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Dissertation

Competition and Collaboration

A Comparison of U.S. and Chinese Energy Outward Direct Investment

Chaoling Feng

RAND CORPORATION

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This document was submitted as a dissertation in October 2014 in partial fulfillment of the requirements of the doctoral degree in public policy analysis at the Pardee RAND Graduate School. The faculty committee that supervised and approved the dissertation consisted of Charles Wolf, Jr. (Chair), Debra Knopman, and Constantine Samaras.

RAND PARDEE RAND GRADUATE SCHOOL

This dissertation is dedicated to the memory of my mother,

Guiying Wang(1959-2014).

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Abstract

The U.S. and China are the world's largest energy importing countries. In 2011, both countries imported approximately half of their total oil supplies from overseas. Due to this great reliance on foreign energy supplies, energy companies from both countries continue to pursue energy outward direct investments (EODIs) as an approach to increase their access to global energy reserves. In this context, my study will compare and contrast the characteristics, current positions, and future trends of both the U.S. and Chinese EODIs--specifically their exploration and development investments. Based on the analysis of current U.S. and Chinese EODI positions, the study goes further to analyze their objectives and determinants, explaining both the similar and different aspects of EODI characteristics, positions and historical trends. By integrating the positions, objectives, and determinants of U.S. and Chinese EODIs into an interactive and dynamic mechanism, the study designs a partial equilibrium model system, in order to predict the future operational outcomes (production, sales, exploration, and profitability) and the competitive positions of U.S. and Chinese EODIs. However, the study's conclusions should be interpreted with caution, since the analysis is based on data and trends up to 2011, and in some cases up to 2008, 2009, and 2011. The major technological breakthroughs in the field, especially in hydraulic fracturing and horizontal drilling technologies, may affect future demand, lifting costs, and geographic locations of energy reserves, and thus may affect the prospects of EODIs in significant ways.

Summary

The U.S. and China are the world's largest energy economies and importers. In 2011, both imported approximately half of their total energy supplies from abroad. Due to this great reliance on overseas sources, energy companies from both countries continue to pursue energy outward direct investments (EODIs), in order to increase their global energy production capacity. In this context, the study intends to understand the status of their EODIs and to examine the interactions between Chinese and U.S. energy companies in the global EODI markets, and further to estimate how these interactions will impact the operational outcomes and the future competitiveness of these EODIs.

Research Questions

Specifically, the study answers three groups of questions:

I. Current positions : status and trends

a) What are the major characteristics (size, type, success rate) of current and historical U.S. and Chinese EODIs around the world? How did these characteristics (size, type, success rates) evolve over time?

b) What are the major characteristics (size, type, success rates) of the current and historical U.S. and Chinese reciprocal investments? How did these characteristics (size, type, success rates) evolve overtime?

II. Determinants and Goals: cost, reserves, profitability, and beyond

a) What are the determinants reflected by these investment characteristics and evolving trends?

b) What are the goals reflected by these investment characteristics and evolving trending?

c) Will the similarities and differences in determinants and goals lead to shared interest (collaboration) or conflicts of interest (competition)?

III. Future Competition Status: the market choices of U.S. and Chinese oil companies

Within the interactive mechanism characterized by their specific objectives, determinants, and current positions, how will the two groups of oil companies compete with each other in the short term (by 2015), medium term (by 2020), and longer term (2025)?

Data and Methods

To answer the three specific questions with regard to the current U.S. and Chinese EODI positions, drivers, and operational outcomes, historical EODI data were collected to measure each of those specific factors. These measurements include: (1) investment (specifically exploration and development) value of historical EODI by project, and aggregate investments by region; (2) investment portfolio (share) by project, by company, or by region; and (3) their historical production, their sales to the investing countries (U.S. and China respectively) and to global markets, and their proven reserves. Measurements (1) and (2) are used to analyze the historical trends and current positions of U.S. and Chinese EODIs specifically with respect to the exploration and development. And measurement (3) is used to predict the operational outcome of EODIs, i.e. their future production, sales, exploration, and profitability.

