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## **Lecture 1: Two-level optimization problems: existence results of solutions and approximate solutions.**

**Abstract.** A two-level optimization problem corresponding to a Stackelberg game in which one of the two players has the leadership in playing the game is considered. First, a review of results about existence of solutions and approximate solutions is presented in the case in which the solutions set to the lower level problem is a singleton.

In the case in which the response function of the follower is multi-valued different models are presented as weak and strong Stackelberg solutions, intermediate solutions, and in these cases existence and stability of solutions and approximate solutions are discussed as well. These models correspond to a precise behavior of the leader: he can act in an optimistic way (strong) or pessimistic one (weak), or he can gather information and estimate the follower response (intermediate).

The models considered in this presentation will be framed in concrete applicative situations: Cournot duopoly, principal agent, IEA International Environment Agreement models.

## **Lecture 2: Two-level optimization problems: some results in probabilistic approach.**

**Abstract.** The mixed extension of a Stackelberg game, where players decide strategies randomizing and consider the average payoff, is presented, and the existence of such mixed (or approximated) solutions is discussed.

Then, the hierarchical situation is extended to  $N$ -player ( $N > 2$ ) case: here the concept of Stackelberg-Nash equilibrium is given and illustrated with examples.

The particular case of one leader and two followers is studied: by using the Shannon entropy, a regularization scheme for the two-stage game is introduced and some properties are presented, as the asymptotic subgame perfectness.