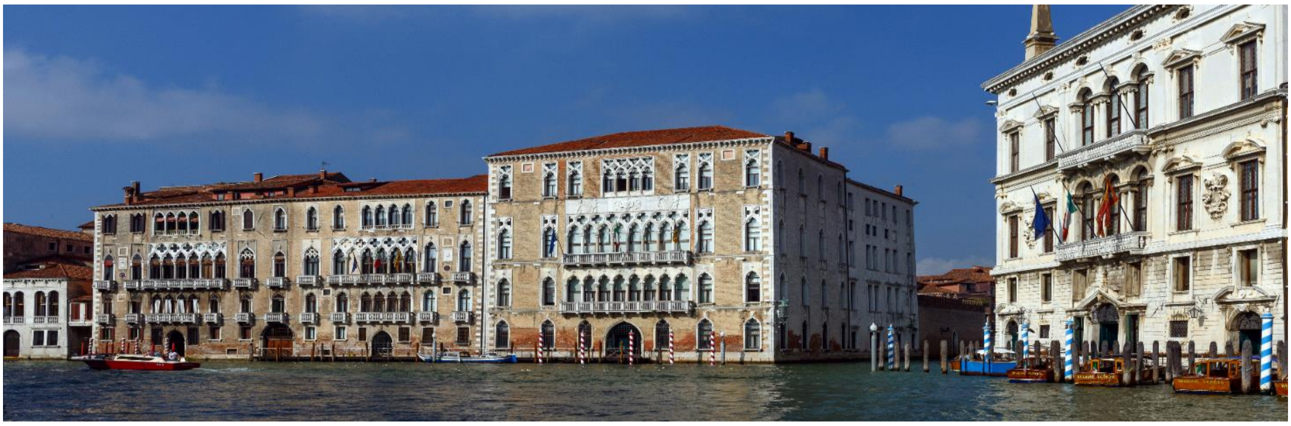

ECSO 2022
European Conference on Stochastic Optimization

CMS 2022
Computational Management Science

Venice 29-30 June - 1 July, 2022

VENUE: Department of Economics, Ca’ Foscari University of Venice
San Giobbe Campus – Cannaregio 873, 30121 Venice, Italy

CONFERENCE WEB PAGE: **www.unive.it/ecsocms2022**

ECSO-CMS 2022

Venice 29-30 June - 1 July 2022

ECSO 2022 is the 3rd edition of a stream of conferences organized by the **EURO Working Group on Stochastic Optimization (EWGSO)**.

CMS 2022 is the 17th edition of an annual meeting associated with the Journal of Computational Management Science published by Springer.

ECSO – CMS 2022 is jointly organized by the Department of Economics of Ca' Foscari University of Venice, the CMS Journal and the EURO Working Group on Stochastic Optimization.

This joint event will provide a forum for fruitful discussions and interactions among researchers and professionals from industry and institutional sectors on decision making under uncertainty in a complex world. The conference will be within the scopes of both CMS and EWGSO and, in particular, it will focus on models, methods and computational tools in stochastic, robust and distributionally robust optimization and on computational aspects of management science with emphasis on risk management, valuation problems, measurement applications. Traditional fields of application, such as finance, energy, water management, logistics, supply chain management, and emerging ones, such as healthcare, climate risk and sustainable development, will be included.

Support by the EWGSO - European Working Group on Stochastic Optimization, the Department of Economics and VERA Venice Center in Economic and Risk Analytics for Public Policies of Ca' Foscari University of Venice, VIU – Venice International University, AMASES- Associazione per la Matematica Applicata alle Scienze Economiche e Sociali, AIRO Associazione Italiana Ricerca Operativa, and Gncs Indam - Gruppo Nazionale per il Calcolo Scientifico is gratefully acknowledged.

Welcome to ECSO–CMS 2022!

Diana Barro, Stein-Erik Fleten, and Martina Nardon
On behalf of the Organizing and Scientific Committees

BEST STUDENT PAPER PRIZE

A prize for the student best paper will be awarded.

Jury for the student best paper prize: Stein-Erik Fleten (NTNU Norwegian University of Science and Technology), Miloš Kopa (Charles University of Prague), Francesca Maggioni (University of Bergamo), Rüdiger Schultz (University Duisburg-Essen).

PLENARY SPEAKERS

DARINKA DENTCHEVA, Stevens Institute of Technology (USA)
DAVID MORTON, Northwestern University (USA)
GAH-YI BAN, Robert H. Smith Business School, University of Maryland (USA)
DANIEL KUHN, École polytechnique fédérale de Lausanne (CH)
GIORGIO CONSIGLI, Khalifa University of Science and Technology (UAE)

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Plenaries

Data-driven Optimization: from Theory to Practice

Gah-Yi Ban (Robert H. Smith Business School, University of Maryland)

In this talk, I will review research in data-driven optimization that has transformed how we think about making decisions over the past decade. I will also discuss some of my on-going research with industry; how they relate to past academic work and the new challenges they present.

Optimal distributionally robust liability-driven-investment for pension funds. Recent advances in stochastic optimization methods for quantitative asset-liability management

Giorgio Consigli (Khalifa University of Science and Technology)

We consider a defined benefit (DB) pension fund management problem formulated as a liability-driven investment problem subject to distributional uncertainty affecting specifically the term structure of interest rates, inflation and mortality intensity. The pension fund manager objective is to minimize the cost of funding, given by the contributions paid by the sponsor and the deficit between liabilities and total asset value at the end of the time horizon. The problem is formulated in constant monetary values to immunize the impact of inflation.

By its nature a DB pension fund problem has to deal with uncertainties that will only be resolved far into the future and lead naturally to distributionally robust optimization (DRO) formulations carrying a complex and necessarily long-term risk exposure. The ambiguous stochastic optimization approach assumes that the underlying probability distribution is unknown and lies in an ambiguity set of probability distributions. We employ the DRO approach with Wasserstein distance of Gao and Kleywegt (2016) to solve the problem. A case study based on US data from 1933 to 2020 is presented in which the DRO solution is compared to the sample average approximation solution.

In the second part of the talk the DRO approach is analysed in comparison with alternative modelling frameworks for pension fund asset-liability management (ALM) problems and more generally quantitative ALM problems that depending on the underlying model of uncertainty, are formulated as dynamic stochastic control or multistage stochastic programming problems or as a combination of the two. We highlight pros' and cons' of the associated optimization approaches, focus on the ALM modelling challenges and mention a few forward research directions in the field.

Multi-stage stochastic optimization with time-consistent risk constraints

Darinka Dentcheva (Stevens Institute of Technology)

We discuss ways to compare random sequences in the context of multistage stochastic optimization problems. While various comparisons of stochastic sequences have been proposed in the literature, their integration in a sequential decision problem is non-trivial and usually results in a time-inconsistent evaluations and inconsistent decisions. We propose a framework for constructing stochastic orders that enable time-consistent comparisons at any stage of the decision process and ensure the dominance property of the optimal policy. Particular attention is paid to constraints based on stochastic dominance of the second order imposed conditionally. This comparison reflects risk-averse preferences and results in problems amenable to numerical treatment. We shall present optimality condition for the new problems and shall discuss their relations to other risk models. Numerical methods for solving the multi-stage problem are outlined.

On Robust Optimization, Blackouts and the Law

Daniel Kuhn (École Polytechnique Fédérale de Lausanne)

Vehicle-to-grid is a concept for mitigating the growing storage demand of electricity grids by using the batteries of parked electric vehicles for providing frequency regulation. Vehicles owners offering frequency regulation promise to charge or discharge their batteries whenever the grid frequency deviates from its nominal value, and they must be able to honor their promises for all frequency deviation trajectories that satisfy certain properties prescribed by EU law. We show that the relevant EU regulations can be encoded exactly in a robust optimization model, and we use this model to demonstrate that the penalties for non-compliance with market rules are currently too low. This suggests that "crime pays" and that the stability of the electricity grid is jeopardized if many frequency providers abuse the system, which could ultimately result in blackouts. The decision problem of a vehicle owner constitutes a non-convex robust optimization problem affected by functional uncertainties. By exploiting the structure of the uncertainty set and exact linear decision rules, however, we can prove that this problem is equivalent to a tractable linear program. Through numerical experiments based on data from France, we quantify the economic value of vehicle-to-grid and elucidate the financial incentives of vehicle owners, aggregators, equipment manufacturers, and regulators. The proposed robust optimization model is relevant for a range of applications involving energy storage.

Design of Covid-19 Staged Alert Systems to Ensure Healthcare Capacity with Minimal Closures

David Morton (Northwestern University)

Community mitigation strategies to combat COVID-19, ranging from healthy hygiene to shelter-in-place orders, exact substantial socioeconomic costs. Judicious implementation and relaxation of restrictions amplify their public health benefits while reducing costs. We derive optimal strategies for toggling between mitigation stages using daily COVID-19 hospital admissions. With public compliance, the policy triggers ensure adequate intensive care unit capacity with high probability while minimizing the expected duration of strict mitigation measures. We show that other sensible COVID-19 staging policies, including France's ICU-based thresholds and a widely adopted indicator for reopening schools and businesses, require overly restrictive measures or trigger strict stages too late to avert catastrophic surges.

This work is co-authored with: Haoxiang Yang, Özge Sürer, Daniel Duque, Bismark Singh, Spencer J. Fox, Remy Pasco, Kelly Pierce, Paul Rathouz, Victoria Valencia, Zhanwei Du, Michael Pignone, Mark E. Escott, Stephen I. Adler, S. Claiborne Johnston, and Lauren Ancel Meyers.

Abstracts

Optimal stopping problems for multi-dimensional stochastic processes with applications to real option theory

Rossella Agliardi (University of Bologna)

I survey some results and open questions regarding the applications of optimal stopping theory to real option analysis. The main focus is on the issue of obtaining explicit solutions for the related free-boundary problems when the underlying stochastic process is a Geometric Brownian motion. I provide a new explicit expression for the value function in the two-dimensional (and n-dimensional) case via fundamental solution method. The value function is written in terms of a modified Bessel function of second kind. Some useful formulas for the one-dimensional case are presented as well.

Extreme dependence in the energy market: a Mixture copula-ARJI-GARCH model

Arianna Agosto (University of Pavia), Luciana Dalla Valle (Plymouth Marjon University) and **Maria Elena De Giuli** (University of Pavia)

Following Chan & Maheu (2002) and Chang (2012), we set up a Mixture copula-based ARJI-GARCH model to investigate the time-varying and non-linear dependence between renewable and non-renewable energies. Our data consists of daily closing prices of the Dax Global Alternative Energy Index and the MSCI World Energy Index for traditional commodities. Based on Chan & Maheu (2002), we develop a GARCH model with the autoregressive jump-intensity (ARJI) specication designed as an autoregressive moving average process, to capture several forms of autocorrelation. The jump model coupled with a generalised autoregressive conditional heteroscedasticity (GARCH) specication of volatility is a very useful framework to provide reliable forecasts. Through this model we can indeed take into account the persistence in conditional variance and the dynamics of conditional jump intensity, which imply time variation in volatility and also in the conditional skewness and kurtosis related to high-magnitude movements in the returns. In fact, many energy markets are characterised by rapid and often unexpected changes that lead to jumps either upwards or downwards, due to natural disasters, geopolitical developments, strategic actions and many other unexpected events. Consequently, a considerable part of variance can be attributed to the extreme price movements leading to heavy-tailed distributions of the observed returns. The ARJI-GARCH model was shown to be a useful tool for dealing with extreme events and sudden price changes (see, e.g., Lee et al., 2010). As a second step of our study, drawing attention to the co-movement structure over time in the extreme left and right tails of return distribution, we show how to capture the asymmetric dependence between renewable and non-renewable indexes through a mixture of Clayton and Gumbel copulas (see Chang, 2012). These results are then effectively used in hedging operations.

Fantasy Sports: A game of skill or chance?

Aishvarya (Indian Institute of Management, Bangalore), Tirthatanmoy Das (Indian Institute of Management, Bangalore) and Dinesh Kumar U (Indian Institute of Management, Bangalore)

Fantasy Sports is one of the fastest growing online gaming industries. An important question surrounding fantasy sports is whether it is a game of skill or chance. Many famous fantasy sports operators across the world have fallen into legal battles for the same. While gaming laws in most countries largely depend on the 'Dominant Factor Test' to determine whether it is skill dominant or chance dominant, the definition of skill and

chance is not very clear. Absence of standardized and uniform laws has added to the confusion surrounding legality of fantasy sports. There is lack of mathematical and/or empirical findings in the literature regarding the question of fantasy sports being skill dominant or chance dominant. Using a fixed effect stochastic frontier technique, we model users' skills and the random chances they face as two distinct error components determining their success in fantasy sports contests. Utilizing the data from Cricket-based fantasy contests of Dream11, the leading fantasy sports operator in India, we find that users' performances in a fantasy contest depend on their past performances, choices of contests, and prior experiences. We also find that the model's signal-to-noise ratio is significantly greater than one, implying that users' skills play a dominant role than chance or luck in determining their success in fantasy sports contests.

Identifying factors that influence the user engagement decision in the NFT Metaverse based on the Theory of Planned Behavior

Hayder Albayati (KAIST), Jae Jeung Rho (KAIST) and Noor Alistarbadi (KAIST)

With the massive adoption of NFT worldwide, purchasing or creating an NFT required considering many aspects and sources before moving along with this decision and engaging with the NFT metaverse. Moving forward and selecting what to create or to buy, it is necessary to assess the NFT and whether it is worth investing in or not. In conclusion, this choice is complicated, especially when it involves extensive knowledge and information taken from different sources and perspectives. Some aspects are related to the customer experience and trust, and others are likely to be asset-related. As we look at the crypto market, we can find a variety of platforms and applications that can be used conveniently, presenting numerous options and possibilities. That brings us to consider some thoughts on the engagement in the NFT metaverse; What is the best and most secure platform to start using? What NFT piece should I create or buy? Is the trading or engaging in the NFT metaverse trustworthy? Is it legal to use and trade NFTs? Assessing the NFTs requires deep research into different sources of controversial information and data that are available and accessible. However, no such reference or study covers these considerations in detail; the lack of trusted resources and knowledge impacts the user experience and engagement. This paper looks into the multi-factor analysis approach that impacts the NFT metaverse engagement behavior and decision. We are using an extended model of the theory of planned behavior (TPB), proposing a model which contains external factors to help identify the variables that influence the engagement with NFTs in the metaverse virtual world. This comprehensive study has a multi-perspective approach; customer perspective, social perspective, technology perspective, legal perspective, and market perspective. We will present extensive knowledge and information that will be a helpful piece of awareness for everyone who intends to buy, invest, or create an NFT. This study will use a qualitative analysis method and expects to provide meaningful results explaining this dilemma and the reasons behind the massive adoption of NFT and its fluctuation worldwide. This work will help the decision-makers, creators, and investors consider new development perspectives in the NFT metaverse. The methodology will use primary survey data and be analyzed with Smart-PLS software to determine variance-based structural equation modeling (SEM) using the partial least squares path modeling (PLS) method.

Selective maintenance strategy under uncertain maintenance duration using distributionally robust chance-constrained programming

Hamzea Al-Jabouri (Dalhousie University), Ahmed Saif (Dalhousie University) and Claver Diallo (Dalhousie University)

In this paper, a distributionally robust chance-constrained program with a Wasserstein ambiguity set is developed to deal with uncertain maintenance durations in the selective maintenance problem (SMP). The SMP arises in mission-oriented systems that perform sequences of missions separated by maintenance breaks. Due to resource limitations, only a subset of possible maintenance actions can be performed during the intermission break. The aim of the SMP is to identify the optimal subset of components to maintain and the maintenance actions to perform such that the system reliability for the upcoming mission is maximized. The large majority of SMP models assume that maintenance activity duration is constant and known with certainty. However, due to the lack of proper historical data or the variability occurring within the system due to unpredictable operating conditions, varying skillsets, and human errors, the uncertainty related to

maintenance duration is unavoidable, and ignoring it may lead to ineffective maintenance planning which may expose the system to risks such as lower reliability and/or delayed mission start. The developed data-driven distributionally robust chance constraints formulation ensures effective maintenance plans can be determined with a high probability of completion.

On modeling distributionally two-stage epsilon-robust optimization for multistage multiscale stochastic optimization

Antonio Alonso-Ayuso (Universidad Rey Juan Carlos), **Laureano F. Escudero** (Universidad Rey Juan Carlos) and Juan F. Monge (Universidad Miguel Hernández de Elche)

The realization of the uncertain parameters in dynamic mathematical optimization is usually structured in a finite set of scenarios along the stages in a time horizon. The representation of the uncertain data affects the type of decision models and the decomposition methodologies for problem solving to be dealt with. While dealing with dynamic problems with a time horizon, say, capacity expansion planning (CEP) and others, there are, undoubtedly, two types of data, two types of uncertainties and two types of variables, namely, strategic and operational ones. The strategic variables are related to the decisions on the location, capacity and timing on the infrastructure elements of the CEP of a system, say supply chain, production system, rapid transit network, energy transmission network and energy generation mix system, to name a few. The operational variables are related to the decisions on the operation planning of the available elements in the system at the stages along the time horizon. Both types of decisions, inherently interlinked in the same optimization model, have their own types of uncertainties in the main parameters. One important information for dealing with the uncertainty in practical applications is the requirement of the probability distribution (PD) followed by the uncertainty. Since usually it is not known, it is a motivation for distributionally robust optimization (DRO) as a counterpart of known true underlying distribution. In this work we extended the data-driven two-stage DRO to the frequent multistage environment, where those two-stage trees are embedded in the multistage one. The MILP model that is proposed deals explicitly with the ambiguity set composed by different probabilistic distributions (PDs) to generate the strategic and operational uncertain parameters realizations in the immediate successor nodes of a given one in the multistage scenario tree. Thus, the model internal chosen of the PD to work in the set of immediate successor nodes of each node in the multistage tree facilitates a local robust optimization to minimizes the expected objective function DRO value along the multistage multiscale horizon. Several approaches are considered for selecting the appropriate PD ambiguity set, such as those based on PD divergences, Wasserstein distance and data’s first and second moments. The model assumes a Markovian inference on the parameters’ realizations. Given the intrinsic problem's difficulty and the huge instances' dimensions (due to the network size of realistic instances as well as the cardinality of the strategic scenario tree and operational ones), it is unrealistic to seek an optimal solution. The matheuristic algorithm SFR3 is considered, it stands for Scenario variables Fixing and constraints and variables' integrality iteratively Randomizing Relaxation Reduction.

Minimax decision rules for planning under uncertainty

Edward Anderson (Imperial College Business School) and Stan Zachary (Heriot-Watt University)

Minimax rules are often used for planning decisions when there is great uncertainty on what will happen in the future and minimax regret is one popular version of this. Two factors make minimax rules attractive. First, a minimax approach is inherently conservative. Second, the ability to make decisions without the use of probabilities is attractive in public sector decisions, where it is necessary to follow a clear-cut procedure to avoid any suggestion of bias or favouritism. However, when regret-based rules are used the independence of irrelevant alternatives property (IIA) fails, and this can lead to opportunities to game the process. We analyse cases with a finite set of decision choices. For example, a planner may need to determine which of many proposed projects should go ahead. We give examples to illustrate the way that IIA failures can occur – and prove that no decision approach based on regret can avoid these problems. Another limitation of minimax rules is their sensitivity to the choice of scenarios. We make this explicit by considering problems where the decision variables x are chosen from a convex set D in R^n and we choose a minimax policy for quasi-convex cost or regret functions f_i for a finite set of scenarios $i \in S$. We prove that there will be a set of *n+1* scenarios which determine the solution. This implies that variations in the outcomes of other scenarios will not usually change the decision. We illustrate this by looking at the case of the National Grid ESO determining the amount of electricity generation capacity to procure. We give details of the process carried out in 2015 which was concerned with the provision of adequate electricity capacity for the winter 2019–20. This process was carried out using least worst regret applied to a set of 5 core, scenarios, together with a further 14 minor scenarios. We show that there are just two minor scenarios which determine the result of the minimax regret analysis in exactly the way that our theoretical discussion implies (since there is just a single decision variable). These two "extreme" scenarios largely determine the result of the minimax regret analysis. The decision made is unaffected by variation of the remaining scenarios so long as they do not become more extreme than either of these two scenarios. This analysis was presented to National Grid ESO and formed the basis for a thorough analysis of sensitivities carried out in 2017. The recommendation in that year proved robust to these further analyses, and a minimax regret analysis continues to be used up to the present. We can also consider a minimax decision rule as a robust version of an expected cost minimizer when there is a range of possible probabilities for the scenarios. This allows some flexibility through the choice of the uncertainty set of probability distributions. We argue for the advantages of this approach when a planner wishes to define some core scenarios around which a wider scenario set is constructed.