The data from which these measurements are derived are extracted from multiple databases. The major databases included are: (1) U.S. EIA Survey Form EIA-28; (2) Heritage Foundation-China Global Investment Tracker; (3) IEA Chinese Foreign Oil and Gas Acquisition data; (4) State Agency of Foreign Exchange (SAFE) of China: Statistical Bulletin of China's outward FDI; (5) Stockholder Forms 10-K or Corporate Annual Reports; (6) IEA Energy Prices and Taxes Statistics; and (7) OECD Data Library China Oil supply/demand statistics; and (7) other anecdotal evidence from journal publications and media coverage.

The analysis in Chapter 3 describes the characteristics of current positions of U.S. and Chinese EODIs in terms of the investment size, investment type (share), and success/failure status. To understand these characteristics, the study conducts descriptive analysis based on multiple data sources. To ensure the comparability and accuracy of multiple data sources, two major steps were taken to process and analyze the data: (1) data integration and validation; and (2) descriptive analysis. Details of their EODI investment amount, year, location, corporate yields and operation outcomes can be found in the Appendix Table 1-5.

The analysis in Chapter 4 employs literature reviews and expert interviews, to further illustrate the EODI determinants and goals. By reviewing classical ODI theories, I explain the general determinants, and identify principal factors of outward direct investment. Furthermore, by examining studies of recent energy investment deals, energy-specific drivers (objectives and determinants) are identified in the special context of U.S. and Chinese EODIs. In addition, several interviews were conducted over the course of this study to complement the perspectives of the literature review. The interviewees include CSIS energy program director, researchers from the Chinese Academy of Social Science, CNOOC business analysts, ExxonMobil policy advisors, a Chevron economist, a University of Southern California law professor, and a Heritage Foundation China program researcher, a WRI Chinese foreign direct investment behavior study researcher, and several U.S. and Chinese government officials.

To understand the mechanism of U.S. and Chinese EODI interaction, the study conducts a partial equilibrium analysis to demonstrate the trends of investment and output factors. This model is also used to predict the magnitude of payoffs for beneficiary stakeholders.

Key findings

- *The study finds that both Chinese and U.S. EODIs have increased in individual project investment size and annual aggregate amounts since 2000, compared to the previous two decades (1980-1999).*

Specifically, U.S. EODIs increased significantly since 2000, after U.S. policy refocused on foreign energy programs; Chinese EODIs increased significantly since 2005, after the Central government launched its "going out" policy. The average annual U.S. EODI total amount increased from $ 21 billion between 1980 and 1999, to $ 41 billion in the decade between 2000 and 2009. The average annual Chinese EODIs reached $ 17 billion between 2005 and 2011, while before 2000 they were minimal, amounting to no more than tens of million U.S. dollars per year. While both U.S. and Chinese EODIs increased as a result of changes in the energy policies of both countries, the comparative roles of their EODIs changed dramatically. China, previously a very minor competitor, had joined the U.S. and other countries as a major competitor in the international EODI market. In fact, by 2009, Chinese EODIs equaled almost 45% of U.S. EODIs.

- *Both the U.S. and Chinese companies (IOCs/NOCs) aim for profitability and resource acquisition through their global EODIs, whereas the Chinese NOCs place considerably higher priority on resource domination.*

In terms of goals, profitability and acquisition of resources are the two principal objectives pursued by both U.S. and Chinese EODIs. However, Chinese NOCs usually placed a considerably higher priority on acquisition of resources than on profitability. In terms of determinants, economic determinants (including energy supply/demand ratio, ownership, and investing location advantages) are the principal drivers for EODIs for both the U.S. and China. However, the investment environment determinants had only a modest effect on EODIs from the two countries.

- *Chinese NOCs will import all their equity production, while the U.S. IOCs will import half of their equity production to their domestic markets. Both the U.S. and Chinese companies will make profits from EODIs in the short, medium and long-term. Collaboration between the U.S. and Chinese oil companies in exploration investments will improve the profitability prospects for both.*

In terms of operations of the EODIs from the two countries, the study finds that: (1) planning for the short-term (2011-2015), U.S. and Chinese EODIs expect to average an annual production of 257 and 135 million barrels respectively; (2) planning for the medium term (2011-2020), the goal will be an average annual production of 285 and 163 million barrels respectively; and (3) planning for the long term (2011-2025), U.S. and Chinese EODIs will target an annual production of 364 and 242 million barrels respectively. Under all of the above planning scenarios, the U.S. IOCs will sell between 40% and 50% of the total EODI production in the global market, and the rest directly to the U.S. market. By contrast, China will sell close to 100% of production directly to its domestic market.

