algorithms.
- Sometimes, we know the distribution – or the family containing the actual distribution.
- Then, we should use maximum likelihood.
- Sometimes, we only know upper bounds.
- This case is called *interval uncertainty*.
- Sometimes, we have no information about the probabilities.
- In this case, we can use *robust* methods like ℓ^p-techniques or *empirical likelihood methods*.

21. Algorithms (cont-d)

- In general, robust predictive econometrics leads to more accurate predictions.
- Robustness can also be used as a criterion for selecting a model.
- For symmetry-motivated non-linear models, the corresponding symmetries help simplify the algorithms.

22. Specific Topics Covered in the Class: Ideal Individual Decision Making

- We will start with a brief overview of the traditional decision making theory.
- This theory is centered around the notion of utility.
- We will then show how symmetries help find the dependence of utility on several parameters.
- We will then analyze how to make decisions under (interval) uncertainty.
- The main idea is Nobelist Leo Hurwicz's optimism-pessimism criterion

$$\alpha \cdot \overline{u}(a) + (1-\alpha) \cdot \underline{u}(a) \to \max_a .$$

- Example: Markowitz's portfolio selection problem when we have no information about correlations.

23. Specific Topics Covered in the Class: How People Actually Make Decisions

- According to the traditional decision theory, ideally, people should:
  - take into account all available information,
  - make adequate estimates of the corresponding probabilities, and
  - select the alternative for which the expected utility is the largest.
- In practice, due to the limited ability of human information processing, we:
  - take only some information into account,
  - use approximate estimates of probabilities, and
  - instead of selecting the best alternative, often select close-to-optimal ones with some probability.

24. How People Actually Make Decisions (cont-d)

- In this class, we will consider, explain, and analyze three example of such behavior.
- First example: *peak-end rule* when people only take into account the peak and the end experiences.
- This rule is related to Dow Peak-and-Trough Theory of stock market behavior.
- Second example is probability-related empirical weights discovered by Nobelish Daniel Kahneman.
- Third example is Nobelist Daniel McFadden's description of *probabilistic choice*.

25. Specific Topics Covered in the Class: Group Decision Making

- We start with the traditional approach: Nash's bargaining solution $\prod_{i=1}^{n} u_i(a) \to \max_a$.
- To illustrate this idea, we will use two examples.
- First example is gauging the state of a country's economy; for this:
  - the formula coming from Nash's bargaining solution is more adequate
  - than the usual Gross Domestic Product (GDP).
- Indeed, Nash's formula takes inequality into account.
- Second example: the bankruptcy problem.
- In this example, we will follow the work of Nobelist Robert Aumann.

26. What We Do Not Cover at All

- We will not cover conflict situations and related *game-theoretic* techniques.
- These techniques are a whole separate topic, requiring a special class.

See you all in class!