Quantile Regression Forest for Value-at-Risk forecasting via mixed-frequency data

Mila Andreani (Scuola Normale Superiore), Vincenzo Candila (MEMOTEF, LA Sapienza University) and Lea Petrella (Sapienza University of Rome)

Quantile regression has been introduced in Koenker and Bassett (1978) as a powerful technique for modeling the entire conditional distribution of a response variable. This technique extends the flexibility of standard regression methods in order to analyse linear and non-linear response models, especially the ones for which the gaussianity assumption does not hold. Quantile regression has been applied in a variety of fields, including economics and finance. Recently quantile regression approach has been also introduced in a machine learning framework by Meinshausen (2006) as an extension of the original Random Forest algorithm (Breiman, 2001). One of the main feature of financial and economics variables, other than being non normaly distributed, is that they are usually observed at different frequencies (for instance, daily financial returns and macroeconomic variables). As a consequence, many potentially useful predictors cannot be included in standard econometric models, which account only for variables sampled at the same frequency. This issue has been tackled in the literature with the Mixed-Data-Sampling (MIDAS) model. With this paper we intend to introduce the MIDAS variables in a quantile regression random forest framework in order to compute high frequency conditional quantiles by means of low-frequency variables. In this way we extend the MIDAS model to a non-parametric setting, building a comprehensive methodology to jointly model complexity, non-linearity and mixed-frequencies. Due to the link between quantile and the VaR risk measure we compare our model with the most popular one in VaR forecasting.

Batch Learning in Stochastic Dual Dynamic Programming

Daniel Avila (Université Catholique de Louvain), Anthony Papavasiliou (Université Catholique de Louvain) and Nils Löhndorf (University of Luxembourg)

We consider the stochastic dual dynamic programming (SDDP) algorithm - a widely employed algorithm applied to multistage stochastic programming - and propose a variant using experience replay - a batch learning technique from reinforcement learning. To connect SDDP with reinforcement learning, we cast SDDP as a Q-learning algorithm and describe its application in both risk-neutral and risk-averse settings. We demonstrate the superiority of the algorithm over conventional SDDP by benchmarking it against PSR's SDDP software using a large-scale instance of the long-term planning problem of inter-connected hydropower plants in Colombia. We find that SDDP with batch learning is able to produce tighter optimality gaps in a shorter amount of time than conventional SDDP. We also find that batch learning improves the parallel efficiency of SDDP backward passes.

Optimal cooperative and diversification strategies during recovery from supply disruptions

Nader Azad (Ontario Tech University), Elkafi Hassini (McMaster University) and Manish Verma (McMaster University)

Supply disruptions are not infrequent, and recovery is more costly and lasts longer. The adverse impact of disruption becomes more pronounced in certain industries, such as automotive, because the suppliers are often small and might not have the necessary capability and resources to facilitate timely recovery. In such situations, it is important that the buyer develop strategic plans for efficient recovery from disruptions. In this study, we investigate the optimal supplier and buyer's reactions to the supply disruption. More specifically, the buyer may need to decide on whether to have a dual supply strategy where one of the suppliers can act as a redundant source, or develop a long-term relationship with one single supplier who would be extended (direct/ indirect) financial support during disruption. To study these issues, we propose a Stackelberg game between a buyer and a supplier that has been disrupted. We consider both deterministic and stochastic demand and present analytical and numerical findings under sole and dual sourcing scenarios. We show that given low downstream supply penalty, the buyer prefers dual sourcing strategy and diversifies her order when time to delivery is short. On the other hand, given high downstream supply penalty, the buyer offers a financial subsidy to the supplier and sole sourcing dominates dual sourcing strategy, when the time to delivery is short and the difference between the wholesale prices of the two suppliers is high. In addition, our numerical result suggests that when the buyer is more powerful by facing a stochastically larger demand, may offer to increase her order and at the same time increase her financial subsidy to the supplier. We also characterize the buyer's preference between two strategies as a function of model parameters and find the direct financial incentive levels that would coordinate the two-party supply chain. Finally, we develop a decision topology that provides guidance to supply chain practitioners to choose the best recovery strategy and help them choose the appropriate sourcing strategy that can mitigate supply disruptions.

Optimal portfolio choice of couples with tax deferred accounts and survival contingent products

Sanghyeon Bae (Korea Advanced Institute of Science and Technology) and Woo Chang Kim (Korea Advanced Institute of Science and Technology)

A lifetime consumption and portfolio choice problem of a married couple grows in importance as retirement planning would be quite difficult in an aging society. In general, financial products for retirement planning, especially survival-contingent products, have complex taxation structures and death conditions. In particular, tax deferred accounts (TDA) can provide tax-sheltered wealth accumulation by deferring taxes even with the same set of financial products. Also, various survival-contingent products such as annuity products and life insurance contracts have different payouts upon the deaths of policyholders. However, existing literature on lifetime portfolio choice problem has focused on only one aspect of these two, while TDAs and various types of survival-contingent products are widely used for retirement planning in practice. In this paper, therefore, we include both aspects for the study of optimal lifetime consumption and portfolio choice problem of a married couple. Considering financial products with different tax structures and death-related conditions would be much closer to the real-world retirement planning and would allow us to draw more useful results. In the taxable account, the couple can hold liquid traditional assets, such as riskless bonds and stocks, and purchase illiquid term life insurance. The couple has an opportunity to invest their savings via TDAs, which consist of qualified accounts (QA) that can trade liquid traditional assets and nonqualified accounts (NQA) that can trade illiquid immediate annuities in the private annuity market. We formulate the couple's lifetime portfolio choice problem as a multistage stochastic programming model. Due to its high dimensional state space and lifelong planning periods, stochastic dual dynamic programming (SDDP) is used to solve the problem. We find that the couple actively utilize the QA in early ages and put a considerable weight on stocks to accumulate tax deferred wealth. In addition, the purchase of life insurance contracts shows a hump-shaped pattern as in other previous studies. At the retirement, the couple withdraws a lump sum of money from the QA to purchase annuities. The results show that a right combination of a joint annuity (becomes invalid only after both are dead) and single annuities (become invalid after the annuitant is dead) can address the couple's

imbalanced life expectancy, and pension income and successfully guarantees the couple's post-retirement consumption.

Alternative probability weighting functions in behavioral portfolio selection

Diana Barro (Ca' Foscari University of Venice), Marco Corazza (Ca' Foscari University of Venice) and **Martina Nardon** (Ca' Foscari University of Venice)

We propose some portfolio selection models based on Cumulative Prospect Theory. In particular, we consider alternative probability weighting functions in order to model probability distortion. The resulting mathematical programming problem turns out to be highly non-linear and non-differentiable. So, we adopt a solution approach based on the metaheuristic Particle Swarm Optimization. We select the portfolios under the behavioral approach and perform an application to the European equity market as represented by the STOXX Europe 600 Index and compare their performances.

Diversifying estimation errors with unsupervised Machine Learning

Merlin Bartel (University of Liechtenstein) and Sebastian Stöckl (University of Liechtenstein)

Regarding the disastrous impact of estimation errors on portfolio optimization, this paper investigates the trade-off between optimization and estimation errors using unsupervised machine learning. Our model uses unsupervised machine learning to reduce estimation errors by clustering stocks into equally weighted portfolios which in turn are plugged into the classical minimum variance optimization. In contrast to previously documented results, the clustered optimization does beat the equally weighted portfolio considerably in all setups. Varying the number of clusters from one (the equally weighted portfolio) to N (the minimum variance portfolio) we find the optimal number of clusters to be approximately N/4.

Adaptive two-stage stochastic programming

Beste Basciftci (University of Iowa) and Shabbir Ahmed (Georgia Institute of Technology)

Multi-stage stochastic programming is a well-established framework for sequential decision making under uncertainty by seeking policies that are fully adapted to the uncertainty. Often such flexible policies are not desirable, and the decision maker may need to commit to a set of actions for a number of planning periods. Two-stage stochastic programming might be better suited to such settings, where the decisions for all periods are made here-and-now and do not adapt to the uncertainty realized. In this paper, we propose an alternative approach, where the stages are not predetermined but part of the optimization problem. Each component of the decision policy has an associated revision point, a period prior to which the decision is predetermined and after which it is revised to adjust to the uncertainty realized thus far. We label the proposed approach as adaptive two-stage stochastic programming and provide a generic mixed-integer programming formulation for finite stochastic processes. We show that adaptive two-stage stochastic programming is NP-hard in general. Next, we derive bounds on the value of adaptive two-stage programming in comparison to the two-stage and multi-stage approaches for a specific problem structure inspired by the capacity expansion planning problem. Since directly solving the mixed-integer linear program associated with the adaptive two-stage approach might be very costly for large instances, we propose several heuristic solution algorithms based on the bound analysis. We provide approximation guarantees for these heuristics. Finally, we present an extensive computational study on an electricity generation capacity expansion planning problem and demonstrate the computational and practical impacts of the proposed approach from various perspectives. As concluding remarks, we present extensions of our model with multiple revision points.

Hedonic and neural network models for real estate appraisal

Antonella Basso (Ca' Foscari University of Venice) and Marco Corazza (Ca' Foscari University of Venice)

In this contribution we deal with the problem of assessing the price of the residential real estates located in all the Italian municipalities with a number of inhabitants between 15000 and 50000. In the study we develop and test different models for determining the minimum and maximum prices in each area and for detecting their determinants. In particular, among the inputs we consider both standard attributes generally providing utility to the owner (like, for instance, the real estate localization in the center of an urban area or in sub-urban ones and the state of the property) and variables describing the economic situation (like, for instance, the average income and the employment rate of the area). As for the models, we develop, test and compare three different ones: the classical and widely used linear hedonic model, the (slightly nonlinear) quadratic hedonic one and the nonlinear neural network model known as multilayer perceptron (MLP). Note that for both hedonic approaches we have to consider two independent modelizations, one for the minimum price and one for the maximum price, while for the MLP only one model needs to be built, given the ability of this method to jointly take into account multiple outputs. With regard to the MLP model, its hyper parametrization has been appropriately optimized and its training has been properly managed in order to obtain the best network and to avoid overfitting. Finally, the results achieved by the MLP model generally show RMSEs significantly lower the those coming from the two hedonic models.

A fast Monte Carlo scheme for additive processes and option pricing

Roberto Baviera (Politecnico Milano) and Michele Azzone (European Central Bank)

In this paper, we present a fast Monte Carlo scheme for additive processes. We analyze in detail numerical error sources and propose a technique that reduces the two major sources of error. We also compare our results with a benchmark method: the jump simulation with Gaussian approximation. We show an application to additive normal tempered stable processes, a class of additive processes that calibrates “xactly” the implied volatility surface. Numerical results are relevant. The algorithm is an accurate tool for pricing path-dependent discretely-monitoring options with errors of one bp or below. The scheme is also fast: the computational time is of the same order of magnitude of standard algorithms for Brownian motions.

Residuals-based stochastic optimization with covariate information

Güzin Bayraksan (The Ohio State University)

We consider data-driven approaches that integrate a machine learning prediction model within stochastic optimization, given joint observations of uncertain parameters and covariates. Given a new covariate observation, the goal is to choose a decision that minimizes the expected cost conditioned on this observation. We first examine a *Sample Average Approximation (SAA)* approach for approximating this problem. We present conditions on the data generation process, the prediction model, and the stochastic program under which solutions of these data-driven SAAs are consistent and asymptotically optimal. We also derive convergence rates and finite sample guarantees. Then, in the limited-data regime, we consider *Distributionally Robust Optimization (DRO)* variants of these models. Our framework is flexible in the sense that it can accommodate a variety of learning setups and DRO ambiguity sets. We investigate the asymptotic and finite sample properties of solutions obtained using Wasserstein, sample robust optimization, and phi-divergence-based ambiguity sets and explore cross-validation approaches for sizing these ambiguity sets. Finally, we discuss how these models and results can be updated in the heteroscedastic case. Computational experiments demonstrate the potential advantages of our data-driven formulations (even when the prediction model is misspecified) and illustrate the benefits of our new data-driven formulations in the limited data regime.

'Buy n times, get one free' loyalty cards: Are they profitable for competing firms?

Amirhossein Bazargan (Fairleigh Dickinson University), **Salma Karray** (Ontario Tech University,) and Saeed Zolfaghari (Ryerson University)

This research evaluates whether firms offering loyalty programs (LPs) should choose a restricted redemption policy by imposing a specific number of purchases before customers can redeem their points. Such restriction is commonly offered in form of 'buy n times, get one free' loyalty cards. We develop a multinomial logit model where consumer's utility is uncertain and depends on the value of the product and of the rewards. Using an iterative algorithm, we numerically solve a Nash game for two firms offering loyalty programs. Optimal strategies and profits are obtained for three different scenarios (games): (1) both firms do not restrict redemption; (2) both firms restrict redemption; and (3) only one firm restricts redemption while the other firm does not. Our main findings indicate that each firm's optimal strategies are significantly affected by whether the competitor decides to restrict or not to restrict redemption. In particular, a firm that restricts reward redemption should offer a higher price if its competitor also restricts redemption. Further, the dominant strategy of the game depends on customers' valuations of time and rewards. For example, when customers highly value time but do not highly value rewards, the dominant strategy for both firms is not to restrict redemption. Alternatively, firms can face a Prisoner dilemma situation leading to unrestricted redemption policy for intermediate levels of customer valuation of both time and rewards.

Deep learning algorithm for pricing of high-dimensional financial derivatives under default risk

Christian Beck (ETH Zurich), Sebastian Becker (ETH Zurich), Patrick Cheridito (ETH Zurich), Arnulf Jentzen (University of Münster) and **Ariel Neufeld** (Nanyang Technological University Singapore)

Partial differential equations (PDEs) are one of the most frequently used tools to mathematically describe phenomena in financial markets. For example, PDEs can be used to price financial derivatives depending on a financial index for instance or to optimize portfolios with respect to a given utility function. The PDEs under consideration are mostly nonlinear and of high dimensions, where the PDE dimension corresponds in the financial context, roughly speaking, to the number of financial assets in the model under consideration. Such high-dimensional nonlinear PDEs in nearly all cases cannot be solved explicitly, and classical numerical methods so far have not been able to approximately solve nonlinear PDEs in very high dimensions. In this talk, we present a numerical algorithm that involves machine learning techniques which can approximately solve very high-dimensional nonlinear PDEs efficiently. The algorithm achieves very good results with short run times in up to 10000 dimensions. The main idea of the algorithm is to solve the PDE iteratively over small time intervals using the Feynman-Kac representation from stochastic analysis, which enables to decompose the PDE approximation problem into a sequence of separate learning problems that can be solved using neural networks. We apply this algorithm to price high-dimensional financial derivatives under default risk, which is a burning issue in quantitative risk management in finance.

Optimal planning of transmission infrastructure expansion to efficiently integrate renewable energy generation

Nikita Belyak (Aalto University), Steven A. Gabriel (University of Maryland, Norwegian University of Science and Technology), Nikolay Khabarov (International Institute for Applied Systems Analysis) and Fabricio Oliveira (Aalto University)

In light of increasing pressure to curb greenhouse gas emissions, many countries have focused on the development of strategies that encourage renewable generation in liberalised energy markets. This paper presents a modelling assessment to plan the renewable-driven expansion of the transmission system infrastructure that accounts for decentralized energy market settings. The mathematical optimisation problem formulation involves the bilevel model in which a welfare-maximizing transmission system operator makes investments in transmission lines at the upper level while considering power market dynamics at the lower level. To account for deregulated energy market structure, we assume the generation com- panies at the lower level make generation capacity investment decisions as either price takers in perfect competition or being capable to influence the price in a Cournot Oligopoly. Considering alternative levels for transmission

infrastructure expansion budget, carbon emission taxes and monetary incentives for renewable generation capacity expansion, we study how various compositions of these three factors affect the share of renewable generation in the total generation mix. The preliminary results suggest the limited efficiency of these measures when applied individually, therefore this investigation aims to identify the best configuration of these measures to meet ambitious CO2 reduction targets.

A stochastic bi-level approach for dynamic electricity pricing in the retail market

Patrizia Beraldi (University of Calabria) and Sara Khodaparasti (University of Calabria)

In this talk we present a stochastic Bi-Level approach for the pricing problem faced by a retailer operating in the electricity market. The offered rates are time-differentiated and are supposed to be announced with short notice. The pricing decisions are influenced by the procurement plan that the retailer defines also exploiting his local energy system composed by photovoltaic panels and a battery storage device. To account for the inherent uncertainty affecting the main parameters involved in the decision process, i.e. the wholesale electricity prices and weather-related variables influencing the solar production, we propose a stochastic Bi-Level formulation based on the two-stage stochastic programming paradigm. The retailer-consumer interaction is modelled as a Stackelberg game, where the retailer, acting as leader, decides first by defining the electricity rates, whereas the consumer, acting as follower, reacts to the retailer's decisions by scheduling the flexible loads with the aim of minimizing the electricity bill. A single level reformulation of the stochastic BL model is derived by exploiting the specific problem structure. Preliminary numerical results carried out on a real case study are presented and discussed.

Optimization in carbon emissions markets

Jörgen Blomvall (Linköping university)

The term structure representing future carbon emission costs cannot be directly observed, it has to be estimated by an inverse problem. A non-parametric inverse problem to obtain accurate measurements of the term structure of EU emission allowances (EUA) within the emission trading system (ETS) for carbon credits is presented. From a time series of measurements, factor analysis is used to determine the systematic risk factors, which allow determination of the risk and to do performance attribution for EUA portfolios. A stochastic programming model for hedging the risk in a EUA portfolio, will also be presented.

The algorithm OPTCON: optimal control of dynamic stochastic economic models

Dmitri Blueschke (Alpen-Adria-Universität Klagenfurt), Viktoria Blueschke-Nikolaeva (Alpen-Adria-Universität Klagenfurt) and **Reinhard Neck** (Alpen-Adria-Universität Klagenfurt)

OPTCON is an algorithm for the optimal control of nonlinear stochastic systems which is particularly applicable to economic models. It delivers approximate numerical solutions to optimum control (dynamic optimization) problems with a quadratic objective function for nonlinear economic models with additive and multiplicative (parameter) uncertainties. The algorithm was first programmed in C# and then in MATLAB. It allows for deterministic and stochastic control, the latter with open-loop (OPTCON1), passive learning (open-loop feedback, OPTCON2) and active learning (closed-loop, dual or adaptive control, OPTCON3) information patterns. In particular, the parts of the algorithm with open-loop feedback and closed-loop information patterns are new and the elements of its development are presented in more detail in this paper.

Rare events, asymptotic analysis and stochastic optimization

Karl Breitung (TU Munich)

In structural reliability in civil engineering an important problem is the calculation of rare event probabilities. Usually one has a limit state function $g(\mathrm{x})$ which defines the rare event F by $F = \{g(\mathrm{x}) < 0\}$. Using the multivariate Laplace method one can show that asymptotically for $\beta \to \infty$ the probability content of βF is concentrated near the points on the limit state surface with minimal distance to the origin, the design points. For high dimensional problems however this asymptotic approximation deteriorates with increasing dimension, so it is no more sufficient. A solution championed in the last years (called subset simulation) is to use a sequential approach, i.e. to start from a value $c_1 > 0$ such that $\Pr(F_1) = \{g(\mathrm{x}) < c_1\}$ is large and then to approximate the searched probability by a sequence of conditional probabilities $\Pr(F_k)$ from the sequence $c_1 > c_2 > \cdots > c_k$ where $F_k = \{g(\mathrm{x}) < c_k\}$ with $c_k = 0$. This gives: $\Pr(F) = \Pr(F_1) \prod_{i=1}^{k} \Pr(F_{k+1}|F_k)$, where $F_{k+1} = F$. However this approach has some deficiencies. It is a sequential stochastic optimization method which might lead to wrong results. Further with decreasing probabilities the variance of the estimators increases. A better solution for the problem seems to be a combination of asymptotic approximation methods and importance sampling. First the design points are determined and then in their neighborhood by importance sampling the estimator is improved.