In terms of profitability, the study finds that: (1) the short-term (2011-2015) projections are for U.S. and Chinese EODIs to earn average annual profits of $ 117 billion and $ 65 billion respectively; (2) the medium term (2011-2020) projections estimate U.S. and Chinese EODIs to reach average annual profits of $ 140 billion and $ 86 billion respectively; and (3) the long-term (2011-2025) projections are for U.S. and Chinese EODIs to earn average annual profits of $ 199 billion and $ 143 billion respectively.

In addition, the study also discusses the effects of different exploration strategies on the profitability and operations of EODIs from the two countries. In terms of the differing levels of exploration strategies, the study finds that: the strategies to focus on longer payback-period exploration activities will disincentivize annual exploration spending, and thus reduce the profitability, production, sales, and exploration investment of both countries in all global regions. In terms of the collaborative or competitive strategies in exploration activities, the study finds that collaborative exploration activities between the U.S. and China will produce additional profits for companies (IOCs/NOCs) from both countries, and will also increase their respective operational outcomes, i.e., the volume of their annual production and sales.

- *The analysis should be interpreted with multiple caveats in the context of the complicated uncertainties connected with technology breakthroughs in hydraulic fracturing and horizontal drilling, as well as other uncertainties relating to the OPEC countries.*

Given the breakthroughs in these critical technologies since 2010, the conclusions of this study should be viewed with special caution because natural gas and oil production and reserves can drastically change decisions relating to EODIs' objectives, scale, location, and yields. Notwithstanding these caveats, the unique data and analysis presented in the study should be of interest and value to the policy communities in both the US and Chinese governments and in the oil companies for comparison with the actual EODIs that emerge in ensuing years, and that reflect the effects of advancing technology as well as changing external circumstances

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Acknowledgments

I want to express sincere thanks for the strong support and mentoring from my dissertation committee Chair Charles Wolf. Jr, Debra Knopman and Constantine Samaras. Charles, as the Chair of my committee, also generously funded my research through Wolf Dissertation Award.

I would like to express my thanks to my outside reviewer, C.S.Kiang. I would also like to thank Jonathan Pollack, who gave me helpful comments on my dissertation. I would like to express my thanks to Krishna Kumar for selflessly sharing his time and wisdom during the process of my model design.

I would like to thank my brother, Guobao Feng, for his assistance in writing the MatLab code that underlies the Partial Equilibrium model. He compiled the code, debugged the program, and ran the model under my direction.

I would like to thank Rebekah Vanderstoep, Beth Seitzinger, and Fatima Ford for scheduling every meeting and call with my committee with kindness and patience. I would like to thank Ingred Globig and PRGS for all their editorial help, without which this dissertation research would have taken much longer.

I would especially like to thank my PI and mentor Stuart E. Johnson and his wife Leah Johnson, for their encouragement and support. I would also like to thank the friendship of Scott Savitz, Olesya Tkacheva, Tom McNaugher, Anita Chandra, Martin Libicki and many other colleagues here in RAND.

I would also thank my friends and classmates Abigail Haddad, Nono Ayivi-Guedehoussou, Megan Clifford, Christina Steiner for their encouragement.

Last but most importantly, I want to thank my family for their faith and unconditional love.

