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ANALYSIS

Stochastic frontier analysis of total factor productivity in the offshore oil and gas industry

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ABSTRACT

We examine the impact of technological change on oil and gas exploration, development and production in the Gulf of Mexico over the past five decades. We analyze the effect of technological change on the production frontier using a unique field-level data set covering 1947 through 1998. We then develop estimates of the growth in total factor productivity (TFP) in the industry at the regional level from 1976 to 1995. To address the unique features of this marine resource industry, we include in our models some key geological variables such as water depth and field size. In addition, the results reveal that environmental regulation had a significantly negative impact on offshore production, although such impact has been diminishing over time.

1. Introduction

The offshore oil and gas industry has played a significant role in energy supply in the United States. Since 1947 in the Gulf of Mexico, as one of the first large-scale offshore production areas in the world, the share of offshore production in the total domestic production has been increasing. In 2001, Federal offshore oil and gas production accounted for 26.3% and 24.3% of total U.S. production, respectively (U.S. Department of Interior, 2001). Oil and gas production in the Gulf, our study region, accounted for 88% and 99% of the total U.S. offshore production in 1997, respectively (U.S. Department of the Interior, 1997). Contrary to earlier predictions of declining production due to resource depletion (Walls, 1994), the output from the Gulf of Mexico has increased in recent years.

Offshore oil and gas operations take place in a much more difficult natural environment than onshore operations. Generally, the long run path of offshore oil and gas production is the net result of two opposing forces: forces that reduce costs by technological change, and forces that increase costs by

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cumulative depletion and the associated decline in resource accessibility such as exploitation moving to fields that are more remote, deeper and smaller. In the past five decades, offshore operations in the Gulf of Mexico expanded first along the coast in shallow waters, and then extended into deep waters. The continued development and production in the region has depended heavily on technological innovation.

The purpose of this study is to examine the role technological change in conjunction with environmental regulation has played in the offshore industry. We first analyze the effect of technological change on the production frontier using a unique field-level data set, and we then develop estimate of the growth in total factor productivity (TFP) in the industry at the regional level.

Introductions to offshore technologies can be found in many studies (e.g., Massachusetts Institute of Technology, 1973; Giuliano, 1981; Farrow et al., 1990; Bohi, 1997). Several recent technological innovations have had significant impact on the offshore industry. Three-dimensional (3D) seismic technology became available in the mid-1980s and has been widely used since 1992 (U.S. Department of the Interior, 1996). The higher-quality images from 3D seismology greatly improved the ability to locate new hydrocarbon deposits, to determine the characteristics of reservoirs for optimal development, and to help determine the best approach for producing from a reservoir. The new technology has substantially increased the success rate of both exploratory and development wells, which has led to reductions in the number of wells drilled for a deposit as well as in exploration and development cost.

Horizontal drilling technology has developed rapidly since the late 1980s. The technology involves a steerable downhole motor assembly and a "measurement-while-drilling" package. With horizontal drilling technology, drillers are capable of guiding a drillstring that can deviate at all angles from vertical. Thus, the wellbore intersects the reservoir from the side rather than from above (U.S. Department of Energy, 1993). Horizontal drilling has been widely used offshore to reach deposits far away from fixed platforms, by that increasing access to dis tant reserves and lowering the cost of production.

Deep-water technology encompasses two production systems: tension leg platforms (TLPs) and subsea completions. TLPs float above the offshore field and are anchored to the sea floor by hollow steel tubes. TLPs have been used in several deep-water fields in the Gulf of Mexico. Although deep-water technologies are mostly used for offshore development and production, they provide a driving force for explorations in deep waters.

There has been a growing literature on technological change and petroleum exploration and development. In a study of natural gas exploration and discovery in the U.S. lower 48 states, Cleveland and Kaufmann (1997) found that depletion effects had outweighed technological improvements from 1943 to 1991. By contrast, Fagan (1997) found that technological change had offset resource depletion in her analysis of onshore and offshore oil discovery costs from 27 large U.S. oil producers over the 1977–1994 periods. Cuddington and Moss (2001) have reached the same conclusion from their analysis of the cost of finding additional petroleum reserves (cost of exploration and development) from 1967 to 1990.

Jin et al. (1998) developed a framework for the estimation of total factor productivity (TFP) in the offshore oil and gas industry. Their model extends conventional TFP measurement by accounting for the effects of increasing water depth and declining field size. They applied the model using regional data in Gulf of Mexico and developed preliminary estimates for TFP change from 1976 to 1995. The results suggest that productivity change in the offshore industry has been remarkable.

In a separate study using our field-level data on production and Data Envelopment Analysis (DEA), we found that the effect of technological progress dominated that of resource depletion in production from fields (Managi et al., 2004a). Statistical relevance of results, however, is not provided. We obtain similar conclusion using the discovery of new fields that the effect of technological progress dominated that of resource depletion in discovery process from fields (Managi et al., 2005a). Inefficiency in field-level activity, however, is not considered. In this study, we consider the inefficiency in field-level production and analyze the impact of technology and the other relevant variables statistically.

We also consider the effect of environmental regulations on field-level production frontier as well as on regional-level productivity measurement (Barbera and McConnell, 1990). Several studies have examined how the oil and gas industry responds to changes in environmental regulations in the literature. Kunce et al. (2004), for example, examines how the oil and gas industry responds to changes in environmental and land use regulations pertaining to drilling. A simulation model for Wyoming shows that drilling and future production are sensitive to changes in costs associated with environmental and land use regulations.

Since the 1970s, the offshore oil and gas industry has been subject to multiple environmental regulations. Under the Clean Water Act of 1972, the Environmental Protection Agency (EPA) first limited the disposal of free oil in drilling muds and issued effluent discharge standards based on existing technologies in 1975. Standards for toxic and nonconventional pollutants in effluent discharges and drilling muds were added in 1986, along with limits on oil and grease in produced water. In 1993, discharge standards were revised and expanded to cover drilling fluids and cuttings; produced water; deck drain age; treatment, completion and workover fluids; and domestic and sanitary wastes for most of the OCS (outer continental shelf). These standards were extended to the Western Gulf of Mexico portion of the OCS in 1998–1999.[1] In addition, under the Clean Air Act, the national ambient air quality standards first became applicable to most of the OCS in 1990. The standards became applicable to the Western Gulf of Mexico in 1993.

The paper is organized as follows. Section 2 presents the methods of our stochastic frontier analysis and TFP assessment. Empirical data used in the study are described in Section 3. We discuss the results in Section 4. Conclusions are summarized in Section 5.

[1] Typically, EPA regulations have taken effect several years later in the Western Gulf of Mexico, where most U.S. offshore oil and gas installations are concentrated, than in other areas of the OCS.