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Analysis of the long-term availability of uranium: The influence of dynamic constraints and market competition

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ABSTRACT`

The availability of natural uranium has a direct impact on the global capability to sustain the demand from nuclear power plants in the coming decades. Therefore, the expansion scenarios of nuclear power should be analysed in conjunction with long-term dynamics of the uranium market. This paper presents three forms of a partial-equilibrium model of the uranium market. All forms consider global demand as exogenous (input scenarios from the literature) and regional estimates of the quantities and the costs of ultimate resources (results obtained from previous work). The three forms differ by the market constraints and the market structure considered. Comparing them highlights the role of the market structure and the impact of some key parameters of the market dynamics on the long-term availability of uranium. An important finding is the influence of two constraints: the anticipation of demand and the significant role played by the correlation between price and exploration expenses in shaping the price trends. In addition, results from simulations highlight different long-term dynamics when the producers are allocated into a limited number of regions (to simulate an oligopoly) compared to a single region (undefined number of players to simulate perfect competition).

1. Introduction

The availability of natural uranium has a direct impact on the global capability to sustain demand from nuclear power plants in the coming decades as it is forecasted that Light Water Reactors will remain the main nuclear technology for most of the 21st century (Baschwitz et al., 2009; Gabriel et al., 2013). Therefore, the expansion scenarios of this low-carbon source of electricity should be considered jointly with the uranium supply. This supply is impacted by the level of uranium resources but also by efforts to identify and then extract them. In this paper, we propose a step-by-step modeling of the uranium market taking into account various market structures, such as perfect competition or oligopolistic market, and dynamic constraints, namely funding of exploration and demand anticipation. Consequently, three forms of a partial-equilibrium model are presented to highlight the key drivers of price dynamics.

The market models consider global demand as exogenous (input prospective scenarios from literature) (§ 2.1). To account for both regional economic specificities and resource depletion, regional estimates of the quantities and the cost of ultimate resources are used (supply curves obtained from previous work) (§ 2.2). The comparison of the three models highlights the role of the market structure and the impact of some key market dynamics parameters on the long-term availability of uranium. This is the aim of this prospective study, which therefore does not be interpreted as a forecast of uranium prices for the 21st century.

Given this objective, § 3 describes the results of a perfectly competitive market in which all resources are assumed to be identified without any exploration effort (first form of the model: M1 mechanism). This market representation is implicit in some recent studies (MIT, 2011; Schneider and Sailor, 2008) that claim to estimate long-term uranium price based on the cost of ultimate resources only. These studies omit two major market constraints introduced in § 4: exploration funding and demand anticipation, which is closely related to the scarcity rent. We show that these constraints have a strong influence on the long-term dynamics of a competitive market (second form of the market model: M2 mechanism, § 5). Finally, the paper focuses on an oligopolistic market (third form of the model: M3 mechanism) in which several mining regions produce uranium (results are analysed in § 6).

The results show that long-term dynamics on the uranium market are strongly impacted both by the oligopoly market structure and by the market constraints (exploration funding, demand anticipation).

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2. Demand scenarios and uranium supply curves

2.1. Demand scenarios

Energy scenarios are uncertain estimates of what may happen based on a range of assumptions, including existing views on demographics and economics change, energy intensity, or political decisions. The underlying assumptions regarding energy policies and competition between electricity generation means are described in the literature (Baschwitz et al., 2009; IIASA and WEC, 1998). This paper does not aim to discuss nuclear capacities to be installed and operated in the 21st century worldwide, nor the future competitiveness of nuclear power. Demand scenarios used in this study are therefore exogenous and based on the existing literature. They serve as input data to compute uranium requirements and then identify key parameters of uranium market dynamics.

We have chosen the IIASA scenarios from 1998 (IIASA and WEC, 1998) which are part of the few scenarios covering the entire 21st century. These scenarios consider a strong increase in the global primary energy demand. Even if the share of nuclear power is less than 20% of primary energy demand, a significant increase of installed nuclear power capacities is forecasted in these scenarios. The “A3” scenario is a strong global growth scenario with a gradual introduction of nuclear energy; nuclear energy represents around 11% of world energy demand in 2050, and 22% in 2100 (5400 GW and 810 ktU_{nat}/year in 2100). The “C2” scenario corresponds to a strong effort to protect the environment against global warming. Nuclear energy represents around 12% of world demand for primary energy in 2050; more than a doubling compared to current level. In 2100 the installed capacities and the uranium demand are respectively 2100 GW and 340 ktU_{nat}/year. The IIASA has produced more recent scenarios (IIASA, 2012), which show more ambitious nuclear energy demands, yet one can argue that their feasibility remains uncertain and prefer consider those from 1998. No scenario of decreasing installed capacities has been considered as uranium availability would not be a constraint in this case.