Risk-averse formulation of a bilevel stochastic linear problem with integer variables

Johanna Burtscheidt (University Duisburg-Essen) and Matthias Claus (University Duisburg-Essen)

Stochastic bilevel problems arise from the interaction between two decision makers at different levels of the hierarchy, where the lower level problem is affected by a random vector. In our context, the decision vector of the follower is additionally integer. We present a deterministic formulation for a bilevel problem under stochastic uncertainty based on special risk measures. In particular, the structural properties of the optimal value function of this model are considered.

A learning exercise in modelling climate-related risks in insurance industry: exploratory scenarios

Maria Carannante (University of Salerno) and **Valeria D'Amato** (University of Salerno)

Climate change risks, i.e. the risks arising from the significant structural changes to the economy needed to achieve net-zero emissions – ‘transition risk’ and risks associated with higher global temperatures – ‘physical risks’, rapidly gained high priority in the agendas of the governments and institutions. Policymakers need to probe the resilience of the financial system and understand the vulnerability of the Countries to climate change. The specificity of the topic “requires to go beyond the usual financial/insurance perimeter” (EIOPA 2021). Running exploratory scenarios could allow policymakers to set up a risk management process for facing the impact of new risk that is likely to be structural, irreversible and non-linear (EIOPA 2021). As pointed out in CEP 2020 “a growing number of market participants and financial authorities are exploring which metrics to use to capture climate risks, and to what extent the use of different metrics delivers heterogeneous results”. In this context, our research focuses on a learning exercise in modelling climate-related risks by exploratory scenarios related to the physical risk in particular regarding the impact on the invested assets of the insurance industry. The scenario specifications we propose build upon a dependent naïve Random Forest. Modelling climate change scenarios using random forest (RF) (Breiman 2001) techniques requires a particular focus on the dependency between data. Climate events are interdependent and an event that occurs on a local scale has a ripple effect on the rest of the planet. Just thinking about the melting of glaciers, which increases the amount of water on the rest of the planet (geographical dependency) or the effects of emissions into the atmosphere, whose effects last over time (time dependence). In this sense, we propose a RF model for dependent data that allows for building a scenario with a systemic approach, highlighting the possible interdependencies between the data, without however losing the explainability as occurs in deep learning models. In particular, a RF algorithm that exploits a bagging strategy for dependent data is proposed. Primarily, we refer to bagging for time-dependent data, using the sieve bootstrap to select the subsample of data for the trees of the forest. In this way, each tree is obtained by maintaining the data dependency structure and not through a traditional bootstrap, which assumes that the data are independent of each other.

EIOPA BOS-21/579, 2021, Methodological Principles of insurance stress testing - climate change component

CEP Council on Economic Policies, 2020, Climate Financial Risks: Assessing Convergence, Exploring Diversity

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Renewable energy communities, digitalization and information

Marta Castellini (Università degli Studi di Brescia, Fondazione Eni Enrico Mattei), Michele Moretto (University of Padua), Sergio Vergalli (Università degli Studi di Brescia, Fondazione Eni Enrico Mattei) and Dirk Bergemann (Yale University)

In this work we study the case of agents willing to invest in renewable energy plants and also interested in joining a Renewable Energy Community (REC). Specifically, we focus on the case of a REC characterized by a Peer-to-Peer(P2P) Platform, which is supervised, in terms of electricity production and consumption, by an Energy Service Company (ESC), operating as a monopolist. The ESC sells energy to all the agents as well as a Smart Grid (SG) service for the REC operation. The provision of the SG service requires collection of energy data from the members of the REC. Such information is needed to assure the exchange of energy within it. On the other hand, the monopolist employs the collected information to identify the optimal price of energy. Under this framework, we study two different cases: one in which the ESC behaves as a profit-maximizer and the other as a utilitarian planner, whose aim is to achieve decarbonization goals while also assuring that the data collection policy performed by the monopolist is undertaken in a way such that the privacy of the consumers is safeguarded. In both cases we focus on: i) the birth of the REC, thus the way in which the latter is created, ii) its size, thus the number of members as well as the overall installed capacity and iii) the use of the information collected from the REC's members by the ESC, which allows the latter to identify the preferences of the former. On the other hand, we do not deal with the criteria of how sharing benefits among the members of the REC, thus in our model the agents are treated symmetrically. Considering the social dimension of data discussed by Bergemann et al. (2020) and the relevance of information externalities presented by Choi et al. (2019), our main aims are the study of: i) the monopolist optimal data collection policy, ii) understand the agents' benefit of becoming members of the REC, given the monopolist data collection strategy; iii) identify the effect on/of the REC dimensions (number of members). We then compare the outcomes of such a framework with the case in which the ESC behaves as utilitarian planner.

Data-driven robust optimization with cluster-based anomaly detection

Aakil Caunhye (University of Edinburgh) and Douglas Alem (University of Edinburgh)

We propose a data-driven robust optimization approach where cluster Voronois are used to identify and discard anomalous regions of the uncertainty set. We identify anomalous regions via sparse clusters and construct Voronois using perpendicular bisecting hyperplanes. With the recognition that not all anomalous data result in anomalous decisions, we also develop a method to maximize the size of the non-anomalous regions, such that decisions remain non-anomalous. Our anomaly-based models show marked improvements in performances over the classical robust optimization with polyhedral uncertainty on a disaster response model that uses real data from the last 18 years of impacts of floods and landslides in Brazil.

A financial trading system with optimized signal aggregation, trading rule definition and indicator setting

Marco Corazza (Ca' Foscari University of Venice), **Claudio Pizzi** (Ca' Foscari University of Venice) and Andrea Marchioni (University of Tuscia)

Algorithmic trading, a widespread practice in the financial industry, is based on the automatic signal generation based on trading rules of one or more technical analysis indicators. Generally, the parameters for computing the indicators (such as the time windows length), the trading rules (converting the indicator into a trading signal) and the weights for signal aggregation (for combining the signals from a plurality of indicators) are established by the trader based on her experience and are treated as fixed inputs of the trading algorithm. In recent literature, simple optimization systems are introduced by varying only one category of parameters at a time, that is only the indicators setting, or only the trading rules definition, or only the signal aggregation while keeping the remaining parameters fixed. Our research goes further and proposes an automated trading

system based on simultaneous optimization of the three categories of parameters. More precisely, we consider four technical indicators widely used in financial practice, the Exponential Moving Average (MA), the Relative Strength Index (RSI), the Moving Average Convergence/Divergence (MACD), and the Bollinger Bands (BB) and we determine the optimal signal aggregation, trading rule definition and indicator setting using the Particle Swarm Optimization (PSO) metaheuristic over two commonly used fitness functions, that are the net capital at the end of the trading period (for the maximization of the return) and the Sharpe ratio at the end of the trading period. We apply our trading system to a set of financial stocks belonging to the Italian index FTSE MIB over a multi-year period for training and testing. We generally achieve superior performance both in sample and out of sample, using as benchmarks a standard technical analysis system and a buy-and-hold strategy.

Conditionally law-invariant risk measures and applications

Bruno Costa (Khalifa university), Luciano de Castro (University of Iowa), Antonio F. Galvao (Michigan State University) and Jorge P. Zubelli (IMPA and Khalifa University)

Risk measures play a fundamental role in Financial Analysis and Portfolio Management. Law-invariance is crucial in the applicability so as to allow assessing risk from historical data using statistical methods. This talk generalizes existing representation theorems for unconditional risk measures to the conditional case, for both the static and dynamic cases. First, we define the concept of conditional law-invariance for conditional risk measurements and show how it leads to a representation of conditional convex and upper continuous risk measure in terms of integrals of conditional quantiles. Second, an equivalent representation in terms of conditional average value-at-risk is derived. Moreover, transition capacities are also introduced, allowing us to provide the connection between the additivity along conditional comonotonic vectors for a conditional risk measure and its representation as a Choquet's integral along a suitable family of transition capacities. Finally, we restrict ourselves to one-step law-invariant and iterative dynamic risk measures to demonstrate their time-consistency and relevance, obtaining representation theorems for such families in a finite-time setting.

Renewable energy investments, support schemes and the dirty option

Domenico De Giovanni (University of Calabria) and Elena Yakimova (University of Calabria)

In a real options framework, we analyse the behaviour of a large energy producer who can invest in a portfolio of Renewable Energy Source (RES) and dirty energy source. Competitive fuel prices challenge the investments in RES. Given a budget constraint, the agent allocates the optimal capacities of both energy instalments and selects the optimal investment time. We use the model to compare the effectiveness of classical support schemes such as Feed-in Taris or Green Certicate with respect to forms of taxation of dirty technology such as Carbon Taxes or Carbon Permits. This paper proposes a conceptual framework and qualitative analysis to understand which support system enhances the attractiveness of renewable energy investments.

Conjugacies for sparse optimization

Michel De Lara (Cermics, École des Ponts ParisTech) and Jean-Philippe Chancelier (Cermics, École des Ponts ParisTech)

The support of a vector (with a finite number of real components) is the set of indices with nonzero entry. Functions of the support are widespread in sparse optimization, like the so-called cardinality function which counts the number of nonzero components of a vector. Functions of the support of a vector have the property to be zero-homogeneous. Because of that, the Fenchel conjugacy fails to provide relevant analysis. In this paper, we display a class of conjugacies that are suitable for functions of the support. For this purpose, we suppose given a (source) norm. With this norm, we define, on the one hand, a family of so-called local coordinate-K norms (with K a subset of the indices) and, on the other hand, a coupling between the finite-dimensional vector space and itself, called Capra (constant along primal rays). Then, we provide formulas for the Capra-conjugate and biconjugate, and for the Capra-subdifferentials, of functions of the support in terms

of the local coordinate-K norms. The special case of nondecreasing submodular functions of the support is considered.

Machine learning techniques in joint default assessment

Margherita Dorina (Politecnico di Torino), Elisa Luciano (Università di Torino) and **Patrizia Semeraro** (Politecnico di Torino)

This paper studies the consequences of capturing non linear dependence among the covariates that drive the default of different obligors in the overall riskiness of their credit portfolio. Joint default modeling is, without loss of generality, the classical Bernoulli mixture model. Marginal and joint defaults depend on a set of covariates, common to all obligors. Linear and nonlinear dependence among covariates is captured by ML methods, while LR captures linear dependence only. We show through an application to credit card datset that the ability of machine learning methods to capture nonlinear dependence among the covariates produces higher default correlation and therefore more conservative risk measures of the quantile type.

A MIP approach to tackle the Optimal Power Flow problem with probabilistic constraints

Concepción Domínguez (Universidad de Málaga), Álvaro Porras Cabrera (Universidad de Málaga), Juan Miguel Morales González (Universidad de Málaga) and Salvador Pineda (Universidad de Málaga)

The Optimal Power Flow (OPF) problem consists in minimizing the operating cost for electric power plants while determining the best operating levels in order to meet demands given throughout a transmission network. In this work, we tackle the resolution of a probabilistically-constrained version of the DC OPF problem with uncertain demand. The chance-constraint requires that the joint probability that the system's inequalities related to physical characteristics (power generation and line-flow limits in the transmission network) be greater than some parameter. We assume that the random vector follows a finite discrete distribution (following the Sample Average Approximation (SAA)) and propose a deterministic large-scale mixed-integer programming reformulation of the problem. The resultant MIP is then tightened by means of valid inequalities and its size is reduced using preprocessing and screening methods. Extensive computational experiments are provided to test our results.

Distributionally robust stochastic programs with side information based on trimmings

Adrián Esteban-Pérez (University of Málaga) and Juan Miguel Morales (University of Málaga)

We consider stochastic programs conditional on some covariate information, where the only knowledge of the possible relationship between the uncertain parameters and the covariates is reduced to a finite data sample of their joint distribution. By exploiting the close link between the notion of trimmings of a probability measure and the partial mass transportation problem, we construct a data-driven Distributionally Robust Optimization (DRO) framework to hedge the decision against the intrinsic error in the process of inferring conditional information from limited joint data. We show that our approach is computationally as tractable as the standard (without side information) Wasserstein-metric-based DRO and enjoys performance guarantees. Furthermore, our DRO framework can be conveniently used to address data-driven decision-making problems under contaminated samples. Finally, the theoretical results are illustrated using some numerical experiments.

Robust and distributionally robust optimization models for linear support vector machine

Daniel Faccini (Università degli Studi di Bergamo), Francesca Maggioni (Università degli Studi di Bergamo) and Florian A. Potra (University of Maryland)

In this talk we present novel data-driven optimization models for Support Vector Machines (SVM), with the aim of linearly separating two sets of points that have non-disjoint convex closures. Traditional classication algorithms assume that the training data points are always known exactly. However, real-life data are often

subject to noise. To handle such uncertainty, we formulate robust models with uncertainty sets in the form of hyperrectangles or hyperellipsoids, and propose a moment-based distributionally robust optimization model enforcing limits on rst-order deviations along principal directions. All the formulations reduce to convex programs. The efficiency of the new classiers is evaluated on real-world databases. Experiments show that robust classiers are especially benecial for data sets with a small number of observations. As the dimension of the data sets increases, features behavior is gradually learned and higher levels of out-of-sample accuracy can be achieved via the considered distributionally robust optimization method. The proposed formulations, overall, allow nding a trade-off between increasing the average performance accuracy and protecting against uncertainty, with respect to deterministic approaches.

Multi-stage Stochastic Portfolio Optimization under Conditional Value at Risk

Edoardo Fadda (Politecnico di Torino), Daniele Manerba (University of Brescia) and Renata Mansini (University of Brescia)

The intent of a rational investor is to maximize return while minimizing risk. This goal has been the foundation of Markowitz's portfolio theory and paved the way to the development of several models for computing a portfolio selection that results to be optimal for a given trade-off between expected profit and suitable risk measures. In such a framework, which considers a long-term investment horizon, the main decision concerns the initial budget allocation and no recourse actions on the portfolio can be taken over time. In this work, we will study a multistage stochastic portfolio optimization problem which allows to change the budget allocation over the available assets to accommodate the investor's choices against unfavourable return realizations. In this setting, contrarily to Markowitz's portfolio theory, the usual goal is to maximize a utility function (commonly, the expected profit over the entire investment horizon). In our case, we want to explicitly optimize the so-called Conditional Value at Risk (CVaR), i.e. the expected value of the left tail of the distribution of portfolio return under a specified β−quantile, $\beta \in [0, 1]$. As usually done in Stochastic Programming problems, we will adopt a Montecarlo simulation for discretizing the distribution of shares' return. However, considering the CVaR within a multistage stochastic optimization problem leads to several issues. First, a huge number of scenarios is required to correctly model such a risk measure, thus increasing the computational burden to solve the problem. Second, and most important, it is not trivial to decide at which stage the CVaR should be evaluated. In fact, if the measure is computed only at the final stage, several intermediate periods might be characterized by bad performance. Moreover, the estimation of the objective function at an advanced stage, besides requiring more scenarios, could lead to non robust decisions at the earlier stages. Instead, too many intermediate risk-averse requirements could lead to an over-constrained problem and, in turn, to potentially limited returns. We will overcome the first issue by using recent results on decomposition techniques, which allow us to apply Progressive Hedging-like algorithms to our multistage stochastic portfolio problem under CVaR. Concerning the second issue, we propose a more flexible optimization setting in which the CVaR is evaluated only at a subset of stages (check steps) along the horizon. Clearly, the choice on the number and the timing of the check steps is critical and thus deserves to be accurately studied. Through several numerical experiments, we will validate the efficiency of the solution algorithm developed and assess different investor's policies concerning check step features.

Using SVD to Handle Ill-Conditioning in Optimization Problems with Applications to Portfolio Theory

Claudia Fassino (Università degli Studi di Genova), Maria-Laura Torrente (Università degli Studi di Genova) and **Pierpaolo Uberti** (Università degli Studi di Genova)

Quadratic programming problems (QPs) minimize a quadratic objective function under linear equality and/or inequality constraints. These problems are popular in many branches of applied mathematics because of their simple formalization and their great capacity to fit in a stylized way complex real-life problems. Nevertheless, despite the apparent simplicity and tractability, solving a QP becomes hard when the matrix describing the quadratic objective function and/or the matrix describing the linear constraints are ill-conditioned. We treat the latter case, since we consider quadratic programming problems whose numerical instability derives from their linear equality constraints. We propose a new theoretical approach to rewrite the QP in an equivalent reformulation by using the singular value decomposition and substituting the ill-conditioned original matrix of the restrictions with a suitable optimal conditioned one. The proposed novel approach is showed, both empirically and theoretically, to solve ill-conditioning related numerical issues, not only when they depend on bad scaling and are relative easy to handle, but also when they result from almost collinearity and numerically rank-deficient matrices are involved. Furthermore, our strategy looks very promising even when additional inequality constraints are considered in the optimization problem, as it occurs in several practical applications, e.g. in the portfolio optimization theory. In this framework, even if no closed form solution is available, we show, through empirical evidence, how the equivalent reformulation of the original problem greatly improves the performances of MatLab's quadratic programming solver and Gurobi. The experimental validation of such results is provided through numerical examples performed on real financial data in the portfolio optimization context.

A theoretical validation of the DDMRP reorder policy

Daniela Favaretto (Ca’ Foscari University of Venice), Alessandro Marin (Ca’ Foscari University of Venice) and **Marco Tolotti** (Ca’ Foscari University of Venice)

A recent heuristic called Demand Driven MRP, widely implemented using modern ERP systems, proposes an algorithm to set a reorder policy that accounts for stochastic demand and lead times. Our primary goal is to propose a theoretical foundation for such a heuristic approach. To this aim, we develop an optimization model inspired by the main principles behind the heuristic algorithm. Specifically, controls are of the type (s(t), S(t)) with time-varying thresholds that react to short-run real orders. We also consider service levels derived as tail risk measures to ensure fulfillment of realized demand with a predetermined probability. Finally, we use our model as a benchmark to theoretically validate and contextualize the aforementioned heuristic.

The multinomial logit model with sequential offerings

Jacob Feldman (Olin Business School) and **Danny Segev** (Tel Aviv University)

In this paper, we consider the assortment problem under the Multinomial Logit model with sequential offerings, recently proposed by Liu, Ma, and Topaloglu (2020) to capture a multitude of applications, ranging from appointment scheduling in hospitals, restaurants, and fitness centers to product recommendation in e-commerce settings. In this problem, the purchasing dynamics of customers sequentially unfold over T stages. Within each stage, the retailer selects an assortment of products to make available for purchase, with the intent of maximizing expected revenue. However, motivated by practical applications, the caveat is that each product can be offered in at most one stage. Moving from one stage to the next, the customer either purchases one of the currently offered products according to MNL preferences and leaves the system, or decides not to make any purchase at that time. In the former scenario, the retailer gains a product-associated revenue; in the latter scenario, the customer progresses to the next stage, or eventually leaves the system once all T stages have been traversed. We focus our attention on the most general formulation of this problem, in which purchasing decisions are governed by a stage-dependent MNL choice model, reflecting the notion that customers’ preferences may change from stage to stage due to updated perceptions, patience waning over time, etc. Concurrently, we consider a more structured formulation, in which purchasing decisions are stage-invariant, utilizing a single MNL model across all stages. Our main contribution comes in the form of a strongly polynomial-time approximation scheme (PTAS) for both formulations of the sequential assortment problem in their utmost generality. We provide evidence for the practical relevance of these theoretical findings through extensive numerical experiments. Finally, we fit our sequential model to historical search data from Expedia’s hotel booking platform. We observe substantial gains in fitting accuracy when our model is benchmarked against other well-known choice models designed for the setting at-hand.