Abbreviations

ASEAN	Association of Southeast Asian Nations
BIT	Bilateral Investment Treaties
CIC	China Investment Corporation
CITIC	China International Trust and Investment Corporation
CNOOC	China National Offshore Oil Corporation
CNPC	China National Petroleum Corporation
EIA	Energy Information Agency
E&P	Exploration and Production
EODI	Energy Outward Direct Investment
EOR	Enhanced Oil Recovery
FDI	Foreign Direct Investment
FRS	Financial Reporting System
FSU	Former Soviet Union
G.E.	General Equilibrium
GCC	Gulf Cooperation Council
IOC	International Oil Company
INOC	Iranian National Oil Company
IG	International Government
M&A	Merger and Acquisition
MBOE	Million Barrel Oil Equivalent
IOC	Multinational Corporation
MOC	Ministry of Commerce
MPK	Marginal Productivity of Capital
NOC	National Oil Company
ODI	Outward Direct Investment
OECD	Organization for Economic Cooperation and Development
OEH	Other East Hemisphere

OWH	Other West Hemisphere
P.E.	Partial Equilibrium
PSA	Profit-Sharing Agreement
RoR	Rate of Return
SAFE	State Administration of Foreign Exchange
SPR	Strategic Petroleum Reserve
TNC	Transnational Companies
TIFA	Trade and Investment Framework Agreements
USCC	U.S.-China Economic And Security Review Commission
WTO	World Trade Organization

1 Introduction

The U.S. and China are the world's largest energy consumers and importers. In 2011, the U.S. consumed 18.8 million barrels of oil per day (MBOE/day), followed by China at 9.8 MBOE/day. Of all the oil currently consumed by the two countries, about half is imported, with the U.S. importing 8.7 MBOE/day, and China importing 5.5 MBOE/day (Energy Information Administration, 2012[1]).

With such a strong reliance on overseas sources, energy companies from both countries continue to pursue energy outward direct investments (EODIs) in order to increase the total global energy production capacity. In 2009, the foreign investment[i] of the top thirty U.S. energy companies reached $50 billion (US Energy Information Agency, 2011[2]). During this period, major Chinese national oil companies (NOCs) also began to expand their foreign investments. The four major Chinese NOCs[ii] dominated most of the forty biggest foreign M&A deals in 2008 (*China Ministry of Commerce et al, 2008*[3]). In 2009, Chinese NOCs continued to seek multi-billion-dollar energy investment deals globally. Among the largest of these deals are: China National Petroleum Corporation(CNPC)'s $ 1.76 billion investment in National Iran Oil company; another sole ownership of $ 2.25 billion oil development project in Iran (project name unidentified); a $2.6 billion deal with the Kazakhstan gas company Kas Muaigas; PetroChina (the listed part of CNPC)'s $1.02 billion (a 46% share) investment in the Keppel oil development project Singapore Petroleum; and Sinopec's $7.2 billion investment in Switzerland's Addax Petroleum. In 2010, CNOOC invested $3.1 billion (a 50% share) in Bridas of Argentina, $2.2 billion (a 33% share) in Chesapeake Energy in the U.S., and $2.47 billion (a 30% share) in Pan America of Argentina; Sinochem invested $3.07 billion in the Peregrino field in Brazil (Nargiza Salidjannova, 2011[4]). By the end of 2010, overseas equity production of the top three Chinese NOCs (CNPC, Sinopec, and CNOOC) accounted for approximately 30% of their total production (*Gilroy and Heginbotham, 2012*[5]).

i Note: the foreign investment in this study refers to exploration and development expenditure, excluding operation-related expenditures.

ii Note: The three largest NOCs are: Sinopec, China Petrochemical Corporation (CPC), and China National Offshore Oil Corporation (CNOOC).

Driven to global expansion by common interests, Chinese and U.S. oil businesses have interacted both collaboratively and competitively. On one hand, Chinese NOCs collaborated with U.S. multinational energy companies by purchasing shares in their international subsidiaries; one example of this is CNPC's $1.5 billion equity investment (a 35% share) in the U.S. Shell affiliate in Syria. On the other hand, they competed in common global energy markets in other countries as well as in their own. In 2005, for example, CNOOC, a Chinese NOC, and Chevron, a U.S. private energy consortium, engaged in a bidding war for the California-based Unocal, with CNOOC outbidding Chevron by $ 1.5 billion[6].

This study will examine the interactions between Chinese and U.S. EODIs, in order to understand their status and how they will impact future competitive relations. Furthermore, the analyses will examine whether and how the two groups of companies may achieve mutually beneficial outcomes, to further improve the energy security positions of their host countries.