The two uranium demand scenarios are based on the assumption that only Light Water Reactors (LWRs) would be operated (Baschwitz et al., 2009) and it is assumed that uranium demand is inelastic and fully satisfied by mining production.[1]

A3 and C2 demand scenarios are shown in Fig. 2-1. Their time horizon is the same as all simulations in this paper: one hundred years, starting in 2013.

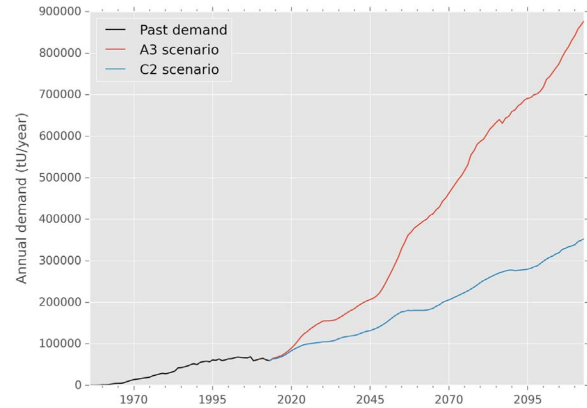

Fig. 2-1. Uranium demand scenarios (Baschwitz et al., 2009).

2.2. Uranium supply curves

The long-term cumulative supply curve (LTCS) is a tool used by resource economists to answer two questions: what quantities and at what cost? This curve depicts the cumulated amount (tU) of all resources, after they have been ranked by unit production cost ($/kgU). It may be noted that there is no time dimension in the LTCS curve.

We argue that most recent studies on the long-term supply of uranium make oversimplified assumptions on the available resources and their production costs. Some consider the whole uranium quantities in the Earth's crust and then estimate the production costs based on the ore grade only, disregarding the size of ore bodies and the mining techniques (Matthews and Driscoll, 2010; MIT, 2011; Schneider and Sailor, 2008). Other studies consider the resources reported by countries for a given cost category, disregarding undiscovered or unreported quantities (Tilton and Skinner, 1987; Tilton and Yaksic, 2009).

While grade is certainly an important factor driving the cost of a resource, there are other technical parameters influencing costs and it may be desirable to integrate them in models. This includes the size of ore bodies and the geochemical nature of deposits. Any change in these parameters can lead to specific mining techniques and therefore specific costs. Consequently, we propose a different methodology based on geological environments to estimate the “ultimate resources” of uranium within a region (their unit production cost & quantities) (see full methodology of the “Regional Uranium Model” (Monnet et al., 2016)). Ultimate resources defined in this paper cover known resources, undiscovered resources and already mined (exhausted) resources.

Unlike recent models in which uranium quantities and costs are estimated worldwide based on earth crust grades only, the RUM model provides more detailed resource estimation and is more flexible regarding cost modeling. In the RUM model, geological availability and production costs are estimated by a bivariate model. The two variables are grade (average grade of a deposit) and tonnage (ore tonnage of a deposit). The scope of the model is divided into several regional crustal abundance estimations defined by theirs own geographical boundaries, resource dispersion (average grade and size of ore bodies and their variance), and cost function. For a given region, the RUM model analyses the properties of known deposits (grade and ore tonnage),[2] the economics of recent mining projects (operating costs, investment costs, production capacities),[3] and the current market conditions (uranium price), to infer the properties of all deposits (known, exhausted and undiscovered deposits). This allows the model to take into account economies of scale (mainly correlated with tonnage) for cost estimation as well as geological, technical and economic specificities for every region.

The resources from all deposits are then aggregated by merit order into a regional LTCS curve. The global LTCS curve can finally be obtained by adding regional supply curves. Six regions have been considered in this paper: United States, Canada, Kazakhstan, Australia, Africa and a region called “Rest of the world” (as depicted in Fig. 2-2). This is motivated by the significant resources and production of the first five regions: United States, Canada, Kazakhstan, Australia and Africa account for 85% of global production and 80% of reasonably assured resources (RAR) below $ 130/kgU in 2013 (OECD NEA and IAEA, 2014).

Fig. 2-3 shows the US endowment (ultimate resources) obtained from RUM model (Monnet et al., 2016). Identified resources (RAR)

[1] Among the secondary sources of uranium, enrichment of depleted uranium can affect demand for natural uranium. Our demand scenarios already take account of low tails assays at enrichment plants (Baschwitz et al., 2009). Recycling can also affect demand for natural uranium. It can represent up to 25% of the consumption of a nuclear fleet (Boullis, 2013). Yet, not all nuclear fleets will be able to benefit from it during the 21st century.

[2] Data from UDEPO database (IAEA, n.d.).

[3] Data from WISE Uranium database (WISE, n.d.).