Scheduling hydropower releases under price and inflow comovements

Stein-Erik Fleten (Norwegian University of Science and Technology), Andreas Kleiven (Norwegian University of Science and Technology) and Simon Risanger (Norwegian University of Science and Technology)

Hydropower producers estimate the opportunity value of their water, known as a water value, by comparing current prices to future opportunities. When hydropower dominates the energy mix, the system's hydrological state predominantly governs supply and thus prices. Despite this intuitive relationship, industry practice is to assume that inflow to reservoirs and prices are independent when they establish operational policies one to two years ahead. To investigate the impact of this assumption, we formulate the hydropower scheduling problem as a Markov decision process (MDP) and develop a novel price model that considers the joint dynamics of forward prices and inflows. We find that producers underestimate their water value when they ignore comovements between price and inflow. The dependency makes producers more willing to postpone generation and tolerate slightly higher spillage risk. This is because high inflow periods tend to observe low prices and the reservoir capacity is limited. Nevertheless, a case study of a hydropower plant with industry data suggests modest economic losses in practice. Our numerical results suggest a modest potential gain of 0.17% in expected revenue and approximately unchanged revenue variance if producers consider the comovements when establishing an operational policy.

A stochastic program for the planning of recharging and relocation activities in car-sharing systems

Lars C.E. Folkestad (Norwegian University of Science and Technology), Mathias D. Klev (Norwegian University of Science and Technology), **Kjetil Fagerholt** (Norwegian University of Science and Technology) and Giovanni Pantuso (University of Copenhagen)

We consider the Stochastic Electric Car-Sharing Relocation Problem (SECReP), which is an important planning problem arising in car-sharing systems with electric cars. The SECReP deals with how to optimally route employees to move cars in need of recharging to charging stations and to relocate cars to better meet uncertain demand in car-sharing system. When traveling between car-moves, it is assumed that the employees use folding bikes or public transport. The SECReP is formulated as a bi-objective two-stage stochastic mixed-integer programming (MIP) model. The model takes as input an initial distribution of cars and employees, as well as a probability distribution of rentals and returns of cars, and returns a vehicle relocation plan for the following planning horizon. The vehicle relocation plan specifies which cars should be moved to where and which employees should perform the different car-moves in what order. The proposed MIP model includes two lexicographically ordered objective functions: 1) maximizing the number of cars in need of charging that are moved to charging stations, and then 2) maximize the operational profit. In the first stage of the stochastic programming model, which is defined by a given number of employee tasks or car-moves, all customer demand is assumed known. In the second stage, several possible demand scenarios are considered to generate solutions that perform better concerning the uncertain future demand. In order to solve real-sized instances of the SECReP, we propose a novel Adaptive Large Neighborhood Search (ALNS) heuristic adapted to the bi-objective two-stage stochastic programming model. The ALNS heuristic is tested on a number of realistic test instances generated based on data from a Norwegian car-sharing company. The computational tests show that the ALNS heuristic finds high-quality solutions within a reasonable amount of time and that the stochastic program provides an expected profit increase of approximately 18% compared to its deterministic counterpart.

Exact quantization of multistage stochastic problems

Maël Forcier (Ecole des Ponts), Stéphane Gaubert (Ecole polytechnique) and Vincent Leclère (Ecole des Ponts)

We show that the multistage stochastic linear problem (MSLP) with an arbitrary cost distribution is equivalent to a MSLP on a finite scenario tree. We establish this exact quantization result by analyzing the polyhedral structure of MSLPs. In particular, we show that the expected cost-to-go functions are polyhedral and affine on the cells of a chamber complex, which is independent of the cost distribution. This leads to new complexity

results, showing that MSLP is fixed-parameter tractable. Understanding this polyhedral structure also allows us to derive new algorithms such as generalized adaptive-partion based methods and secondary simplex methods that we will briefly present.

Stochastic Dual Dynamic Programming algorithms for non-finitely supported distributions

Maël Forcier (CERMICS, Ecole des Ponts) and **Vincent Leclere** (ENPC)

Stochastic Dual Dynamic Programming (SDDP) is a well known algorithm for multistage stochastic program. Due to its success in numerous applications (energy, finance, inventory management, ...) multiple variants have been proposed. Some rely on non-linear cuts (e.g. SLDP, MIDAS), or new linear cuts (SDDiP) to extend the scope of SDDP; others propose alternative exploration strategy (EDDP, Problem-Child methodology) For all these variants the convergence theory is generally not well understood and crucially rely on a finite noise, and hence finite scenario tree, assumption. In this talk we propose a flexible framework that incorporate more than 10 variants of SDDP. The main idea is that all these algorithms maintain an upper and lower (potentially inexact) approximations of the cost-to-go functions, sometimes without computing it. In this framework we obtain a convergence speed that does not make the finite noise assumption. We also briefly point how SDDP can be implemented in for some multistage linear program with non-finite cost distribution.

Extreme Value Theory-based Deterministic Equivalent Closed-Form for special classes of Stochastic Programs

Lohic Fotio Tiotsop (Politecnico di Torino), Michel Bierlaire (Ecole Polytechnique Fédérale de Lausanne), Edoardo Fadda (Politecnico di Torino) and **Daniele Manerba** (Università degli Studi di Brescia)

Being able to derive an analytical expression of the expected optimum of the second-stage problem is a necessary requirement to obtain a closed deterministic form of a two-stage Stochastic Programming (SP) problem. However, in practice, finding such an analytical expression is hindered by the complexity of the multidimensional integral from which it derives, given that the probability distribution of the random variables representing the uncertainty is completely known. In this work, we consider and formally define a large class of two-stage Stochastic Programs whose second-stage expected optimum is Decomposable into a finite number of expectations of Extreme Values (tsSP-DEV). Typical applications of tsSP-DEVs can be found, e.g., in location-allocation problems under allocation costs uncertainty. In a sense, a tsSP-DEV involves characteristics both from the classical SP paradigm and from the Robust Optimization one. In fact, the tsSP-DEV optimization perspective is still focused in making here-and-now decisions by also evaluating the expected value of an uncertain problem over all the possible future situations, but assuming that such a value can be obtained as a function of extreme future behaviors. We show that a closed-form analytical expression of the expected second-stage optimum of any tsSP-DEV can be derived by exploiting some results coming from the Extreme Value Theory [1], and thus an equivalent deterministic version of the SP problem can be obtained. This can be done under the mild hypothesis that the involved uncertain data follow a Multivariate Extreme Value (MEV) distribution. The MEV family includes many common distributions, and some of them are of practical interest since they enable a modeling of the second-stage problem uncertainty structure through well-known and widely used Discrete Choice Models (e.g., Logit, Nested Logit, Cross-Nested Logit). A tsSP-DEV special case, named tsSP-DCP, is further defined. In a tsSP-DCP, the second stage consists of a sequence of independent Discrete Choice Problems, each one triggered or weighted by the value of a specific first-stage variable. In this case, the deterministic equivalent problem results to be linear and thus further properties can be derived. This allows to well-approximate many realistic uncertain MILP problems by solving their deterministic versions [2]. A numerical show-case will validate our approach in terms of efficiency and effectiveness with respect to scenario-based paradigms. Finally, some multi-stage extensions of the results will be discussed [3].

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A new framework to generate Lagrangian cuts in multistage stochastic mixed-integer programming

Christian Füllner (Karlsruhe Institute of Technology), Andy X. Sun (Massachusetts Institute of Technology) and Steffen Rebennack (Karlsruhe Institute of Technology)

Based on recent advances in Benders decomposition and two-stage stochastic integer programming we present a new generalized framework to generate Lagrangian cuts in multistage stochastic mixed-integer linear programming (SMILP). This framework can be incorporated into decomposition methods for multistage SMILPs, such as the stochastic dual dynamic integer programming (SDDiP) algorithm. We show how different normalization techniques can be applied in order to generate cuts satisfying specific properties with respect to the epigraph of the value functions, e.g. having a maximum depth or being facet-defining. In addition, we show that the proposed methodology can be extended to cases where regularized value functions are considered. We provide results for the computational comparison of our proposed cut generation approach with existing techniques from the literature, as well as the comparison of different normalization techniques within our framework.

Generalized Nash equilibrium models for asymmetric river systems

Steven A. Gabriel (University of Maryland) and Nathan T. Boyd (University of Maryland)

We present a novel approach to balancing the asymmetry in river systems relative to downstream and upstream users. The resulting models allow for consumptive loss-reduction markets whereby downstream users can pay upstream ones to improve losses in their systems. The resulting models are instances of mixed complementarity problems (MCPs) given separate optimization models by each river user. We show benefits to establishing such markets which are not usually present for water but are so for other infrastructure areas like energy and transportation. We present both theoretical and numerical results to highlight the benefits of the approach.

Tri-level equilibrium modeling for energy-environmental planning

Steven Gabriel (University of Maryland), Fabricio Oliveira (Aalto University), **Olli Herrala** (Aalto University) and Tommi Ekholm (Finnish Meteorological Institute)

In this presentation we present new results for solving tri-level equilibrium models. These formulations allow for a regional/national policy-maker at the top, a network operator in the middle, and network users at the bottom level. We present both general theoretical results as well as those geared at infrastructure (e.g., energy, the environment). We discuss the theoretical aspects of casting tri-level problems as LPCC (linear program with complementarity constraints) equivalents, the necessary assumptions for optimality and approaches for overcoming some of the challenges that can arise in the formulation. We also present practical implementation insights for modelling the resulting LPCC using SOS1 constraints and spatial branch-and-bound. The main application discussed in this presentation is an energy market model where a regional policy maker imposes taxes on energy sources, the middle-level transmission system operators trade electricity between the nodes and the bottom level producers maximize their profits from producing and selling energy in a Nash-Cournot oligopoly setting.

Penalty functions in maximum likelihood estimating regime switching matrices and sectoral conditional migration probabilities

Timon Gaertner (Provincial Statistics Institute - ASTAT), Serguei Y. Kaniovski (Austrian Institute of Economic Research - WIFO) and **Yuri M. Kaniovski** (Free University of Bozen)

We demonstrate that migration counts bear sufficient information for estimating both industry-specific conditional migration matrices and the Markovian regime switching matrix. Debtors are classified into S industry sectors and M non-default credit classes. Assuming that the migration counts are sampled according to a mixture of multinomial distributions, several likelihood functions are written down. To account for the variety of almost-stationarity patterns exhibited by business cycles, penalty terms are suggested. The technique is tested on a S&P's dataset. The estimated regime switching matrices are compared with their counterparts evaluated according to the OECD data. Analyzing the losses generated by simulated migrations, we compare quantitatively different parameterizations of the model.

Solver SQG for stochastic optimization of complex network models by stochastic gradient methods: optimization of simulation models

Alexei Gaivoronski (NTNU)

We describe the structure of the SQG solver developed for solution of complex nonlinear stochastic optimization problems. Its field of application includes optimization of simulation models, nonlinear stochastic optimization with substantial number of random parameters, bilevel stochastic optimization and stochastic equilibrium problems. In this talk we present its different applications to network optimization problems, including water resources management, transportation, energy, financial networks.

Scenario optimization with relaxation: a new theory for data-driven decision with improved performance

Simone Garatti (Politecnico di Milano) and Marco Campi (University of Brescia)

Scenario optimization is by now a well established technique to perform designs in the presence of uncertainty. It relies on domain knowledge integrated with first-hand information that comes from data and generates solutions that are also accompanied by precise statements of reliability. In this presentation, we venture beyond the traditional set-up of scenario optimization by introducing and analyzing the concept of constraints relaxation. By a solid theoretical underpinning, we show that this new paradigm furnishes fundamental tools to perform designs that meet suitable compromises between robustness and performance.

On a two-stage stochastic binary quadratic model for Cross-Dock infrastructure Design problem under uncertainty, S-CDD

Maria Araceli Garin (University of the Basque Country), Laureano F. Escudero (King Juan Carlos University) and Aitziber Unzueta (University of the Basque Country)

A two-stage stochastic binary quadratic optimization model is presented for the Cross-Dock infrastructure Design (CDD) problem, where the strip and stack related doors as well as their corresponding capacity levels must be decided at the first stage. The problem to tackle is the decision-making planning on the number of strip and stack doors and the capacity of each of them under uncertainty on the sets of origin and destination nodes in real-life and, then, on the number of product pallets from each origin node to each destination one to transverse the cross-dock. The other source of uncertainty that is considered in this work is the varying capacity disruption, due to different reasons as sabotage, misuse, etc. So, once decided on the contents of each scenario where the uncertainty is realized (a crucial topic out of the scope of this work), the next step in the proposal is to decide on the cross-dock infrastructure. The goal is to minimize the cross-dock infrastructure installation cost plus the expected cost of the standard and outsourcing operations in the given scenarios. That standard operation consists of the assignment of vehicle (transporting the product pallets) to the strip doors, the pallet consolidation, and its assignment to the stack ones, for a given net capacity of the doors (as the result of subtracting from it the fraction disrupted in the scenario). The outsourcing operation occurs in

following cases: No strip door is available for entering a pallet load from an origin node, no stack door is available for exiting a pallet load to a destination node, and neither a strip door nor a stack one is available for standard cross-dock operations. Thus, the uncertainty lies in the set of origin nodes, the set of destination ones, and the door capacity diminishing due to possible disruptions in a fine set of scenarios at the second stage. A Linearized mixed Integer Programming (LIP) model, mathematically equivalent to the quadratic one, is introduced by using the Reformulation Linearization Technique RLT1 when the circumstances allow it and otherwise, by using the Fortet (also known as the McCormick) inequalities. Moreover, a Lagrangean decomposition is presented by dualizing the first-stage variable splitting constraints (i.e., the system that builds the cross-dock infrastructure). By exploiting the special structure of the CDD problem, matheuristic algorithms are introduced for obtaining (hopefully, strong) lower bounds as well as (hopefully, good) feasible solutions for the original model.

Recent developments in volatility modelling

Martino Grasselli (University of Padua and DVRC Paris La Défense)

Using a large dataset on major FX rates, we test the robustness of the rough fractional volatility model over different time scales, by including smoothing and measurement errors into the analysis. Our findings lead to new stylized facts in the log-log plots of the second moments of realized variance increments against lag which exhibit some convexity in addition to the roughness and stationarity of the volatility. We then introduce a rough volatility model that takes into account these new stylised facts in a parsimonious way.

Multiobjective robust regret

Patrick Groetzner (Augsburg University) and **Ralf Werner** (Augsburg University)

In this presentation, we consider multiobjective decision problems under uncertainty. In the single criteria case, robust optimization methodology can help to identify solutions which remain feasible and of good quality for all possible scenarios. An alternative method is to compare possible decisions under uncertainty against the optimal decision with the benefit of hindsight, i.e. to minimize the (possibly scaled) regret of not having chosen the optimal decision. In this exposition, we extend the concept of regret to the multiobjective setting and introduce a proper definition of multivariate (relative) regret. All early attempts in such a setting mix scalarization and modelling efforts, whereas we clearly separate both steps. Moreover, in contrast to existing approaches, we are not limited to finite uncertainty sets or interval uncertainty and further, computations remain tractable in important special cases.

An empirical study of the efficiency and influence factor of selected OECD life insurance markets

Biwei Guan (Technical University of Ostrava)

Efficiency has recently become a popular measure for assessing the state of the insurance industry and the competitiveness of insurance companies. The goal of this paper is to examine the efficiency of 10 OECD life insurance markets from 2014 to 2019, as well as to offer methods for improving the efficiency of potentially inefficient markets and find out the factors that influence efficiency. To uncover the associated outcomes, we use a three-stage data envelopment analysis, stochastic frontier slack regression, Malmquist index, and multiple linear regression model. The Greek life insurance market is the least efficient, followed by Hungary; the German life insurance market is efficient. The improvement of total factor productivity in most life insurance market is due to the support of its technical efficiency change. The log of total assets and the ratio of return on equity has a positive influence on technical efficiency; the debt to ratio has a negative influence on technical efficiency. And the largest impact on technical efficiency is total assets with the highest confidence level, followed by return on equity and debt to assets ratio.

Twenty Years of Multi-Stage Scenario Generation: Learnings and Pitfalls from Decision Science to Data Science

Ronald Hochreiter (Vienna University of Economics and Business)

In this talk we will summarize the personal experience with multi-stage scenario generation over a time span of twenty years (2001-2021). We will focus on computing dependencies between correlated variables which basically is also the main problem of classification problems in the field of Machine Learning. The learnings and pitfalls from multi-variate, multi-stage scenario generation for stochastic programming will be described and conclusions for future developments for decision science and data science applications will be discussed. Numerical results substantiate the presented findings.

Stochastic Sequential Decision Making In The Conversion From Conventional to Organic Farming

Mahboubeh Jahantab (RMIT University), Babak Abbasi (RMIT University) and Pierre Le Bodic (Monash University)

Organic farming refers to an agricultural system that excludes or strictly limits the use of external inputs such as synthetic fertilizers, herbicides, and pesticides. The adoption of organic farming is affected by the financial difficulties in terms of a decrease in production and an increase in farming costs owning to transitional practices during the conversion from conventional to organic farming. In this study, we aim to find the optimal conversion plan to optimize a farmer's payoff in the conversion to organic farming, with respect to the uncertainty in the crop's revenue that is drawn by uncertainty in the price and yield. We present a multi-period optimization model for the allocation of the farmland among crops and agricultural practices which allows farmers to plan a transition to organic farming while incurring a bounded shortfall of income. The model is calibrated to represent a grower of corn and soybean in Iowa and using a seemingly unrelated regression model, the crops' revenues are simulated and utilized in the numerical experiments. The results show that i) the optimized crop rotation pattern outperforms other policies in the agriculture industry and that ii) the gradual conversion plan decreases the chance of profit shortfall by 11% on average in comparison with whole-farmland conversion.

ZESOpt: energy-system optimization model using derivative-free solvers

Michal Kaut (SINTEF)

We present a model for optimizing the composition of hybrid energy systems. The goal is to find the optimal component selection and sizes, given a power load the system has to satisfy. We focus on zero-emission examples such as off-grid installations with energy generation and storage, or hydrogen-electric hybrid vehicles or boats. An important aspect of such systems is ageing/degradation of components such as batteries or fuel cells. Unfortunately, modelling these aspects lead to non-linear mixed-integer problems, making the model intractable for many practical cases. We try to avoid these issues by modelling the system using a sequence of simulation steps, and optimizing it 'on the outside' using a derivative-free solver. In this talk, we present the setup and some preliminary results.

Decomposition algorithms and solver for distributionally robust mixed-integer programming

Kibaek Kim (Argonne National Laboratory)

We present the decomposition algorithms for solving distributionally robust mixed-integer programming (DRMIP) problems. The two well-known decomposition algorithms for stochastic MIP — Benders and Lagrangian dual decomposition — are reviewed and extended for the distributionally robust optimization variants based on the Wasserstein ambiguity set. In particular, we focus on the recent algorithmic advances in the dual decomposition of DRMIP. We have implemented both Benders and dual decomposition in an open-source solver DSP written in C++, which can run on high-performance computing clusters (HPC) with many CPUs. We demonstrate how DRMIP models can be created in Julia and solved with DSP on HPC. We also present and discuss the numerical results from the methods by using the solver in various instances.

Asymptotic confidence intervals for quantile estimators in nested simulations

Maximilian Klein (University of Augsburg) and Ralf Werner (University of Augsburg)

The Solvency II framework provides a standard formula for the calculation of the risk capital (SCR=Solvency Capital Requirement) in one year, but also gives (life) insurance companies the freedom to develop an own internal model. By using such an internal model, life insurance companies aim to reduce their risk capital, as specific business strategies and diversification effects can be better taken into account by an internal model instead of the predefined standard formula. One way of determining risk capital on the basis of an internal model is to use a nested Monte Carlo simulation, which also is the only reliable basis for comparison for more advanced models such as LSMC or Replicating Portfolios. A nested simulation is mathematically characterized by samples from random variables V and Z from L^2. Thereby, N_1 outer scenarios are used for modelling Z (e.g. for an insurance framework this represents risk factor modelling) and N_2 (conditional) inner scenarios for V . Based on these samples, it is possible to approximate the conditional expected value, e.g. the MCEV by a nested Monte Carlo simulation. In our talk, we will essentially analyze and show for fixed outer scenarios the asymptotic behavior of confidence intervals for quantiles respectively the Value-at-Risk (VaR). We conclude our presentation with a numerical simulation study and a comparison against the only related results from Lan et al. (2007, 2007, 2010). This comparison indicates that the proposed approach leads, on the one hand, to narrower confidence intervals and, on the other hand, to a simpler parameter control.