1.1 Research Questions

I. Current positions : status and trends

c) What are the major characteristics (size, type, success rates) of current and historical U.S. and Chinese EODIs around the world, excluding their reciprocal investments? How did these characteristics (size, type, success rates) evolve over time?

d) What are the major characteristics (size, type, success rates) of the current and historical U.S. and Chinese reciprocal investments? How did these characteristics (size, type, success rates) evolve over time?

II. Determinants and Goals: cost, reserves, profitability, and beyond

d) What are the determinants reflected by these investment characteristics and evolving trending?

e) What are the goals reflected by these investment characteristics and evolving trending?

f) Will the similarities and differences in determinants and goals lead to shared interests (collaboration) or conflicts of interests (competition)?

III. Future Competition Status: the market choices of U.S. and Chinese oil companies

Within the interactive mechanism characterized by their specific objectives, determinants, and current positions, how will the two groups of oil companies compete with each other in the short term (by 2015), medium term (by 2020), and longer term (2025)?

1.2 Assumptions

The above research questions are suggested based on the author's observations of U.S. and Chinese EODI prior to 2011. However, the trends of global energy investment markets are subject to major changes from both internal and external sources. In this consideration, the underlying assumptions are as follows:

I. The historical EODI data used in the study is up to 2011, and in some instances up to 2008, 2009, and 2010. The study assumes that the historical data are sufficient to make satisfactory estimates for all major trends in the short-, medium, and long-term. However, it is noteworthy that major changes that have occurred and continue to occur from 2012 to 2014---specifically, changes in hydraulic fracturing and horizontal drilling technology, and in other energy-related technologies---may affect the data, analytical methods, findings, and prospects in significant ways.

II. The components within EODI systems (e.g., exploration/exploitation technologies, geographic distribution of reserves, and the corporate structures of investing firms) maintain smooth trends in the short-, medium, and long-term. To elaborate, the study does not consider the wide application of hydraulic fracking, a disruptive technology that may have the potential to increase oil production by 17% annually alone (IHS, 2009[7]), thus substantially impacting the U.S./China oil trade balance.

III. The external factors impacting the EODI system, specifically the market demands for crude oil and its derivatives, will maintain smooth[iii] trends. For example, the study does not consider a scenario in which the pervasive use of electric cars greatly reduces gasoline consumption in the U.S. or China.

1.3 Organization of this Dissertation

The thesis is organized in this way: Chapter 2 describes the data and methods used to answer each of the three questions described in section 1.1; Chapter 3 analyzes the current positions of China and U.S. global and reciprocal EODIs; Chapter 4 identifies the determinants and goals of U.S. and Chinese EODIs; Chapter 5 constructs a competition model based on Chapters 3 and 4, and further analyzes their competitive positions in the short-, medium, and long-term.

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iii Note: by "smooth trends", the study also there is no special inflection points or spikes in the future.

2 Data and Methodology

To answer the research questions in Section 1.1, the study in this chapter intends to: (1) describe the data collection and validation process (Section 2.1); (2) describe the data use and processing methods throughout the dissertation research (Section 2.2).

2.1 Data Collection

This study collects the historical data of Chinese and the U.S. EODIs from multiple sources. The main targets of data collection are to: (1) collect data on investment amount of historical EODI by project and then aggregate them by region, or directly by region; (2) collect data on investment portfolio (share) by project, by company or by region; and (3) collect data on their historical production, sales to the investing countries (U.S. and China respectively) and to global markets, and proven reserves.

To serve these goals, this study has used a comprehensive list of databases detailed in Table 2.1. The major databases include: (1) U.S. EIA Survey Form EIA-28; (2) Heritage Foundation-China Global Investment Tracker; (3) IEA Chinese Foreign Oil and Gas Acquisition data; (4) State Agency of Foreign Exchange (SAFE) of China: Statistical Bulletin of China's outward FDI; (5) Stockholder Form 10-K or Corporate Annual Reports; (6) IEA Energy Prices and Taxes Statistics; and (7) OECD Data library China Oil supply/demand statistics; and (7) other anecdotal evidence from journal publications and media coverage.

