Math Camp

Advanced Studies Program
Kiel Institute for the World Economy

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Course Description

Modern analytical economics runs on math. Whether you are building structural models, estimating causal effects, or forecasting the macroeconomy, a firm command of mathematical tools is essential. This bootcamp-style course is designed to sharpen your intuition and fluency in the core mathematical concepts that underpin advanced economic analysis. From the rigor of real analysis to the power of linear algebra and the logic of optimization, we will build the quantitative foundation needed for sound research in economics. We will also dive into the probabilistic thinking and estimation techniques that drive econometrics, and explore how machine learning is reshaping the frontier of macroeconomic forecasting.

But this course is not just about theory. Through interactive tutorials and hands-on coding sessions, you will put mathematical ideas into action, applying abstract reasoning to concrete economic problems. Working through guided examples in R and MATLAB using interactive notebooks, you will translate equations into code and analysis. By the end, you will have a stronger command of both the core mathematical methods and the computational tools essential for advanced economic modeling.

Topics Covered

I. Mathematical Analysis for Economic Modeling

1. **Introduction and Foundations of Real Analysis**: Mathematics in economic theory and practice, sequences and series, limits of functions, limit theorems, and continuity.
2. **Calculus Fundamentals**: Differentiation, linear approximation and Taylor's theorem, multivariable calculus, gradient and Hessian, implicit differentiation and implicit function theorem, Riemann integral and fundamental theorem of calculus.
3. **Essence of Linear Algebra and Data Science**: Matrix algebra and rules of matrix calculus, inner vs. outer products, determinants and matrix inversion, rank, linear systems, eigenvalues and eigenvectors, eigendecomposition, curse of dimensionality, principal component analysis, and sufficient dimension reduction.
4. **Optimization Methods**: Convex optimization and principle of duality, linear and nonlinear programming, Newton-Raphson method, and gradient descent.

II. Probability Theory and Econometrics

1. **Probability Theory and Essential Asymptotics**: Random Variables and probability distributions, Bayes' rule, expectations, moments, correlation, law of large numbers, central limit theorem, consistency and convergence in probability and distribution, and Slutsky's Theorem.
2. **Regression Analysis in Applied Economic Research**: Causal effects in observational data, hypothesis testing, endogeneity and solutions via instrumental variables, identification challenges and classical remedies.
3. **Estimation Methods**: Least squares, maximum likelihood estimation, M-estimation, Bayesian methods and simulation-based techniques.

III. Essential Tools for Advanced Macroeconomic Modeling and Forecasting

1. **Dynamic Programming and Reinforcement Learning**: Foundations of intertemporal decision-making, state and control variables, the Bellman equation, principle of optimality, Monte Carlo integration, value function iteration and policy function iteration.
2. **Econometric Frameworks for High-Dimensional Macro-Forecasting**: Dimensionality reduction with dynamic factor models, Bayesian VARs and shrinkage priors.
3. **Machine Learning Fundamentals for High-Dimensional Macro-Forecasting**: Bias-variance trade-off, regularized linear regressions, tuning and time series cross-validation, nonlinearities, decision trees, random forest and boosting, interpretability and model evaluation.

Prerequisites: Participants should have a solid foundation in undergraduate-level calculus, linear algebra, and probability theory. Familiarity with basic programming concepts is also recommended to fully engage with the coding exercises and interactive notebooks.

Credits: 25 hours (lecture + tutorial).

Assessment: 90-minute exam. The precise time and location of the exam will be announced in due time.

Planned Course Structure

Day	Content
Sep 4th	I. Mathematical Analysis for Economic Modeling 1. Introduction and Foundations of Real Analysis 2. Calculus Fundamentals
Sep 5th	I. Mathematical Analysis for Economic Modeling 3. Essence of Linear Algebra and Data Science 4. Optimization Methods
Sep 8th	II. Probability Theory and Econometrics
Sep 9th	III. Essential Tools for Advanced Macroeconomic Modeling and Forecasting 1. Dynamic Programming and Reinforcement Learning 2. Econometric Frameworks for High-Dimensional Macro-Forecasting
Sep 10th	III. Essential Tools for Advanced Macroeconomic Modeling and Forecasting 3. Machine Learning Fundamentals for High-Dimensional Macro-Forecasting