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Contamination in decision dependent randomness stochastic programs

Miloš Kopa (Charles University) and Tomáš Rusý (Charles University)

Contamination technique is a well-known method for performing stress testing of various stochastic programs. The methodology investigates the effect of perturbation of the underlying probability distribution of the stochastic program by some contamination distribution. Especially the change in the optimal value of the stochastic program is of interest. For this purpose, (local) lower and upper bounds for the optimal value function are constructed. These then give us an interval where the true optimal value of the petrubed program lies. Such bounds were constructed for various model formulations, where uncertainity entered in the usual exogenous way. In this talk we will present an extension of this methodology to a certain class of decision dependent randomness stochastic programs. We will show both, how to calculate lower and upper bounds as well as a practical example of the use of the methodology illustrated on a multistage stochastic program with decision dependent randomness from a financial industry.

Robust approaches in portfolio optimization with stochastic dominance

Karel Kozmík (Charles University) and Miloš Kopa (Charles University)

We use modern approach of stochastic dominance in portfolio optimization, where we want the portfolio to dominate a benchmark. Since the distribution of returns is often just estimated from data, we look for the worst distribution that differs from empirical distribution at maximum by a predefined value. First, we define in what sense the distribution is the worst for the first and second order stochastic dominance. For the second order stochastic dominance, we use two different formulations for the worst case. We derive the robust stochastic dominance test for all the mentioned approaches and find the worst case distribution as the optimal solution of a non-linear maximization problem. Then we derive programs to maximize an objective function over the weights of the portfolio with robust stochastic dominance in constraints. We consider robustness either in returns or in probabilities for both the first and the second order stochastic dominance. We apply all the derived optimization programs to returns of assets captured by Dow Jones Industrial Average, and we analyze the problems in detail using optimal solutions of the optimization programs with multiple setups. The portfolios calculated using robustness in returns turned out to outperform the classical approach without robustness in an out-of-sample analysis.

Trading strategies for battery storages in reserve and spot markets under uncertainty

Emil Kraft (Karlsruhe Institute of Technology), Steffen J. Bakker (Norwegian University of Science and Technology), Stein-Erik Fleten (Norwegian University of Science and Technology) and Wolf Fichtner (Karlsruhe Institute of Technology)

Quantity and price risks determine key uncertainties market participants face in electricity markets with increased volatility, for instance due to high shares of renewables. In the time from day-ahead until real-time, there lies a large variation in best available information, leading to market volatility that flexible assets, particularly battery storages, can exploit economically. This uncertainty reflects in market outcomes, making the determination of optimal trading strategies across different market segments a complex task, especially when considering time-coupling constraints and a horizon of multiple days. The scope of this work is to optimize day-ahead and intraday trading decisions jointly for a battery storage asset under consideration of risk. We develop a multi-stage stochastic program that covers a reserve market, a day-ahead market and an intraday market for several subsequent days. To cope with computational challenges that are caused by temporal dependencies, we apply the Stochastic Dual Dynamic Programming algorithm. We assess the expected profitability as well as the risk exposure, quantified by the conditional value at risk metric, of trading strategies following different risk preferences. As the trade-off between profitability and risk exposure comes naturally when making decisions under uncertainty, we determine optimal trading strategies under different sets of parameters defining the risk preferences and interpret these as efficient frontier of optimal decisions to the problem. We apply the developed model to a case study in the German electricity market, which suits the problem due to its high shares of renewables and its sequential market structure. In Germany, among others there is an established primary reserve market with 4 hour products, followed by a day-ahead spot market with hourly products and subsequently liquid intraday trading with 15 minute products. Based on stochastic models, we generate a set of price scenarios for each considered market segment and deploy them in the developed problem setting. As results, for each trading strategy we obtain detailed bidding curves for each traded product in each market segment. We discuss the different arbitrage rationales contained in the trading strategies. We find that the intraday market appears as a very profitable but risky option, whereas the day-ahead market allows to reduce the risk exposure. Further, providing reserve capacity appears as a mean to hedge risk by diversifying the revenue streams but limits the operational flexibility on the later stages. Finally, we discuss the advantages and particularities of trading battery storage assets compared to asset-free arbitrage trading.

The economics of frequency regulation through electricity storage: An analytical solution

Dirk Lauinger (Ecole Polytechnique Fédérale de Lausanne), Francois Vuille (Etat de Vaud) and Daniel Kuhn (Ecole Polytechnique Fédérale de Lausanne)

Future low-carbon societies will need to store vast amounts of electricity to balance intermittent generation from wind and solar energy, for example, through frequency regulation. Here, we derive an analytical solution to the decision-making problem of storage operators who sell frequency regulation power to grid operators and trade electricity on day-ahead markets. Mathematically, we treat future frequency deviation trajectories as functional uncertainties in a receding horizon robust optimization problem. We constrain the expected terminal state-of-charge to be equal to some target, which should allow storage operators to not only make good decisions for the present but also for the future. Thanks to the terminal constraint, the amount of electricity traded on day-ahead markets is an implicit function of the regulation power sold to grid operators. The implicit function quantifies the amount of power that needs to be purchased to cover the expected energy loss that results from providing frequency regulation. We show how the associated marginal cost of frequency

regulation decreases with roundtrip efficiency and increases with frequency deviation dispersion. We find that the profits from frequency regulation over the lifetime of energy-constrained storage devices, such as lithium-ion batteries, are roughly inversely proportional to the length of time for which regulation power must be committed. Establishing an intra-day market for frequency regulation would thus make electricity storage devices more competitive with other regulation providers, such as thermal power plants.

Day-ahead and intra-day co-optimization of a power unit under uncertainty

Adrien Le Franc (Cermics Ecole des Ponts), Michel De Lara (Cermics Ecole des Ponts), Jean-Philippe Chancelier (Cermics Ecole des Ponts) and Pierre Carpentier (ENSTA Paris)

We consider renewable power units equipped with a battery and engaged in day-ahead load scheduling. In this context, the unit manager must submit a day-ahead power production profile prior to every operating day, and is engaged to deliver power accordingly. During the operating day, the unit manager is charged penalties if the delivered power differs from the submitted profile. First, we model the problem of computing the optimal production profile as a parametric multistage stochastic optimization problem. The production profile is modeled as a parameter which affects the value of the intra-day management of the power unit, where the photovoltaic production induces stochasticity. Second, we expose numerical methods to compute or approximate a subgradient of the value functions of the problem with respect to the parameter, and finally, we showcase applications in the context of the French non-interconnected power grid and benchmark our method against a Model Predictive Control approach.

An enhanced column and constraint generation method for adaptive robust optimization

Ricardo Lima (King Abdullah University of Science and Technology), Antonio Conejo (The Ohio State University) and Omar Knio (King Abdullah University of Science and Technology)

In this talk, we present an enhanced column and constraint generation (CCG) method for solving two-stage adaptive robust optimization (ARO) problems. The proposed method is computationally more efficient than the standard one and has new features to handle nonlinear programming (NLP) subproblems. The method has two phases. In phase I, the objective is to improve an upper bound (considering a maximization problem) on the optimal objective function value, whereas in phase II, the objective is to improve a lower bound on the optimal objective function value. The move from phase I to phase II is triggered by a novel auxiliary bound based on the subproblem solution. As the algorithm progresses, this auxiliary bound is compared to the upper bound and used to indicate if the current solution is optimal. The enhanced CCG method can return to phase I from phase II if a better solution is found in phase II. The proposed method uses this two-phase approach for ARO problems with both mixed-integer linear programming (MILP) subproblems and NLP subproblems. We demonstrate the performance of the enhanced CCG method on the self-scheduling problem of a virtual power plant. In this problem, wind power production and electricity prices are uncertain. We consider two alternative approaches to describe the uncertainty sets: discrete and continuous. The results show that for MILP subproblems, the computational performance of the enhanced CCG method is superior to that of the standard CCG method. For NLP subproblems, we show a relation between the quality of the bounds obtained and the budget of time assigned to the solution of the subproblems. We also analyze the scheduling and market involvement results obtained with these two alternative uncertainty sets. We conclude presenting a risk management analysis comparing the results obtained with both types of uncertainty sets. This analysis is made using the bound estimation stage of a Sample Average Approximation methodology.

Random games under elliptically distributed dependent joint chance constraints

Abdel Lisser (Université Paris Saclay), Vikas Vikram Singh (IIT Delhi) and **Hoang-Nam Nguyen** (Université Paris Saclay, CentraleSupelec)

We study an n-player game with random payoffs and continuous strategy sets. The payoff function of each player is defined by its expected value and the strategy set of each player is defined by a joint chance

constraint. The random constraint vectors defining the joint chance constraint are dependent and follow elliptically symmetric distributions. The Archimedean copula is used to capture the dependence among random constraint vectors. We propose a reformulation of the joint chance constraint of each player. Under mild assumptions on the players' payoff functions and 1-dimensional spherical distribution functions, we show that there exists a Nash equilibrium of the game.

Market connectedness and systemic risk

Mario Maggi (University of Pavia), Mishel Qyrana (University of Pavia), Maria-Laura Torrente (University of Genova) and Pierpaolo Uberti (University of Genova)

It is well known that, during volatile and turbulent times, not only the volatility increases but also the correlations among the assets increase, making diversification harder to achieve. The strengthening of the connection between assets can be measured by a class of indicators commonly known as connectedness. Among the Proper Measures of Connectedness, we propose a novel one based on Random Matrix Theory results, which estimates how many diversification opportunities get lost during turbulent periods. The usefulness of the method is empirically studied with different datasets, and in different periods, showing good predictive power in terms of volatility and Value at Risk. Moreover, a comparison with other measures of risk and connectedness is performed.

Bounds for multistage mixed-integer distributionally robust optimization

Francesca Maggioni (University of Bergamo), Guzin Bayraksan (The Ohio State University), Daniel Faccini (University of Bergamo) and Ming Yang (The Ohio State University)

Multistage mixed-integer distributionally robust optimization (DRO) forms a class of extremely challenging problems since their size grows exponentially with the number of stages. One way to model the uncertainty in multistage DRO is by creating sets of conditional distributions (the so-called conditional ambiguity sets) on a finite scenario tree and requiring that such distributions remain close to nominal conditional distributions according to some measure of similarity/distance (e.g., phi-divergences or Wasserstein distance). In this talk, new bounding criteria for this class of difficult decision problems are provided through scenario grouping using the ambiguity sets associated with various commonly used phi-divergences and the Wasserstein distance. Our approach does not require any special problem structure such as linearity, convexity, stagewise independence, and so forth. Therefore, while we focus on multistage mixed-integer DRO, our bounds can be applied to a wide range of DRO problems including two-stage and multistage, with or without integer variables, convex or nonconvex, and nested or non-nested formulations. Numerical results on a multistage mixed-integer production problem show the efficiency of the proposed approach through different choices of partition strategies, ambiguity sets, and levels of robustness.

Robust planning of production routing problem in closed-loop supply chain of glass bottles

Ahmadreza Marandi (Eindhoven University of Technology) and Ali Borumand (Isfahan University of Technology)

A closed-loop supply chain (CLSC) integrates forward and reverse flows of products and information. This integration helps companies manage their supply chain better as they have more control and a broader view of the whole chain. Also, companies can gain economical and environmental benefits from their returned products. Despite these advantages, a decision-maker should deal with diverse uncertainties in a CLSC, including supply processes, demands, travel times, and quantity and quality of returned products. In this talk, we propose an MILP model for a CLSC of beverage glass bottles, in which production planning, inventory management, and vehicle routing decisions are involved. Since there are uncertainties in this CLSC, we use robust optimization as the approach to deal with some of the uncertainties by proposing a multi-stage adjustable robust optimization (ARO) formulation. A novel branching technique is developed to solve the ARO problem, and a heuristic search approach is designed to decrease the solution time. Numerical experiments

not only show the incompetency of the customary method, namely the affine decision rule approach but also illustrate how the developed branching and heuristic techniques can solve the small-size problems and improve the quality of the obtained solution dramatically.

Adjusted distributionally robust bounds on expected loss functions

Yasemin Merzifonluoglu (Tilburg University) and Joseph Geunes (Texas A&M University)

Optimization problems in operations and finance often include a cost that is proportional to the expected amount by which a random variable exceeds a given quantity, known as the expected loss function. In practical settings, a decision maker may possess limited information about the underlying distribution of the associated random variable, such as the mean and variance, but not the exact form of the associated probability density or distribution function. In such cases, a distributionally robust optimization approach seeks to minimize the maximum expected cost among all possible distributions that fit the available information. Past research has recognized the overly conservative nature of this approach because it accounts for worst-case probability distributions that almost surely do not arise in practice. Motivated by this, we propose a distributionally robust approach that accounts for the worst-case performance with respect to a broad class of common continuous probability distributions, while producing solutions that are less conservative (and, therefore, less expensive, on average) than those produced by existing distributionally robust approaches in the literature. To do this, we generalize the concept of standardized loss functions for normal distributions to other well-known classes of distributions, while also using a generalized and standardized version of the Student's t-distribution to determine worst-case bounds for the associated standardized loss functions. For variables with finite support, we also provide best-case bounds. Finally, we draw a connection between Scarf-type bounds with mean-MAD (mean absolute deviation) bounds when MAD information is available too.

Integration of machine learning and bayesian optimization for multistage stochastic programming problems

Enza Messina (University of Milano - Bicocca) and Bruno Galuzzi (University of Milano - Bicocca)

Multi-Stage Stochastic Programming (MSSP) has become an important framework for optimization problems involved in decision-making under uncertainty. The standard technique for solving approximately MSSP problems is based on a discretization of the underlying stochastic process called scenario tree. For the sake of the computational efficiency, the scenario tree must include only a finite (rather small) number of scenarios, and therefore, it provides decisions only for some values of the random parameters. Efficient scenario tree generation methods have proved to be a useful approach for a wide class of stochastic programming problems. However, these approaches fail to provide optimal decisions for all values of random parameters. Therefore, the question is: which stage decision should we made if the real-world scenario does not coincide with a scenario in the tree? In this case, we need a decision policy, which is a rule specifying the decisions to take for any possible scenario. Such policy can be built using Machine Learning techniques [1], where the main idea is that the set formed by all the decision-observation pairs can be used to learn a regression model for each stage t, and the quality of such decision policy can be measured in terms of feasibility and optimality. Nevertheless, a random strategy for the generation of such policies is computationally expensive. Indeed, the generation of each policy requires the scenario-tree solution of the MSSP, and it could require the generation of a considerable number of policies for ensuring with a certain probability the quality of the selected decision policy. Building on [1], in this talk the emphasis is on how to obtain the best policy in an efficient way. In order to reach this goal, we propose an active scenario-tree generation mechanism to efficiently derive a decision policy through a sequential method that iteratively adds new scenarios through the solution of a black-box global optimization problem using Bayesian Optimization [2]. We assess the quality of the decision policy associated with a given scenario-tree both in terms of objective function value than in terms of feasibility with respect to a large set of possible out of sample scenarios that has not been used for building the policy. Promising computational results will be discussed to show the effectiveness of the procedure.

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Optimising Italian electricity and gas sectors coupling in a 2030 decarbonized energy system

Giovanni Micheli (Università degli Studi di Bergamo), Maria Teresa Vespucci (Università degli Studi di Bergamo), Laura Tagliabue (RSE Milano) and Dario Siface (RSE Milano)

Due to growing concerns about anthropogenic interference with the climate system, in December 2019 the European Commission presented the new program Green Deal, which denes the ambitious European strategy to mitigate climate change. According to the document, the European Commission aims at achieving climate neutrality in 2050 by cutting green-house gas emissions by 55% compared to 1990 levels by 2030. The power systems will be particularly involved in the transformation process due to the need for electrication and the development of renewables, especially non-programmable ones. The strong increase in renewable sources will also require major overhauls of exible resources to comply with the secure operation of the system. Furthermore, as early as 2030, the rst applications of the hydrogen vector and biomethane are considered to appear. These are the reasons why Power-to-Gas (PtG) technology is considered of large interest: it allows converting surplus renewable generation into gas fuel (hydrogen or biomethane), which can be stored locally to be used later or injected into the natural gas network. The deployment of PtG plants increases the interconnection between electricity and gas systems and requires new modeling tools to analyze all new interdependencies. The aim of this contribution is twofold: (i) to present a novel medium-term simulation tool for the operational planning of integrated systems with bi-directional energy conversion; and (ii) to present the results of the application of this tool to a case study focused on Italy challenges exploring the decarbonization pathways. Specifically, the tool here introduced simulates the simultaneous operation of the power and of the gas systems to supply the demand for electricity and gas at minimum total cost, with an hourly detail and while respecting all the technical constraints of the considered systems, in terms of (among the others): (i) hourly electricity generation from hydroelectric and thermal power plants; (ii) natural gas consumption and CO2 emissions for electricity generation; (iii) hourly synthetic gas production; (iv) electricity and gas storage use; (v) exchange of electricity between market zones; and (vi) integrated energy system adequacy in terms of hourly excess of energy, renewables curtailment and unmet load.

Medical face mask detection using deep learning techniques: limitations and perspectives

Pavle Milosevic (University of Belgrade, Faculty of Organizational Sciences), Miroslav Minovic (University of Belgrade, Faculty of Organizational Sciences), Milos Milovanovic (University of Belgrade, Faculty of Organizational Sciences), Arso Vukicevic (University of Kragujevac, Faculty of Engineering) and Velibor Isailovic (University of Kragujevac, Faculty of Engineering)

The role of modern technologies is crucial in establishing and maintaining a safe and healthful work environment nowadays. There are numerous approaches for automated detection of personal protective equipment in order to enhance workplace safety. Still, the detection of medical face masks emerged as a hot topic in the last 2 years due to COVID-19 pandemics. In this research, we aim to identify the most important issues regarding this problem and to present possible directions of future research. First, we aim to systemize the existing research on this topic and to analyze publicly available datasets. The most prominent datasets in this field (e.g. Moxa3K, RMFRD, WDM, etc.) are not scene datasets in general, since the majority of images contain only one face with a mask. Therefore, in nearly all of the papers on this topic, authors utilize a single shot deep learning detector as a whole detection framework. Therefore, these approaches may not be utterly suitable for scene analysis, e.g. hospital waiting rooms. The other crucial matter regarding face mask usage is the question if it is worn properly, i.e. is the mask well-attached and does it cover both mouth and nose. That is a huge challenge in terms of detection, since in many state-of-the-art researches the position of the mask is neglected. Also, the recognition of a certain mask type, e.g. FFP2 mask, KN95 mask or classical surgical mask, in order to assess the level of protection is an open topic in literature. These issues should be addressed

carefully when designing an experiment regarding COVID-19 face mask detection as well as when preparing a dataset for that purpose. To the best of the authors' knowledge, there is no dataset that covers all of the listed issues and problems. Therefore, we aim to collect a diverse dataset before proposing a suitable medical face mask detection procedure. From the standpoint of the algorithm, deep learning models are the center of our attention, since they outperform traditional computer vision methods in terms of both performance metrics and ability to deal with complex problems. Thus, we provide an illustrative example using a deep learning algorithm: SSD: Single Shot MultiBox Detector.

Distributionally Robust Chance-constrained Optimal Power Flow with Contextual Information

Juan Miguel Morales (University of Malaga) and Adrián Esteban-Pérez (University of Malaga)

We introduce a distributionally robust chance-constrained formulation of the Optimal Power Flow problem (OPF) that allows the system operator to account for contextual information. Specifically, our formulation exploits the strong statistical dependence between the point forecast of wind power outputs and its associated prediction error. To this end, we make use of an ambiguity set based on probability trimmings and optimal transport by which we protect the OPF solution against the uncertain process of inferring the distribution of the wind power forecast errors conditional on the prediction itself from a sample of their joint probability distribution. Numerical experiments show the ability of our approach to disclose OPF solutions with a better tradeoff between solution reliability (understood as the probability of violating the OPF constraint system) and expected cost with respect to alternative approaches that either ignore the context and/or disregard the ambiguity in the conditional inference process.