- U.S. EIA Survey Form EIA -28

This survey, as mandated by the U.S. Energy Information Agency, collects operational data from major energy firms in the U.S.—or the list of companies listed in Financial Report System. The most recent wave of this survey data was collected in 2010, covering the time period between 1979 and 2009. In the statistical summary of this survey, the EODIs (Specifically Oil and Gas) of the 30 major U.S. energy firms were included. In this dissertation study, the data regarding the EODIs of the 30 major U.S. energy firms is used as a measure for the overall U.S. EODIs. The major metrics and data extracted from this survey summary include: (1) Table 17-Exploration and Development Expenditures by Region; (2) Table 18-lifting cost by region; (3) Table 19-Oil and Natural Gas Reserves by region; and (4) Table 21- Exploration and Development Expenditures, Reserves, and Production by Region. All the data tables and variable codebook can be found here online: http://www.eia.gov/finance/performanceprofiles/

- China Global Investment Tracker-Heritage Foundation

This database is prepared by the Heritage Foundation. The database covers Chinese FDIs between 2005 and 2011. The database is maintained on a monthly basis. The analysis of this dissertation study utilizes the major investment transactions (>100 million USD) data updates as of June 2012. The data metrics used in this analysis: (1) Sector (Energy); (2) Subsector (Oil & Gas; excluding Coal, Alternative, and unidentified sub sector); (3) Share size (% of equity ownership); (4) investment size (million USD); (5) investors; (6) hosting country; (7) success/failure status; (8) month/year. The study only uses successful investment records in the study of Chinese current positions, except in Chapter 3.2, where the analysis use data of Chinese failed bids in the U.S. market to analyze the U.S-China reciprocal investment positions. In total, this dissertation study retrieved 76 data points (investment projects) from this database. The study identifies missing data on share size (% of equity ownership) in several data entries. The study also identifies a few false investment size data points. This study conducts further data cleaning of this dataset (elaborated in Section 2.2). This database has been frequently cited in other studies including the USCC China investment analysis (cited later in the analysis Chapter 3), which used its data from 2008 to 2010, including multiple industry (Oil/Gas), Energy (Alternative), Coal, Iron, Gas, Metal, Food, and so on.

- IEA 2011: Chinese Foreign Oil and Gas Acquisition deals since 2002

This dataset is summarized in IEA official report- *Overseas Investments by China's National Oil Companies*. It has already synthesized multiple data sources from FACTS Global Energy (energy consulting firm), Interfax (media), Company websites, and CNPC Research Institute of Economics and Technology reports. This dataset provides 57 counts of successful Chinese EODI (Oil & Gas) records from 2005-2010. In addition, the dataset also identifies 7 transactions between 2002 and 2004. By comparing this dataset with that provided by Heritage Foundation, this database has captured the major big transactions (>0.5 billion U.S. Dollars) investments. Most of these EODIs are oil well investment (either development or exploration projects). There are a few EODIs(non-Oil or Gas) identified in this database, including one coal bed methane bid in Australia, one deep water gas project (Sinopec) $ 680 million in Indonesia (18%) in Dec 2010, and another portfolio investment of CNOOC of Indonesia Husky Energy, $125 million USD(50%).This dissertation study has already excluded these (non-Oil or Gas) investments.

- Statistical Bulletin of China's outward FDI

This data set is collected in the request of Chinese regulation on FDI reporting (Ministry of Commerce, 2009[8]). The reporting regulation requires Chinese firms to report their investment size, share, location of investment, and sector of investment (including oil and natural gas extraction), and profit margins. The data summary tables are not cleared for publication. However, several Chinese research studies, authorized to data access, did publish the unclassified aggregate investment data points, which are cited in this study to test the validity of data collected outside China. For example, the 21st century economic journal (a widely circulated Chinese newspaper[9]) concluded that as of Dec 2010, the Chinese NOCs have completed a total of 144 projects, reaching a total of $ 70 billion. Other analytical data quotes of this statistics are cited in the analysis.

- Corporate Reports/10-K form

The research also extracts data from corporate stakeholder reports (10-K form) or corporate annual reports or financial reports to identify company-specific data regarding: overseas versus domestic investment distribution; RoR on capital investments; 10-K or annual reports; share range; proven reserves (BoE), production, and sales.

