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A review on the economics of underground space utilization

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ABSTRACT

The necessity for modern cities to develop efficient infrastructure continues to bring forth the options for a systematic utilization of the subsurface space. Nevertheless, the economics of underground space utilization are a key parameter for the adoption of such kind of functions and infrastructure over traditional surface solutions. The paper attempts to enlighten the current trends of the modern underground industry and, furthermore, reviews the construction cost levels for various infrastructure types. Finally, since an important part of the economic benefits of underground structures are latent and are associated with social and environmental externalities, the paper analyzes the principles of environmental economics and presents case examples where such benefits are expressed in monetary terms.

1. Introduction

At the end of the day it all comes down to the cost. This is the case when a project is evaluated in order to take the "go" or the "no go" decision. Thus, the project should prove its efficiency, as expressed in monetary terms, and bear results, not only with positive bottom-lines, but at more competitive levels than its alternatives.

Today, the advantages offered by the utilization of the subsurface are important for the modern societies and, gradually, underground uses (UUs) are gaining ground, becoming an integral part of modern infrastructure (Durmisevic, 1999; Kaliampakos and Benardos, 2008; Bobylev, 2009). However, underground projects should comply with the abovementioned cost criteria. It is well-known that underground projects usually have an unfavorable starting point, as compared to surface projects, a fact which is mainly derived from their higher initial capital/construction cost requirements. However, a sound evaluation process is imperative to include all parameters yielding costs or benefits, including maintenance and operation cost, as well as non-market values. Sterling et al. (2012) further support that in order to maximize the efficiency of underground infrastructures a careful strategic planning is required which will consider life-cycle cost-benefits and the selection of projects that offer the highest contribution to urban sustainability rather than a short-term fix to an individual need.

Finding and analyzing the cost parameters of underground projects is not an easy task, since the subject itself is considered a sensitive issue, resulting in sporadic and fragmentary data publications. Therefore, comprehensive reviews of the subject are also missing, a fact that further limits the dissemination of relevant information among the various stakeholders, resulting in vague assumptions or biased assessments.

The present paper is based on a systematic collection and analysis of up to date published research and other available data related to the economics of several UUs types. In addition, it also incorporates research on the economic analysis of underground space utilization conducted by the authors. Its main objectives are to identify and analyze the economic dimension behind the successful real-life underground projects. More particularly, it firstly provides an assessment of the order of magnitude of the underground "business", as well as the relative contribution of the various underground types, as given by the sum of their gross value or their importance as niche markets. Secondly, it summarizes important cost data for the majority of UUs, from tunneling projects and urban underground projects to special infrastructure cases.

As mentioned, the incorporation of latent cost/benefits, usually termed as externalities has been proved to be the pivotal point in an evaluation process that can render an underground project not only feasible but also favorable (Kotsareli et al., 2012; Bassam, 2006; Tsimplokoukou et al., 2012; Zhu et al., 2009). Nevertheless, it is usually omitted from the analysis, thus penalizing the underground projects. The tools to monetize such benefits (or drawbacks) are described and real cases are presented in detail, portraying the correct use of this modern type of analysis.

Based on the above, through the paper the readers would have the opportunity to adequately decode the issue of the economics of

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the underground space utilization, facilitating the identification of strong points and drawbacks moneywise.

2. World industry output – underground construction

Identifying the global underground construction output is a complicated task. It is quite a difficult feat to be exact as there are issues that can cloak the economic dimension of the market related to subsurface construction activities. Firstly, the discrimination and categorization currently used cannot allow for an easy identification of the underground construction projects. Either such projects are part of a broader infrastructure category (e.g. road projects, energy projects) making it difficult to discern the precise portion of the underground works compared with the overall project's activities, or the categorization of specialized underground construction activities is too segmental to get either comparative statistics (e.g. metro construction) or to get any statistics at all (e.g. underground oil storage infrastructure). Thus, both the existing "noise" and the limited data create a challenging framework for the researchers to identify the market output of the modern construction industry of underground projects.

The estimates given in the paper present a rough although representative assessment of the annual revenues of the construction sector related to the development of underground works. In order to see the dynamics of underground construction and to assess its overall importance the data regarding the whole construction sector are presented first.

The construction industry, as a whole, is showing promising signs of recovery after the prolonged plunge experienced after the onset of the 2008 crisis. This is mainly happening because of the increased spending from the BRIC countries as well as from other developing countries. On the other hand, the European construction sector seems, still, not fully recovered, while the US construction is on the verge of a rebound. Thus, emerging markets are and will be the most significant players for the construction industry, further raising their portion from today's 52% of the total construction activity to 63% by 2025 (Global Construction Perspectives and Oxford Economics, 2013).