Multivariate second order stochastic dominance constraints for pension fund multistage stochastic models

Vittorio Moriggia (University of Bergamo), Sebastiano Vitali (University of Bergamo) and Milos Kopa (Charles University)

Multistage stochastic programming models are often adopted in all type of Asset and Liability Management problems including long-term asset allocation of pension fund. Recent implementations of such models introduce first order and second order of stochastic dominance constraints to improve the adaptability of an ALM model. In fact, the stochastic dominance constraints ensure that the optimal strategy is able to stochastically dominate a benchmark portfolio. The stochastic dominance allows to compare different portfolios and guarantees the preference of one portfolio to a benchmark portfolio under various utility functions. Most works propose univariate stochastic dominance constraints to guarantee the dominance of the optimal solution, while only few adopt a multivariate approach. In this work we extend previous results in multivariate stochastic dominance considering alternative types that can be more suitable in a multistage framework. In particular, we propose a goal-based ALM model implemented in the form of multistage stochastic optimization model with second order dominance constraints. As a stress-test, we use the `safety margin' concept to study the differences among the alternative definition of SSD in terms of economic cost of stochastic dominance constraints.

A bilevel framework for decision-making under uncertainty with contextual information

Miguel Angel Muñoz (University of Malaga), Salvador Pineda (University of Malaga) and Juan Miguel Morales (University of Malaga)

In this work, we propose a novel approach for data-driven decision-making under uncertainty in the presence of contextual information. Given a finite collection of observations of the uncertain parameters and potential explanatory variables (i.e., the contextual information), our approach fits a parametric model to those data that is specifically tailored to maximizing the decision value, while accounting for possible feasibility constraints. From a mathematical point of view, our framework translates into a bilevel program, for which we provide both a fast regularization procedure and a big-M-based reformulation that can be solved using off-theshelf optimization solvers. We showcase the benefits of moving from the traditional scheme for model estimation (based on statistical quality metrics) to decision-guided prediction using three different practical problems. We also compare our approach with existing ones in a realistic case study that considers a strategic power producer that participates in the Iberian electricity market. Finally, we use these numerical simulations to analyze the conditions (in terms of the firm's cost structure and production capacity) under which our approach proves to be more advantageous to the producer.

Problem-based scenario generation by decomposing output distributions

Benjamin S. Narum (NHH Norwegian School of Economics), Jamie Fairbrother (Lancaster University) and Stein W. Wallace (NHH Norwegian School of Economics)

We address problem-based scenario generation for two-stage stochastic programming by decomposing output distributions. A novel scenario generation procedure is proposed, agnostic to the specific problem and input distribution, computed using standard and efficient linear algebra algorithms that scale well. The method is especially well suited to address complicated input distributions such as mixed, binary and multi-modal. Continuity results bounding the resulting approximation error are provided. We demonstrate its effectiveness on four case study problems from typical applications of stochastic programming to show it is more effective than its alternatives.

On the Use of Return Scenario Generation Techniques in Large-Scale Portfolio Optimization Framework

David Neděla (Technical University of Ostrava) and Sergio Ortobelli (Università degli studi di Bergamo)

In this contribution, we investigate the effect of asset return approximation using several scenario generation techniques in the large-scale portfolio selection strategy. Specifically, we evaluate two general approaches for scenario generation, which allow us to capture precisely the empirical behaviour of approximated series: parametric and non-parametric. Due to the large-scale selection problem, we use the multifactor model for the factors determined by the principal component analysis (PCA) applied on several dependency matrices to reduce the dimensionality. Nevertheless, even we consider the first 5% of factors, we capture approximately one half of the variability and the remaining part represents the random error variable. Therefore, we aim to precisely approximate the errors considering an identical procedure. As a parametric approach, we assume ARMA–GARCH processes with stable distributed innovations and the skewed t copula dependency structure. In contrast, the second approach is based on non-parametric regression estimated by a multivariate kernel estimator. To examine the impact on the portfolio optimization strategy, we illustrate the dynamic efficient frontier of the mean-variance model and also use a model maximizing well-known reward-risk measures. Our further empirical analysis is performed assuming a dynamic dataset formed by shares contained in the S&P 500 index in the selected investment interval. The dynamics lie in changes capturing of the index composition over time, which allow us to evaluate the impact of the approximation approaches more realistic.

Detecting data-driven robust statistical arbitrage strategies with deep neural networks

Ariel Neufeld (Nanyang Technological University), Julian Sester (Nanyang Technological University) and **Daiying Yin** (Nanyang Technological University)

We present an approach, based on deep neural networks, that allows identifying robust statistical arbitrage strategies in financial markets. Robust statistical arbitrage strategies refer to self-financing trading strategies that enable profitable trading under model ambiguity. The presented novel methodology does not suffer from the curse of dimensionality nor does it depend on the identification of cointegrated pairs of assets and is therefore applicable even on high-dimensional financial markets or in markets where classical pairs trading approaches fail. Moreover, we provide a method to build an ambiguity set of admissible probability measures that can be derived from observed market data. Thus, the approach can be considered as being model-free and entirely data-driven. We showcase the applicability of our method by providing empirical investigations

with highly profitable trading performances even in 50 dimensions, during financial crises, and when the cointegration relationship between asset pairs stops to persist.

Numerical method for approximately optimal solutions of two-stage distributionally robust optimization with marginal constraints

Ariel Neufeld (Division of Mathematical Sciences, Nanyang Technological University) and **Qikun Xiang** (Division of Mathematical Sciences, Nanyang Technological University)

We develop a numerical algorithm for computing an approximately optimal solution of a two-stage distributionally robust optimization (DRO) problem with linear objectives and constraints. Specifically, we consider a two-stage DRO problem in which the ambiguity set is constrained by fixed marginal distributions that are not necessarily discrete. Through replacing the marginal constraints by a finite collection of linear constraints, we derive a relaxed DRO problem which serves as an upper bound for the original DRO problem. Moreover, we are able to control the error incurred by the relaxation to be arbitrarily close to 0 under mild conditions. Subsequently, we develop duality results tailored to this setting and transform the inf-sup DRO problem into an inf-inf problem. This leads to a numerical algorithm for two-stage DRO problems which solves a linear semi-infinite optimization problem via a cutting-plane method. Besides an approximate optimizer of the two-stage DRO problem, the proposed algorithm is able to compute both an upper bound and a lower bound on the optimal value of the two-stage DRO problem. The difference between the computed bounds provides us with a direct estimate of the sub-optimality of the computed approximate optimizer. Most importantly, one is able to choose the inputs of the algorithm such that the sub-optimality can be controlled to be arbitrarily small. In our numerical examples, we apply the two-stage DRO model and the proposed algorithm to prominent decision problems including appointment scheduling, multi-product assembly, and supply chain network design. The numerical examples showcase that the proposed algorithm is able to compute high-quality robust decisions along with their corresponding sub-optimality estimates with practically reasonable magnitudes that are not overly conservative.

Robust portfolio dominance for different investors' preferences

Sergio Ortobelli Lozza (University of Bergamo), Tommaso Lando (University of Bergamo), Miloš Kopa (Charles University) and Tomas Tichy (VSB-TU Ostrava)

We propose a methodology to obtain optimal portfolios that stochastically dominate a benchmark with respect to different stochastic orderings, in a robust sense. Firstly, we recall some recent ordering rules, that classify the optimal choices for different non satiable investors' categories. Secondly, we discuss the selection models of optimal portfolios which stochastically dominate a given benchmark, taking into account a significative distance according to stochastic dominance tests. Finally, we propose an ex-post empirical analysis in which we evaluate the proposed models for different investors' preferences.

Modelling profile heterogeneity on retirement via Deep-RL: Intelligent Agents working towards retirement

Fatih Ozhamaratli (University College London) and Paolo Barucca (University College London)

The transition from Defined Benefit to Defined Contribution Pension Plans shifts the responsibility for saving towards retirement from govern- ments and institutions to the individuals. Determining optimal saving and investment strategy for individuals is paramount for avoiding poverty after retirement, and for healthy financial stance during work-life; especially in a world where form of employment and income trajectory experienced by dif- ferent occupation groups are highly diversified. We introduce a model where agents learn optimal saving and portfolio allocation strategies suitable to their heterogeneous profiles. We utilise Deep RL for training the agents. The environment is calibrated with occupation and age dependent income evolution dynamics. The research focuses on behavioural parametrisation of agents and heterogeneous income

trajectories dependent on agent profiles. The model provides a flexible methodology to estimate lifetime consumption and investment choices for heterogeneous profiles under varying scenarios.

Solving constrained consumption-investment problems by decomposition algorithms

Bernardo Pagnoncelli (SKEMA Business School), Tito Homem-de-Mello (Universidad Adolfo Ibáñez) and Guido Lagos (Universidad Adolfo Ibáñez)

Consumption-investment problems with maximizing utility agents are usually considered from a theoretical viewpoint, aiming at closed-form expressions for the optimal policy. However, such an approach requires that the model be relatively simple: even the inclusion of simple nonnegativity constraints can prevent the derivation of closed-form solutions. In such cases, it is necessary to solve the problem numerically, but standard dynamic programming algorithms can only solve small problems due to the curse of dimensionality. In this paper, we adapt the Stochastic Dual Dynamic Programming (SDDP) algorithm to numerically solve a standard dynamic utility consumption-investment problem with stochastic labor income. Unlike classical dynamic programming approaches, SDDP allows us to analyze problems with multiple assets and a very large number of scenarios. We illustrate our methodology by solving a life-cycle problem with a portfolio default constraint, for which no solution is available.

Chance Constrained Game Problem with Mixture of Elliptical Distribution

Shen Peng (Department of Mathematics, KTH Royal Institute of Technology), Vikas Vikram Singh (Department of Mathematics, IIT Delhi) and **Abdel Lisser** (Laboratoire de Recherche en Informatique, Universite Paris Sud)

We consider an n-player non-cooperative game with stochastic strategy sets. The stochastic strategy set of each player contains a set of stochastic linear constraints. The stochastic linear constraints of each player are modeled as a joint chance constraint. We assume that the row vectors of a matrix defining the stochastic constraints of each player are pairwise independent and each row vector follows a multivariate mixture of elliptical distribution. Under certain conditions we show the existence of a Nash equilibrium for this game.

Guaranteed bounds for pathwise stochastic dynamic programming

Georg Pflug (University of Vienna), Martin Glanzer (University of Vienna) and Sebastian Maier (University College London)

Starting with the famous paper by Longstaff and Schwartz [Review of Financial Studies, 2001; Vol. 14. No. 1, pp. 113-147] their backward regression method for solving multistage stochastic programs was applied and extended in various ways in the last years. Since the method is based on a simulated set of paths from the underlying stochastic process, there is always a sampling error present. We investigate the problem of finding "guaranteed" bounds for the solution. While lower bounds (we maximize) are easy to get, we concentrate on upper bounds. While some authors propose to find lower bounds for the dual problem instead, we work with methods of guaranteed uniform over-estimation of regression functions. Under some assumptions on the regularity of the "true" regression functions, we establish some guaranteed bounds (guaranteed with a confidence level, which can be prespecified).

A variant of the level-based learning swarm optimizer for solving a portfolio optimization problem maximizing the inner rate of risk adversion

Filippo Piccotto (University of Trieste) and Massimiliano Kaucic (University of Trieste)

This study proposes a novel portfolio optimization model where we aim to maximize a recently developed performance measure, the so-called inner rate of risk aversion (IRRA). This performance index is defined as the solution of an implicit function that also involves the high moments of return distribution. Our portfolio design

includes cardinality, box, and budget constraints. Furthermore, we insert an upper bound for the portfolio turnover in order to maintain a control on the transaction costs during the rebalancing phases. For solving the resulting mixed-integer optimization problem we propose a variant of the dynamic level-based learning swarm optimizer, shortly DLLSO. DLLSO is an extension of the more popular particle swarm optimization algortihm, that has been developed to better deal with high-dimensional optimization problems. The swarm update mechanism of this solver is based on two strategies. At first, according to their fitness, swarm individuals are separated into a number of levels in which they are treated differently. Then, an exemplar selection strategy randomly selects two predominant particles from two different higher levels in the current swarm to guide the learning of particles. This cooperation provides a good compromise between exploration and exploitation of the search space. Our procedure integrates into the standard DLLSO a new hybrid constrainthandling strategy that uses an improved version of the compressed coding scheme to directly handle portfolio cardinalities by encoding the binary decision variables into the continuous ones. Then, a repair operator deals with box and budget constraints, and an adaptive penalty function approach is used for the turnover constraint. The investible universe for the experimental analysis consists of a set of 1263 stocks belonging to the MSCI World Index with daily prices observed from December 2009 to December 2019. We structure the ex-post investment analysis as a multi-period asset allocation plan with monthly rebalacing. The analysis involves the last 87 months of the data set, covering the period from 4/1/2013 to 31/12/2019. We use the so-called stationary bootstrap to generate monthly scenarios and estimate the IRRA value for a given portfolio. The vector of portfolio weights maximizing the IRRA is determined at the last trading day of each month. The ex-post performance analysis moves towards two directions. From one hand, we study how the ex-post performance of our investment model can vary by using daily and weekly data for the future scenario generation in the boostrap procedure. On the other hand, we perform a sensitivity analysis considering three different cardinalities, $K \in \{63, 189, 378\}$. These values correspond to 5%, 15% and 30% of the investible universe respectively. The empirical results suggest that the best strategy is the one with scenarios constructed with daily data and $K = 63$. Finally, we observe that our asset allocation model is able to outperform an artificial benchmark constructed using the market capitalization of the assets, and shows comparable performance with respect to an investment strategy based on the Sharpe ratio.

Stochastic programming approach to electric vehicle charging on a university campus

Pavel Popela (Brno University of Technology), Pavel Charvat (Brno University of Technology), **Matous Cabalka** (Brno University of Technology), Jan Fiser (Brno University of Technology) and Martin Zalesak (Brno University of Technology)

The well-organized charging of electric vehicles is one of the important goals in the electrification of mobility. For many employees the workplace is the area where they usually spend most time out of home. The paper discusses the stochastic programming approach to a suitablee organization of electric vehicles charging at the Faculty of Mechanical Engineering of Brno University of Technology (FME BUT) in the Czech Republic. We can recognize that the market penetration of electric vehicles in the Czech Republic is expected to increase at a relatively slow pace, which would provide enough time for a suitable equipping the workplace parking lots with electric vehicle chargers. Following the problem discussion, several modelling ideas related to optimal decision making about charging capacities and their distribution at the FME BUT campus will be introduced. At first, the model inspired by a newsvendor problem ideas is built and it combines an expected value-based objective function, two-stage decision structure and almost surely satisfied constraints dealing with uncertainties mostly related to varying car owners needs. Then, the available real-world data and their expert-based updates have obviously shown that the initial model must be further refined. Then, the two extensions are studied. The first one deals with the spatial distribution of the important charging places within the campus and leads to introduction of needed indicator variables and related constraints. Then, the next model enhancements include the time role in the model and focus on the step-by-step building of charging places campus network. The obtained optimal results based on real-world data can be compared with the common sense based development of charging network and its use by electric vehicles. Charging of electric vehicles could also become an incentive for the expansion of building-integrated photovoltaics on the campus as there is a strong correlation between the working hours when the employees park their vehicles on the campus and the electricity generation by the photovoltaic panels. Though only a few electric vehicles park regularly on the FME BUT campus, the ownership of electric vehicles seems to be much higher among the university

employees than among the general population. It can be expected that this trend will continue, and the charging infrastructure needs to become part of the long-term plans for the development of the campus. Therefore, further enhancements of presented models will be discussed.

A partial decomposition approach to solve the stochastic uncapacitated lot-sizing problem

Franco Quezada (Sorbonne Université), **Céline Gicquel** (Université Paris-Saclay) and Safia Kedad-Sidhoum (Conservatoire National des Arts et Métiers)

The uncapacitated lot-sizing problem (ULS) is an industrial production planning problem which considers a single type of item and seeks to determine the quantity of this item to be produced in each time period to meet demand over a finite discrete-time planning horizon. In the ULS, producing a positive amount in a period incurs both a fixed set-up cost and a linear production cost while inventory holding costs are incurred to hold the item in stock between two periods. The objective is to build a production plan such that the customer demand is met in each time period and the total cost over the planning horizon is minimized. The ULS naturally appears as an embedded subproblem in many practical production planning problems. Solving it efficiently is thus essential to develop algorithms capable of dealing with real-world problems. We study a stochastic extension of the ULS in which both the demand and the costs are subject to uncertainty. We consider a multi-stage decision process. The underlying stochastic input process is assumed to have a finite probability space so that the information on the evolution of the uncertain parameters is represented by a discrete scenario tree. This representation usually leads to the formulation of large-size mixed-integer linear programs which can be solved by implicit enumeration methods such as branch-and-cut algorithms. Unfortunately, those methods do not scale up well with the size of the scenario tree, leading to prohibitive computation times for large-size scenario tree. Decomposition methods, such as the recently introduced Stochastic Dual Dynamic integer Programming (SDDP) algorithm, are thus an attractive option to solve these large-size instances. In this work, we propose a new solution algorithm combining both kinds of approaches. As in the SDDiP algorithm, we exploit a dynamic programming formulation and decompose the problem into smaller subproblems. However, whereas the SDDiP algorithm fully decomposes the original problem into single-node subproblems, we propose to use a partial decomposition of the problem into a set of smaller sub-problems, each one expressed on a subtree of the initial scenario tree. As a result, each subproblem is a tractable mixed-integer linear program which can be efficiently solved by a branch-and-cut algorithm. This partial decomposition has two main advantages. First, it leads to a decrease in the number of expected-cost-to-go functions which must be approximated in the SDDiP algorithm. Second, the tree structure of the sub-problems allows us to exploit valid inequalities to generate a wider set of strengthened Benders cuts in the backward step of the SDDiP algorithm and improve the quality of the solutions obtained within the available computation time. We compare the performance of the proposed algorithm with the one of the mathematical solver ILOG-CPLEX and the one of the standard SDDiP algorithm. Our computational results show that the proposed algorithm outperforms CPLEX 12.8 and the SDDiP algorithm for large-size scenario trees, providing solutions with smaller optimality gaps in shorter computation times.

Joint stocking and pricing decisions for distributionally robust inventory problems with decision-dependent demands

Hamed Rahimian (Clemson University) and Sanjay Mehrotra (Northwestern University)

We study a distributionally robust approach to multi-product inventory problems, where the joint discrete probability distribution of the products demands is unknown and depends on the products prices. Our goal is to obtain the optimal joint stocking and pricing decisions for some classes of polyhedral-representable decision-dependent ambiguity sets, including Wasserstein and moment-based sets. We reformulate this problem as a two-stage stochastic bilinear program and propose a finitely convergent algorithm to solve it. We illustrate our results on stylized problems.

Robust conic satisficing

Arjun Ramachandra (Singapore University of Technology and Design), **Napat Rujeerapaiboon** (National University of Singapore) and Melvyn Sim (National University of Singapore)

Inspired by the principle of satisficing (Simon 1955), Long et al. (2021) propose an alternative framework for optimization under uncertainty, which we term as a robust satisficing model. Instead of sizing the uncertainty set in robust optimization, the robust satisficing model is specified by a target objective with the aim of delivering the solution that is least impacted by uncertainty in achieving the target. At the heart of this framework, we minimize the level of constraint violation under all possible realizations within the support set. Our framework is based on a constraint function that evaluates to the optimal objective value of a standard conic optimization problem, which can be used to model a wide range of constraint functions that are convex in the decision variables but can be either convex or concave in the uncertain parameters. We derive an exact semidefinite optimization formulation when the constraint is biconvex quadratic with quadratic penalty and the support set is ellipsoidal. We also show the equivalence between the more general robust satisficing problems and the classical adaptive robust linear optimization models with conic uncertainty sets, where the latter can be solved approximately using affine recourse adaptation. More importantly, under complete recourse, and reasonably chosen polyhedral support set and penalty function, we show that the exact reformulation and safe approximations do not lead to infeasible problems if the chosen target is above the optimum objective obtained when the nominal optimization problem is minimized. Finally, we extend our framework to the data-driven setting and showcase the modelling and the computational benefits of the robust satisficing framework over robust optimization with three numerical examples: portfolio selection, log-sum-exp optimization and adaptive lot-sizing problem.

