

POLICY MODEL FOR POLLUTION CONTROL IN THE COPPER INDUSTRY, INCLUDING A MODEL FOR THE SULFURIC ACID MARKET

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In this paper we develop a policy model for pollution control investment and operational decisions in the copper industry. The system consists of (i) a nonlinear integer model to optimize smelter operations, including the investment decisions relating to smelting capacity and pollution control plants that complies with environmental regulations, and (ii) a network flow model to describe the economic behavior of the sulfuric acid market, which considers the sulfuric acid produced at the pollution abatement stages in the smelting process. This second model solves for an equilibrium among spatially separated markets, that determines the price and distribution of acid in each demand and supply region. The two models interact through the input each receives from the other. Thus, the smelter model uses the sulfuric acid price at each smelter to find optimal operational and investment decisions, whereas the sulfuric acid market model considers sulfuric acid output at the smelters as part of the supply input to find the price of this product at each smelter location. The solution given by the policy model is the global equilibrium obtained when this iterative process between the two models converges. Thus, the price of the sulfuric acid, which is the central component when deciding when and where to locate a sulfuric acid plant, is determined endogenously, rather than assumed exogenous as in most models of this type. Computational experiments show that expected profits associated with the copper industry can increase significantly when the problem is solved in aggregate, as compared with the smelters making their decisions independently. Several applications of the policy model are described.

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1. INTRODUCTION

In this paper we develop a policy model for pollution control investment and operational decisions in the Chilean copper industry. This project, mainly motivated by environmental issues, was supported by the Chilean Copper Commission (Cochilco) as part of a set of initiatives that the Chilean government has been promoting to improve efficiency in the mining sector (Cochilco's main mission is to develop policies, strategies, and actions to promote permanent and sustainable development of the mining sector). The model presented in this paper is currently used by Cochilco and has become an important decision-making tool. For example, this model is extensively used to revise new investment projects, analyze the economic impact of different environmental standards, and anticipate future infrastructure requirements related to the commercialization of copper and sulfuric acid. The goal of this paper is to describe how operations research tools can be applied to efficiently incorporate the environmental regulations into the copper production process, using the Chilean case as a motivating example.

Copper is one of Chile's most important industries, accounting for approximately 38% of the country's total

exports. Over the last hundred years copper production has increased significantly, growing from 21 tons/year in 1897 to 828,300 in 1975 and 3,115,800 tons/year in 1996. Despite such significant industry growth over the years, only in the 1980s did the Chilean government begin to study the environmental effects of the copper production process. The smelting process that transforms concentrate into refined copper, contributes significantly to the air pollution through the emissions of sulfur dioxide, particulate matter, and arsenic. For example, in 1989 stationary sources produced 99.3% of all sulfur emissions in the country, 91% of this emitted by the copper smelters (a total of 874,400 tons of sulfur per year were produced by the copper smelters; see Solari 1992). In 1991 this led to new environmental regulations governing emissions of sulfur dioxide and particulate matter. A new environmental regulation on arsenic emissions was introduced in 1999. One of the most significant environmental challenges faced by the public-sector mining industry today is how to solve the pollution problem in copper smelters.

There are currently seven copper smelters in the country, two private and five state-owned. These receive concentrate for transformation into refined copper from 22