In 2009 the market of the construction industry was around US $7.5 trillion, accounting for the 13.4% of the global GDP (Global Construction Perspectives and Oxford Economics, 2009). It was forecasted, at the time, that by 2020 the total output volume will have grown by 67% reaching a total of US$12 trillion. These figures were updated in 2012 (Global Construction Perspectives and Oxford Economics, 2013), where the annual global construction output was estimated at US$8.7 trillion. Furthermore, the projections for 2025 were further raised to US$15 trillion, accounting for more than the 13.5% of world output (Global Construction Perspectives and Oxford Economics, 2013). Currently, China is leading the construction market share with 18%, followed by US (12%), Japan (8%), India, Canada, Germany and France (4% each).

Now, regarding the underground construction industry, the data presented focus on the major markets. Starting from the US, in 2009, the revenue of bridge and tunnel construction (NAICS 23412) ranged at about US$22 billion. This represents roughly a 25% of the total road construction output in the States. From 2009, the average annual increase in revenue is approximately 2.8% resulting to a figure of around US$24 billion for 2014 (Statista, 2015). For the tunneling industry alone (rail, road, sewer, cable, water and scientific tunnels) the total revenue is estimated at about US$3 billion (IBISWorld, 2015). Nevertheless, this is only attributed to tunnel construction for road projects excluding all other infrastructure, (e.g. metro, storage, energy, etc.).

According to the European Construction Industry Federation (FIEC, 2015), the total output of the European construction industry is around €1.2 trillion in both 2013 and 2014 (8.8% of EU-28 GDP). The civil engineering's portion (roads, railways, bridges, tunnels, concrete structures, special foundations, electrical works, water supply, wastewater treatment and works on maritime or river sites) was about 21%. This agrees with the Eurostat's data (2015) in which the construction output of the civil engineering sector (NACE Rev. 2, F42) is around €255 billion (2013) from which the largest portion is attributed to the construction of roads and railways (48%). The construction of railways and underground railways (F42.12) amounts to €21 billion, while the construction of bridges and tunnels (F42.13) accounts for €11.5 billion (2012 data). Finally, the construction output for utility projects as a whole is €51 billion.

These numbers although important, are no match for the Chinese construction powerhouse. In the past decade China experienced a tremendous boom in underground construction. For example from 2007 to 2014 the Beijing metro expanded by more than 385 km, while a further expansion is being planned. In China, the "Bridge, Tunnel and Subway Construction" industry has been growing rapidly, at annual growth rates of more than 15%, yielding revenues of US$559 billion in 2014 (IBISWorld, 2015b). This output includes all bridge, tunnel, rail and metro infrastructure in the country and is more than double from the respective "Road & Highway Construction" figure of US$300 billion. It is interesting to know that major underground infrastructure is underway and until 2020 China is expected to top all statistical categories regarding underground construction.

In other developing countries the underground space utilization is also gaining ground fast. For example India is carrying out the modernization of its metro and road infrastructure in parallel with the development of hydropower and oil storage projects. At the same time Brasil from the start of the decade has boosting the development of underground projects (metro, road, and railway) having projects completed or currently under-way with a total length of more than 130 km (Celestino and Rocha, 2011). Finally, subsurface construction projects are flourishing in the Arabic region where new infrastructure is being developed, especially focused on urban transit systems. Two of the most notable projects there, started just a couple of years back (Riyadh metro, Doha metro) and expected to become operational by the start of the 2020's, have a combined budget of around US$57 billion and a total length of 390 km.

Given the above data, the construction activities relating to the development of underground faculties and functions represent a multibillion market. With modest estimations more than US$50 billion spent in new construction projects in an annual basis. This number is expected to grow fast as more and more developing countries are attracted by the advantages offered and integrate underground projects in their infrastructure planning.

3. Economics of underground space projects

The cost of setting up an underground installation is a key element included in every design study. Many cost assessment studies exist in the literature, focusing on the utilization of the underground space and thus highlighting the cost characteristics of the project. This is made in terms of capital/construction costs for tunnel and metro construction (Sinfield and Einstein, 1997; Isaksson and Stille, 2005; Flyvbjerg et al., 2008; Petroutsatou and Lambropoulos, 2010; HM Treasury, 2010; Efron and Read, 2012; Paraskevopoulou and Benardos, 2013; Rostami et al. 2013), oil storage caverns development (e.g. Froise, 1987; Zhao et al., 1996; Zhao et al.,1999; Benardos and Kaliampakos, 2005), warehouses (e.g. Zevgolis et al. 2004; Ikiiheimonen et al., 1989), or other underground infrastructures as automated waste collection systems (Nakou et al. 2014; Miller et al., 2014).