A scenario-based solution to portfolio optimization in the energy market

Elisa Raspanti (University of Bologna) and Maria Prandini (Politecnico di Milano)

We consider a stochastic optimization problem for a portfolio of futures contracts in the energy market. Our goal is to maximize profit subject to constraints on risk, position and liquidity. More specifically, we have to solve a finite horizon decision making problem so as to best hedge the starting position for all monthly deliveries of a given year, for all underlyings in the portfolio. Since the prices for future dates are stochastic, uncertainty must be taken into account when choosing the volumes to be traded. This can be done according to three main different paradigms: maximize the profit on average, robustly over all uncertainty instances, or with a certain probability larger than $1 - \epsilon$, with $\epsilon \in (0, 1)$. Here, we take the third perspective and apply the sample discarding scenario approach to solve the resulting chance-constrained optimization problem, which reduces to first generating N prices realizations using a suitably designed stochastic model, and then dropping the $k < N$ worst-case scenarios so as to best improve the profit objective function. If k and N are suitably chosen according to the desired ϵ, then, the obtained optimal profit value is guaranteed to be the maximum over all price realizations except for a set with probability at most ϵ, with high confidence. By exploiting the fact that stochastic uncertainty enters the scenario optimization program linearly, we are able to cope with the memory requirement growth as a function of the time horizon and number of underlyings by using a convex hull approximation of the prices realizations.

Achieving emission-reduction goals: long-term power-system expansion under short-term operational uncertainty

Tuomas Rintamaki (Aalto University), **Fabricio Oliveira** (Aalto University), Afzal S. Siddiqui (Stockholm Univesity) and Ahti Salo (Aalto University)

We consider the generation and transmission expansion planning (G&TEP) problem, i.e., the required infrastructural expansions, e.g., transmission line, VRES, and other generation, for meeting long-term GHG emission-reduction goals. We require meeting short-term operational constraints on demand, transmission, generator ramping, and availability taking into account related uncertainties and the decision maker's robustness requirements. To this end, we employ a tri-level model representing two stages, in which the first stage and level consider a multi-year investment horizon for generation and transmission expansion. At the second stage, the second level uses robust optimization (RO) to choose a worst-case demand for the third level that uses stochastic programming (SP) to minimize the cost of detailed, multi-hour power-system operation under a set of operating conditions (scenarios) for uncertain parameters such as VRES output and generation costs. This combination of RO and SP in two stages is called stochastic adaptive robust optimization (SARO). SARO optimization is capable of handling short-term uncertainties in demand and variable renewable energy sources that affect investment in generation and transmission capacity. We build on this setting by considering a multi-year investment horizon that also reduces greenhouse gas emissions. In addition, we incorporate multiple hours in power-system operations to capture hydropower operations and flexibility requirements for utilizing variable renewable energy sources such as wind and solar power. To improve the computational performance of existing exact methods for this problem, we employ Benders decomposition and solve a mixed-integer quadratic programming problem to avoid computationally expensive big-M linearizations. Therefore, our first contribution is to propose a SARO model for the G&TEP problem with multiple long- and short-term time periods along with detailed power-system operations and an emission-reduction goal. Our second contribution is to deploy Benders decomposition and MIQP reformulations for improving the solution time of the problem over earlier MILP methods. We apply the model to a Nordic and Baltic power system and draw important conclusions on energy policy. Specifically, the results for a realistic case study for the Nordic and Baltic region indicate which investments in transmission, wind power, and flexible generation capacity are required for reducing greenhouse gas emissions. Through out-of-sample experiments, we show that the stochastic adaptive robust model leads to lower expected costs than a stochastic programming model under increasingly stringent environmental considerations.

Optimal liquidation through a limit order book: a neural network and simulation approach

Alexandre Roch (University of Quebec in Montreal)

We present a learning algorithm based on simulation and neural networks to solve a stochastic optimal control problem with a large state space using dynamic programming. The problem consists in liquidating a given number of shares of a stock through a limit order book (LOB). The state space includes prices and quantities at each level in the LOB. The objective is to maximize the expected liquidation proceeds. Shares are sold by market orders matching the current limit orders in the LOB and have an impact on the future evolution of the LOB. The optimal strategy is obtained using a hybrid form of performance and value iteration procedures based on neural networks. The probability distribution of the LOB is estimated by a deep learning classification task. The model is tested on 12 stocks traded through the NYSE Arcabook, and a numerical implementation shows that the model outperforms the most common optimal liquidation models in the literature by a significant amount.

Robust optimization for the berth allocation and quay crane scheduling problem under uncertainty

Filipe Rodrigues (Lisbon School of Economics and Management) and Agostinho Agra (University of Aveiro)

We consider an integrated berth allocation and quay crane scheduling problem where the arrival times of the vessels may be affected by uncertainty. The problem is modelled as a two-stage robust mixed integer program where the berth allocation decisions are taken before the exact arrival times are known, and the crane assignment and scheduling operations are adjusted to the arrival times. The robust problem is solved by a decomposition algorithm that decomposes the problem into a master problem and a separation problem. The second-stage decisions are represented by binary variables that strongly affect the overall efficiency of the decomposition algorithm. In this talk, we present several improvement strategies to make the proposed algorithm more efficient. Such strategies can easily be extended to other optimization problems and their positive effect is clearly shown by the computational results.

Scaled cuts for two-stage mixed-integer stochastic programs

Ward Romeijnders (University of Groningen) and Niels van der Laan (University of Groningen)

We consider a Benders' decomposition algorithm for two-stage mixed-integer stochastic programs with general mixed-integer variables in both time stages. In our algorithm, we iteratively construct tighter approximations of the expected second-stage cost function using a new family of optimality cuts. We derive these so-called scaled cuts by parametrically solving extended formulations of the second-stage problems using deterministic mixed-integer programming techniques. We establish convergence by proving that the optimality cuts recover the convex envelope of the expected second-stage cost function. Finally, we demonstrate the potential of our approach by conducting numerical experiments on several investment planning and capacity expansion problems.

Optimal withdrawal policies for GMWB Variable Annuities under stochastic interest rates

Francesco Rotondi (Università degli Studi di Padova) and Claudio Fontana (Università degli Studi di Padova)

Variable annuities are complex financial products sold by insurance companies to retail investors to complement their retirement plans. Along with the reimbursement of the nominal amount, a variable annuity promises to provide returns linked to the performance of an underlying market index or fund. If the annuity comes with a Guaranteed Minimum Withdrawal Benefit (GMWB) rider, its holder is entitled to make periodic withdrawals from a benefit account paying no penalties if the amount withdrawn is smaller than a guaranteed minimum withdrawal. At inception, the value of the benefit account matches the annuity's nominal value. Afterwards it decreases when withdrawals are made. The choice of the amount and of the timing of these withdrawals leads to a challenging stochastic control problem when it comes to find the fair market price of a GMWB annuity. Moreover, since the maturity of a typical GMWB annuity is quite long and since its nominal amount is substantially protected, the time value of money is of great relevance, especially in the current European environment characterized by extremely low interest rates. Within a realistic stochastic interest rate environment with correlated market and interest rate risks, we propose a novel lattice-based dimensionality reduction technique for the pricing of a GMWB annuity with several contractual features. On top of standard ones, we consider two common features that can be added to the contract: a step-up feature (sometimes also referred to as the Ratchet feature) and a bonus one. The main impact of these two features is that they might increase the value of the benefit account during the life of the annuity. These features modify substantially the behavior of the benefit account which can now raise after a positive performance of the equity fund or if the holder does not withdraw from the benefit account. The algorithm we propose enables us to assess the determinants of the initial premium and of the optimal withdrawal policy even when these extra features are added to the standard specification of a GMWB annuity. This analysis sheds lights on how the fair values and management fees, along with optimal withdrawal policies, react to different interest rate levels and outlooks, from the current negative interest rate environment to more traditional ones. To the best of our knowledge, this is one of the first papers that analyzes the impact of current market circumstances on guaranteed annuities, which should be of great relevance for the insurance industry.

Advances in Risk-Averse Learning

Andrzej Ruszczynski (Rutgers University)

We shall discuss learning problems where the objective is to optimize a risk measure of the random performance (loss function). Problems of this type involve adversarial learning, distributionally robust learning, and riskaverse reinforcement learning. We shall discuss difficulties associated with the construction of stochastic subgradient methods for risk measures and present convergence results for a class of composition risk measures. Next, we shall discuss a novel reinforcement learning methodology where the system performance is evaluated by a Markov coherent dynamic risk measure with the use of linear value function approximations. We construct projected risk-averse dynamic programming equations, study their properties, and propose risk-averse counterparts of the methods of temporal differences. The results will be illustrated with examples of adversarial learning and risk-averse control of a complex transportation problem.

Less is more: Ranking information, estimation errors and optimal portfolios

Lukas Salcher (University of Liechtenstein) and Sebastian Stöckl (University of Liechtenstein)

Despite its significance for Finance as an academic field, mean-variance optimization has yet to be broadly accepted as an investment opportunity in practice due to the crippling effects estimation errors have on the out-of-sample performance of such portfolios. In this paper we offer a novel approach that aims at resolving this issue. More precisely, we propose optimizing portfolios based on forecasted ranking information instead of historical data. The main idea behind this approach is that reducing the informational content of input parameters eliminates outliers caused by estimation errors which in turn means mean-variance optimization suggests less extreme weights resulting in an overall better diversified and less concentrated portfolio. Our results confirm that our approach has a higher risk-adjusted performance compared to the plug-in mean-variance approach and also outperforms naively diversified portfolios. Furthermore, our approach is more effective when estimation errors are expected to be larger.

Risk-averse production planning in the aquaculture industry

Peter Schütz (Norwegian University of Science and Technology) and Andreas Røv Lien (Norwegian University of Science and Technology)

The revenue of farmed salmon depends on the size of the fish with larger fish achieving a higher per kilo price than smaller fish. However, producing larger fish requires more time and the salmon might mature during this period. As the value of mature salmon is reduced by up to 40%, there is an important trade-off to consider between the potential revenue from selling larger fish versus the risk of reduced income due to a salmon of lower quality. We present a two-stage stochastic programming model for tactical production planning of a salmon farmer given uncertainty in growth and maturation. The goal is to determine the optimal timing and amount of smolt deployments and salmon harvesting such that the conditional value-at-risk is optimized. We will present computational results for a real-world case from Northern Norway.

Quadratic hedging of futures term structure risk in merchant energy trading operations

Nicola Secomandi (Tepper School of Business, Carnegie Mellon University) and Bo Yang (Tepper School of Business, Carnegie Mellon University)

Merchant energy trading companies manage conversion assets to exploit price differences across time, space, and sources of energy in the face of energy futures term structure risk. Financial hedging of this risk is standard practice. Market incompleteness, such as limited futures liquidity, complicates the management of this activity. We apply quadratic hedging, a pragmatic approach to mitigate financial risk when markets are incomplete, to the management of term structure risk in real option models of merchant energy trading operations. We develop a model that, in contrast to known applications of this methodology, pools cash flows across dates, establish the structure of its optimal policy, which is intractable to obtain in general, and use it to propose a novel computationally efficient heuristic. This method is provably optimal if there are only two dates or under a martingale assumption for the futures curve evolution and a simplifying restriction. Our technique performs near optimally in a realistic natural gas storage numerical study in which these conditions do not hold, outperforming a benchmark from the literature adapted to our setting that relies on the latter ones. The procedure put forth in this paper has potential applicability beyond this application.

Regularized quasi-monotone method for stochastic optimization

Vladimir Shikhman (Chemnitz University of Technology) and Vaycheslav Kungurtsev (Czech Technical University in Prague)

We adapt the quasi-monotone method from Nesterov, Y., Shikhman, V.: Quasi-monotone subgradient methods for nonsmooth convex minimization. Journal of Optimization Theory and Applications 165(3), 917–940 (2015) for composite convex minimization in the stochastic setting. For the proposed numerical scheme we derive the convergence rate optimal for black-box convex optimization in terms of the last iterate, rather than on average as it is standard for subgradient methods. The theoretical guarantee for individual convergence of the regularized quasi-monotone method is confirmed by numerical experiments on l1-regularized robust linear regression.

Approximating two-stage chance-constrained programs with classical probability bounds

Bismark Singh (University of Erlange-Nuremberg)

We consider a joint-chance constraint (JCC) as a union of sets, and approximate this union using bounds from classical probability theory. When these bounds are used in an optimization model constrained by the JCC, we obtain corresponding upper and lower bounds on the optimal objective function value. We compare the strength of these bounds against each other under different sampling schemes, and provide various reformulations of the corresponding mathematical models for these approximations.

An equivalent mathematical program for general-sum games with random constraints

Vikas Vikram Singh (Indian Institute of Technology Delhi), Abdel Lisser (Universite Paris Saclay) and Monika Arora (Indraprastha Institute of Information Technology, Delhi)

We consider an n player non-cooperative game where the strategy set of each player is defined using chance constraints. The random vectors defining the constraints follow elliptical distributions. We show that there exists a Nash equilibrium of the game. We show an one-to-one correspondence between a Nash equilibrium of the chance-constrained game and a global maximum of a certain mathematical program.

(Distributionally) robust higher order portfolio selection: application to energy modelling

Natalia Sirotko-Sibirskaya (University of Oslo)

We propose a method for optimal portfolio selection using a distributionally robust optimization framework that addresses two major shortcomings of the traditional Markowitz approach: the ability to handle higher moments and distributional uncertainty. Distributional uncertainty is defined as the ambiguity set, or the region around the empirical measure where the discrepancy between probability measures is dictated by the Wasserstein distance. We use a successive convex approximation algorithm in order to determine weights of the higher-order portfolio and a successive convex programming methods which finitely generates inner approximation of the ambiguity set. The proposed framework is tested extensively on the financial data as well as energy data and compared with the mean-variance approach and higher-order portfolio models, where distributional uncertainty is not taken into consideration.

Risk Averse Dynamic Programming

Martin Smid (UTIA) and Miloš Kopa (Charles University)

The paper deals with risk averse dynamic programming problem with the infinite horizon. First, the required assumptions are formulated to have the problem well defined. Then the Bellman equation is derived, which may be also seen as a standalone reinforcement learning problem. The fact that the Bellman operator is a contraction is proved, guaranteeing convergence of value iteration algorithm. Finally, the situation when the

time between decision points converges to zero, is studied. In particular, it is numerically demonstrated on the problem of optimal trading that scaling the CVaR risk measure similar to that proposed by Pichler and Schlotter (2020) gives non-degenerate optimal policies with the inter-decision interval approaching zero.

Facility location and capacity expansion for hydrogen production under uncertainty

Šárka Štádlerová (Norwegian university of science and technology), Peter Schütz (Norwegian university of science and technology) and Asgeir Tomasgard (Norwegian university of science and technology)

Hydrogen is considered as a way to decarbonize the maritime sector which is an important step in order to meet the requirements of the Paris agreement. Hydrogen demand is expected to increase over the next years but is also the main source of uncertainty. However, the hydrogen infrastructure has to be established to ensure the supply before the uncertainty is disclosed. We study the problem of where to locate hydrogen plants, which production technology to choose, and when to invest and when to expand to satisfy future uncertain customer demand for minimal costs. We have a model with modular capacities that can capture economies of scale in investment as well as in production costs as we provide a specific short-term cost function for each capacity level. We formulate the facility location and capacity expansion problem as a two-stage stochastic programming model. The first stage decisions cover decisions regarding location, capacity, and technology as well as production and distribution plans for deterministic demand. The second stage decisions relate to capacity expansion and production and distribution. We use a method based on Lagrangian relaxation to solve our problem. The lower bound is calculated using a dynamic programming approach. To obtain an upper bound, we develop a heuristic based on the solution to the Lagrangian dual to build a feasible solution. We apply our model to a case from Norway and design the hydrogen supply chain for coastal maritime transportation and passenger ferries.

Matching Revenue Management using Graphical Processing Units (CUDA)

Kalyan Talluri (Imperial College Business School) and Sumit Kunnumkal (Indian School of Business)

Matching Revenue Management comes up in many business situations where the firm matches demand dynamically with limited resources and a stochastic view of the future. In some of these applications the scale of the problem is tremendous and the challenge is to be able to solve this problem numerically. We formulate the problem as a stochastic dynamic program with loosely coupled constraints. Even small sized problems are impossible to solve exactly. Moreover, many applications require an online solution with strict computational time and space requirements. Our objective is not so much to solve the problem in an online manner, but obtain good revenue performance and tight upper bounds in an offline setting. This is useful for evaluating the revenue performance for the simple heuristics feasible in online settings. In this paper we describe and implement a Lagrangian approach to approximately solve the DP. More important, our method is parallelizable to a high degree and we describe an implementation on graphics processors using CUDA and the resulting revenue of the controls and speed improvements.

A neural network approach for joint chance constrained geometric optimization

Siham Tassouli (Paris-Saclay University) and Abdel Lisser (Paris-Saclay University)

In this talk, we present a dynamical neural network approach for solving geometric programs with joint probabilistic constraints (GPPC for short). We study the special case where the stochastic variables are normally distributed and mutually independent. We first give a deterministic equivalent for the initial stochastic program. The obtained deterministic equivalent is biconvex. Thus, to derive the optimality conditions we introduce the partial KKT system. Based on the correspondent partial KKT system of our problem, we construct the ordinary system of the neural network. We prove later that the constructed neural network is stable and converges in the sense of Lyapunov to a partial KKT point of the biconvex problem. To illustrate the effectiveness of the proposed method, we solve a transportation problem using the neural network where the objective is to find the optimal shape of a transportation box subject to some geometric constraints. We also solve a generalized version of the shape optimization problem to evaluate the performance and the robustness of our approach for different sizes of problems.

Semi-discrete optimal transport: Hardness, regularization and numerical solution

Bahar Taşkesen (EPFL), Soroosh Shafieezadeh-Abadeh (Tepper School of Business, CMU) and Daniel Kuhn (EPFL)

Semi-discrete optimal transport problems, which evaluate the Wasserstein distance between a discrete and a generic (possibly non-discrete) probability measure, are believed to be computationally hard. Even though such problems are ubiquitous in statistics, machine learning and computer vision, however, this perception has not yet received a theoretical justification. To fill this gap, we prove that computing the Wasserstein distance between a discrete probability measure supported on two points and the Lebesgue measure on the standard hypercube is already #P-hard. This insight prompts us to seek approximate solutions for semi-discrete optimal transport problems. We thus perturb the underlying transportation cost with an additive disturbance governed by an ambiguous probability distribution, and we introduce a distributionally robust dual optimal transport problem whose objective function is smoothed with the most adverse disturbance distributions from within a given ambiguity set. We further show that smoothing the dual objective function is equivalent to regularizing the primal objective function, and we identify several ambiguity sets that give rise to several known and new regularization schemes. As a byproduct, we discover an intimate relation between semi-discrete optimal transport problems and discrete choice models traditionally studied in psychology and economics. To solve the regularized optimal transport problems efficiently, we use a stochastic gradient descent algorithm with imprecise stochastic gradient oracles. A new convergence analysis reveals that this algorithm improves the best known convergence guarantee for semi-discrete optimal transport problems with entropic regularizers.

Dependency in non-Gaussian settings: The generalized precision matrix and its financial applications

Gabriele Torri (University of Bergamo), Sandra Paterlini (University of Trento), Emanuele Taufer (University of Trento), Rosella Giacometti (University of Bergamo) and Gyorgy Terdik (University of Debrecen)

Partial correlation networks allow studying the interconnectivity of a financial system. Still, outside the Gaussian framework, they do not allow to fully characterize the interconnectivity structure of random variables. This severely limits its applications in finance where distributions with fat tails and high levels of tail correlation are a better fit for the data. Starting from local dependency measures, we propose a generalization of the precision matrix that describes the interconnectivity structure of multivariate random variables in a single point of the probability space, in a region, or under any conditioning. We use a Gram-Charlier expansion of the density to show how this matrix is related to the traditional precision matrix, we then discuss several parametric cases, focusing on distribution with fat tails, and we illustrate financial applications.

Network-dual reoptimization strategies for managing energy real options with timing decisions

Alessio Trivella (University of Twente), Selvaprabu Nadarajah (University of Illinois at Chicago) and Francesco Corman (ETH Zurich)

Energy operations and investments are managed with real option models that embed timing and/or switching decisions, where the former and latter types of decisions change irreversibly and reversibly, respectively, the status of the real asset. Optimizing the flexibility in these models under realistic state-variable dynamics is typically intractable and requires heuristic approaches. Least squares Monte Carlo (LSM) is popular for this purpose while a known forecast-based reoptimization heuristic (FRH) is not well suited to handle timing decisions. We develop a network dual reoptimization framework that leverages network flow algorithms and employs a novel class of partial information relaxations to overcome this shortcoming. Our framework provides both a new policy and a dual bound that is provably tighter than a known penalized perfect information bound. Numerical experiments show that our network-dual reoptimization policy outperforms

both FRH and LSM on two energy real option problems dealing with commodity and energy production (a compound timing and switching option) and the electrification of a vehicle fleet (a pure timing option).

Pragmatic distributionally robust optimization for simple integer recourse models

Ruben van Beesten (NTNU), David Morton (Northwestern University) and Ward Romeijnders (University of Groningen)

We consider distributionally robust simple integer recourse (DRSIR) models. For typical choices of the uncertainty set, the integer restrictions cause the resulting model to be non-convex and hence, hard to solve. To overcome this issue, we propose a pragmatic approach in which we restrict the uncertainty set in such a way that the problem becomes convex. We coin this approach pragmatic DRSIR. We present our pragmatic approach in two settings: one with an uncertainty set based on the Wasserstein distance and one with an uncertainty set based on generalized moment conditions. In both settings, we show how our approach leads to tractable problems. An important side-result of our analysis is the derivation of performance guarantees for convex approximations of SIR models. In contrast with the literature, these error bounds are not only valid for continuous distribution, but hold for any distribution.

Flexibility pre-contracting: A design for short-term markets for electricity

Felipe Van de Sande Araujo (Norwegian University of Science and Technology), Stein-Erik Fleten (Norwegian University of Science and Technology), Endre Bjørndal (Norwegian School of Economics) and Steven A. Gabriel (University of Maryland, Norwegian University of Science and Technology)

Participants of the electricity market that are exposed to redispatch costs might want to protect themselves from uncertainty by contracting flexibility directly. In the simplest form, these contracts mean that surplus or deficit power from an intermittent production is fully physically compensated by a flexible producer. In this paper we explain how those contracts might affect the outcome of the balancing market, and how taking them into account can lead to a more socially efficient solution, while providing the market participants cost-recovery in all scenarios and transparency. We propose a framework that calculates the intermittent generators' flexibility costs and thus potentially rearranges the dispatch order, resulting in an adjusted meritorder curve. Our framework uses a bilevel mathematical program with equilibrium constraints (MPEC). We discuss scalability and policy implications.

A distributionally robust perspective on the extremal queue problem

Wouter van Eekelen (Tilburg University)

Stochastic models are traditionally built on the assumption that the probability distributions of the driving random variables are known, whereas a distribution-free perspective assumes that these distributions are only partially known. Distributionally robust analysis seeks to calculate the worst-case model performance over the set of distributions satisfying this partial information. For most stochastic models, finding this worst-case scenario requires convex optimization methods, which are strongly linked to the generalized moment problem. However, in this talk, we emphasize specific methodological challenges for stochastic models with multiple random variables that are independent and identically distributed (i.i.d.). Applying existing optimization methods then becomes difficult, or even impossible, since the resulting optimization problem is no longer convex. We will connect these challenges with the problem of finding tight bounds for waiting time moments in the GI/GI/1 queue, as one of many examples from applied probability with i.i.d.~random variables as input. For example, one of the most notorious (and still open) problems in queueing theory is to compute the worst possible expected waiting time of the GI/GI/1 queue under mean-variance constraints for the interarrival- and service-time distributions. In this setting, the extremal distribution has only been determined numerically as the solution of a nonconvex optimization problem. We will instead address the extremal queue problem by measuring dispersion in terms of Mean Absolute Deviation (MAD) as a substitute for the more conventional variance. Using MAD instead of variance alleviates the computational intractability of the extremal GI/GI/1 queue problem, which arises from the i.i.d.~property, enabling us to state the worst-case distributions explicitly. Combined with classical random walk theory, we then obtain explicit expressions for the best possible upper bounds for all moments of the waiting time.

Joint chance-constrained Markov decision processes

V Varagapriya (Indian Institute of Technology Delhi), Vikas Vikram Singh (Indian Institute of Technology Delhi) and Abdel Lisser (Laboratory of Signals and Systems)

In this talk, we consider a finite state-action uncertain constrained Markov decision process under discounted and average cost criteria. The running costs are defined by random variables and the transition probabilities are known. The uncertainties present in the objective function and the constraints are modelled using chance constraints. The dependence among the random constraint vectors is driven by a Gumbel-Hougaard copula. We propose two second order cone programming problems whose optimal values give upper and lower bounds of the optimal value of the uncertain constrained Markov decision process. As an application, we study a stochastic version of a service and admission control problem in a queueing system and illustrate the proposed approximation methods on randomly generated instances of different sizes.

A tractable class of Partially Observed Markovian Decision Process: det-POMDP

Cyrille Vessaire (CERMICS), Jean-Philippe Chancelier (CERMICS), Michel De Lara (Ecole des Ponts ParisTech, CERMICS), Pierre Carpentier (ENSTA ParisTech), Alejandro Rodríguez-Martínez (IAM, TotalEnergies SE) and Anna Robert (OneTech/R&D, TotalEnergies SE)

Partially Observed Markovian Decision Processes constitute a class of problems which can be theoretically solved by reformulating them as a much bigger fully observed MDP (Markovian Decision Process). Such reformulation cannot be exactly solved through dynamics programming in the general case. However, when considering deterministic dynamics and observation functions, we obtain a class of POMDP first studied by Littman [1] and called det-POMDP. Det-POMDP is of interest as the number of reachable states used for the dynamic programming algorithm is bounded above, be it in the finite or infinite horizon cases. The focus of this talk is on finite horizon problems, whereas most of the literature on POMDPs focuses on problems with infinite horizon. We first present improvements of the bounds presented by Littman. Then, by adding further conditions on the dynamics and observations, we get a subclass of det-POMDP whose bounds are again improved. Through this subclass, we are able to further push back the dimensionality wall of dynamic programming. We hence obtain partially observed problems that are tractable by dynamic programming algorithms, whereas they are usually solved by approximating the Bellman value functions when considering general POMDP algorithms. We illustrate our approach on a toy problem.

[1] M.L. Littman, Algorithms for Sequential Decision Making, Ph.D. thesis, Brown University, 1996.

High-dimensional dependent random variables in stochastic programming

Stein W. Wallace (Norwegian School of Economics), Zhaoxia Guo (Sichuan University) and Michal Kaut (SINTEF)

In stochastic programming we sometimes face problems where it is unavoidable that the number of random variables is very high, and where dependence is obvious. A good example is speeds on road links in a city. These are dependent in both time and space. With a reasonable time discretization, we easily end up with tens or even hundreds of thousands of dependent random variables. The point of this talk is to discuss under what circumstances we can possibly handles such dimensions, and to give numerical examples of how it might function. For a case with about 28,000 dependent random variables we show how it is possible to to use just 15 scenarios to achieve an accuracy of about 1%.

K-adaptable robust pre-allocation of emergency supplies

Paula Weller (Aalto University) and Fabricio Oliveira (Aalto University)

Emergency response refers to the systematic response to an unexpected, dangerous occurrence such as a natural disaster. The response aims to mitigate the consequences of the occurrence by providing the affected region with necessary supplies such as water and medicine. To organize an effective response, we must face a challenging combination of uncertainty, complexity, and urgency. Disasters are not only preceded by uncertainty via their unpredictable nature, but also followed by it. Even after the event, data is frequently unreliable and incomplete. This difficulty is enhanced by the complex operating conditions, including the available infrastructure and the involvement of other players, humanitarian, industrial, or political. The most limiting factor, however, is urgency. In such situations, a short response time is not a matter of money, but rather of life and death. Still, a swift response is often obstructed due to disorganized cooperation, inefficient logistics and, most importantly, a lack of preparation. Preparation allows for shifting the most time-consuming processes, i.e., decision-making and organizing response actions, to the time before the contingency, thus allowing for efficient and streamlined response. However, the unpredictable nature of disasters makes it difficult to anticipate levels of demand and create optimal operations in advance. Yet, since the transport itself only takes place after the contingency, when problem data have become certain, it is possible to profit from a reactionary strategy without renouncing the temporal advantage of preparation. To this end, we employ a two-stage robust optimization approach, which, in addition to two decision stages (pre- and post-contingency) takes into account all possible scenarios concerning the uncertainty. Specifically, we model the pre-allocation of emergency supplies with a K-adjustable robust model, which allows a maximum of K second stage decisions, i.e., response plans. This mitigates tractability issues resulting from the high number of possible combinations of first- and second stage decisions, mitigates a lack of data due to the categorization of the scenarios, as well as allowing the decision-maker to seamlessly navigate the gap between the accuracy of a highly adjustable response and the simplicity of a more static one. We solve the model approximately via an iterative partition-and-bound method which solves the problem with increasing accuracy, providing a feasible solution at every step, thus enabling control over the conservativeness of the solution. We map the increasing degree of adaptability to the progression of the solution quality, which indicates a large potential especially for the more convenient early stages. For small K, preparations are easier to organize, and the improvement in solution quality is comparatively large. For a number of randomly created instances, the objective is improved significantly after the first two iterations across different instance sizes, which suggests the reliability as well as scalability of the approach.

Splitting a random pie: Nash-type bargaining with coherent acceptability measures

David Wozabal (Technical University of Munich), Raimund Kovacevic (Vienna University of Technology) and Walter Gutjahr (University of Vienna)

We propose an axiomatic solution concept for cooperative stochastic games where risk averse players bargain for the distribution of profits from a joint project that depends on management decisions by the agents. We model risk preferences by coherent acceptability functionals and show that in this setting the axioms of Pareto optimality, symmetry, and strategy proofness fully characterize a bargaining solution, which can be efficiently computed by solving a stochastic optimization problem. Furthermore, we demonstrate that there is no conflict of interest between players about management decisions and characterize special cases where random payoffs of players are simple functions of overall project profit. In particular, we demonstrate that for players with distortion risk functionals, the optimal bargaining solution can be represented by an exchange of standard options contracts with the project profit as the underlying. We illustrate the concepts in the paper by an extended example of risk averse households that jointly invest into a solar plant.

A dynamical neural network approach for solving stochastic two-player zero-sum games

Dawen Wu (Centralesupelec, Université Paris-Saclay) and Abdel Lisser (Centralesupelec, Université Paris-Saclay)

In this talk, we study a stochastic two-player zero-sum Nash game problem. We model this game problem as a dynamical neural network (DNN for short). We show that the saddle point of this game problem is the equilibrium point of the DNN model, and we study the globally asymptotically stablity of the DNN model. In our numerical experiments, we present the time-continuous feature of the DNN model and compare it with the state-of-the-art convex solvers, i.e., Splitting conic solver (SCS for short) and Cvxopt. Our numerical results show that our DNN method has two advantages in dealing with this game problem. Firstly, the DNN model can converge to a good quality equilibrium. Secondly, the DNN method can solve all problems, even when the problem size is large.

Distributionally robust inventory management

Yilin Xue (National University of Singapore), Yongzhen Li (Southeast University) and Napat Rujeerapaiboon (National University of Singapore)

We propose a distributionally robust inventory model for finding an optimal ordering policy that attains the minimum worst-case expected total cost. In a classical stochastic setting, this problem is typically addressed by dynamic programming and is solved by the famous based-stock policy. This approach however crucially relies on two controversial assumptions: the demands are serially independent and the demand distribution is perfectly known. Aiming to address these issues, inspired by the seminal work of Scarf (1958), we adopt a mean-variance ambiguity set that imposes neither the shape of each marginal demand distribution nor their independence structure. The proposed distributionally robust inventory model provably reduces to a finite conic optimization problem with however an exponential number of constraints. To gain tractability while simultaneously erring on the safe side, we propose two conservative approximations. The first approximation is obtained by recognizing the problem as an artificial two-stage robust optimization problem and then by restricting each adaptive decision to a linear decision rule. The second approximation, on the other hand, is obtained by upper bounding the maximum sum with a sum of maxima in the dualized formulation of the problem. We then present a progressive approximation based on a scenario reduction technique to gauge the quality of the proposed conservative approximations. We prove that this progressive approximation is exact when the inventory problem consists of two periods and then use it to show that our conservative solutions are close to being optimal. All of our exact and approximate inventory models are expressed as standard conic programs which allow for the incorporation of additional distributional information. The extensions are easy to develop by deriving a new cone that corresponds to the restricted ambiguity set and embedding it in the original problems. Numerically, we derive the worst-case demand distribution from the mean-variance ambiguity set and use it to show that our robust inventory policy is more resilient to the misspecification of the demand distribution, which is assumed by the state-of-the-art non-robust policies.

Distributionally robust optimization under stochastic disruptions

Haoxiang Yang (The Chinese University of Hong Kong, Shenzhen)

A stochastic disruption is a type of infrequent event in which the timing and the magnitude are random. We introduce the concept of stochastic disruptions, and a stochastic optimization framework is proposed for such problems. In this talk, we discuss two possibilities where we do not know the exact probabilistic distribution of the uncertainty under the stochastic disruption setting, one for the uncertainty magnitude and the other for the timing. We propose stochastic programming models for each case and solve them using cutting-plane methods. We present computational results of our approach applied to an optimal power flow problem with N-1 contingencies.

Moving average options: Machine Learning and Gauss-Hermite quadrature for a double non-Markovian problem

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Evaluating moving average options is a tough computational challenge for the energy and commodity market as the payoff of the option depends on the prices of a certain underlying observed on a moving window so, when a long window is considered, the pricing problem becomes high dimensional. We present an efficient method for pricing Bermudan style moving average options, based on Gaussian Process Regression and Gauss-Hermite quadrature, thus named GPR-GHQ. Specifically, the proposed algorithm proceeds backward in time and, at each time-step, the continuation value is computed only in a few points by using Gauss-Hermite quadrature, and then it is learned through Gaussian Process Regression. We test the proposed approach in the Black-Scholes model, where the GPR-GHQ method is made even more efficient by exploiting the positive homogeneity of the continuation value, which allows one to reduce the problem size. Positive homogeneity is also exploited to develop a binomial Markov chain, which is able to deal efficiently with medium-long windows. Secondly, we test GPR-GHQ in the Clewlow-Strickland model, the reference framework for modeling prices of energy commodities. Then, we investigate the performance of the proposed method in the Heston model, which is a very popular model among the non-Gaussian ones. Finally, we consider a challenging problem which involves double non-Markovian feature, that is the rough-Bergomi model. In this case, the pricing problem is even harder since the whole history of the volatility process impacts the future distribution of the process. The manuscript includes a numerical investigation, which displays that GPR-GHQ is very accurate in pricing and computing the Greeks with respect to the Longstaff-Schwartz method and it is able to handle options with a very long window, thus overcoming the problem of high dimensionality.

Stochastic analysis of the performance of national industrial sectors facing the environmental measures

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Current environmental policies applied in the EU and elsewhere in the world are often the subject of debate and criticism. Concerns are often raised about the impact of measures on businesses, national economies and their competitiveness. Our contribution explores how the national industrial sectors perform under the environmental policy measures like green deal target and emissions trading and the risk which they imply. We introduce the model which capture the most important economic and environmental indicators which are expected to be touched by the environemntal policy. Using the combination of Stochastic Multi-criteria Acceptability Analysis (SMAA) and the PROMETHEE decision making method, we rank the national industrial sectors according to their environmental and economic performance and assess the impact of the environmental policy measures on them. The analysis explores the probability under which the sectors are considered efficient. The profiles of the efficient units are analysed and discussed.

Investment planning of multi-region power systems with uncertainty using stabilised Benders decomposition with adaptive oracles

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Long-term investment planning of a power system usually faces uncertainty from strategic and operational time horizons. The multi-horizon formulation was proposed to include uncertainty on both time horizons with a much smaller scenario tree than the traditional multi-stage formulation. However, a model may become intractable once multiple uncertainties and multiple planning stages are included. Therefore, decomposition techniques, such as Dantzig-Wolfe decomposition and Benders type decomposition, have been developed to solve such large-scale problems efficiently. Benders decomposition solves a sequence of approximations and builds cutting planes iteratively until reaching a predefined convergence gap. However, it can be computationally expensive to solve all subproblems to build exact cutting planes. Therefore, two adaptive oracles have been proposed to generate inexact cuts and provide guaranteed upper and lower bounds, and the decomposition with these adaptive oracles has been shown to solve single region problems significantly faster. In the following, we call this adaptive Benders decomposition. However, investment planning of power systems normally involves multiple regions that are connected by transmission lines. We noticed a slow down in performance when applying Benders decomposition to solve multi-region planning problems: both adaptive Benders decomposition and standard Benders decomposition suffered from oscillation and the oscillation becomes more serious as more regions are introduced. Therefore, in this paper, we apply a level set method to stabilise the decomposition. We compare stabilised adaptive Benders with the unstabilised versions of adaptive Benders and standard Benders on a multi-region long-term investment planning problem with short-term and long-term uncertainty. The computational results show that for a 1.00% convergence tolerance, the proposed stabilised method is up to 17.5 times faster than standard Benders decomposition and 5.6 times faster than adaptive Benders decomposition without stabilisation.

Optimal control based trajectory planning under uncertainty

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In this talk, we propose a constrained optimal control approach as a reference trajectory generator for a driving scenario with uncertainty. Given a scenario, this generator can produce a reference trajectory in order to make validations for autonomous vehicles decision-making problems. The constrained optimal control problem guarantees to obtain a collision-free trajectory with safety and comfort based on the design of the objective function and the constraints of the vehicle. The uncertainty of environmental information provided by sensors is taken into account, and a stochastic optimization problem is proposed to limit the risk of violating safety requirements. Numerical experiments show that the stochastic model can better ensure the robustness of the obtained solutions.

Local volatility estimation in the presence of jumps

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Recently, we have once again faced sudden changes in stock and commodity prices as well as in major currencies and indices. This is a reminder of the importance of taking into account jumps in option pricing and hedging. On the other hand, the classical Black-Scholes model is based on the continuous Brownian motion paradigm. It is undeniable that the latter model for option pricing led to a tremendous development of financial instruments in stock exchanges throughout the world. Such a model provided a fair way of evaluating option prices making use of simplified assumptions. Indeed, soon it was realized that the Black-Scholes model was inadequate and required realistic extensions. One of the most well-accepted of such extensions is to consider variable diffusion coefficients thus leading to the so-called local volatility models. Local volatility models are extensively used and well-recognized for hedging and pricing in financial markets. They are frequently used, for instance, in the evaluation of exotic options so as to avoid arbitrage opportunities with respect to other instruments. The PDE (inverse) problem consists in recovering the time and space varying diffusion coefficient in a parabolic equation from limited data. It is known that this corresponds to an ill-posed problem. The ill-posed character of local volatility surface calibration from market prices requires the use of regularization techniques either implicitly or explicitly. Such regularization techniques have been widely studied for a while and are still a topic of intense research. We have employed convex regularization tools and recent inverse problem advances to deal with the local volatility calibration problem. In this talk after a short introduction to the main issues in local volatility calibration, I shall discuss recent work on the solution of the inverse problem for Dupire's local volatility model in the presence of jumps.