- OECD, IEA Tax and Price Statistics: Data used for parameter estimation

The study also collects energy market data from OECD, IEA databases regarding the sale prices of crude oil in the U.S. and Chinese domestic and international market. The data are used to estimate price parameters, which will be described in Section 5.3.

- Others

The study also cited well-documented research articles such as Wolf et al(2011) , Salidjiannova et al(2011), and Downs(2000) to capture Chinese investments in 2009, 2010, or before 2000. During this study, the author also collects qualitative data regarding the objectives of investments, performance, determinants and hosting country conditions through interviews with stakeholders or researchers, including those from academia, think tank, government agency, and individual companies.

To sum up, the data collected from these comprehensive sources complement each other and also show a high level of consistency.

Table 2.1 Major Data Sources and Use in this Dissertation Research

Database	Time Period	Metrics	Type	Usage
Financial Reporting System Survey - Form EIA-28 -Schedule 5211 -Schedule 5246	1979-2009	T-16. Exploration and Development Expenditures by Region Proven Reserve(More detail in Table 5.3)	U.S. Data(government)	U.S. Historical EODI descriptive Statistics
EIA U.S. Oil Demand and Supply	1981-2011	Domestic Production Imports Exports	U.S. Data(government)	U.S. Descriptive Analysis
U.S.-China Economic And Security Review Commission(USCC)	2008-2010	Summary of major Chinese investments between 2008 and 2010.	Secondary (U.S.government) Based on Heritage Foundation data	China Historical EODI descriptive statistics
Heritage Foundation -China Global Investment Tracker	2005-2011	Month/Year, Investment Size(USD million), share size(%) , Sector, Sub-sector, Hosting Country, Success/Failure(Troubled assets)	China Data (Non-Profit Think Tank)	
IEA(2011)	2002-2011	Time(Month/Year) of investment; Company; Hosting country; equity share(%), Deal size(USD billion)	China Data(IG)	
State Agency of Foreign Exchange(SAFE)-MOC -Statistical Bulletin of China's outward FDI(Chinese: 对外直接投资统计公报)	2002, 2004, 2005-2011	Aggregate investment value, number of investment projects, success/failure ratio.	China Data(government)	
Annual Report/ Form 10-K -ConocoPhillips -Chevron -CNOOC -CNPC -ExxonMobil -Hess -PetroChina	2000-2012	RoR on capital employed 2011 foreign investment equity shares (%) investment.(Upstream, downstream).	U.S. and China Data(Corporate Reports)	U.S./China Historical EODI descriptive statistics

-Sinopec				
OECD Database - China Oil demand & Supply	1981-2010	Domestic Production Imports Exports Crude Oil sale price(Intl) Crude Oil price(domestic)	China Data	China EODI position descriptive analysis
IEA Energy Prices and Taxes Statistics --Crude Oil price	1979-2010	International Crude Oil price; Sale price to domestic markets.	U.S. Data	Parameter Simulation
Others	1992-1998; 2009-2010	Eric Downs, Wolf et al , Salidjiannova et al Interviews	U.S./China Data	Objectives, determinants, technology innovation performance, other external conditions

2.2 Methods

In this section, the study will describe how the data collected is processed and analyzed to answer the research questions. Specifically, Section 2.2.1 describes how the data are processed and used to answer research questions about the current positions of U.S. and Chinese EODIs(I.(a) and I(b) in the previous section 1.1); Section 2.2.2 describes how data are processed and used to answer research questions about the determinants and objectives of U.S. and Chinese EODIs(II.(a), II(b), and II(c) in section 1.1); and); Section 2.2.3 describes how data are processed and used to answer research questions about the future competitive positions of U.S. and Chinese EODIs(III.(a) , III(b) and III(c) in section 1.1).

2.2.1 Characterize historical EODI current Positions

The characteristics of current positions of U.S. and Chinese EODIs, as discussed in section 1.1, can be indicated by several metrics: the investment size, investment type(share), success/failure status. To understand these characteristics, the study conducts descriptive analysis based on multiple data sources. Specifically, the study takes the following two major steps to process and analyze the data: (1) data integration and validation; (2) descriptive analysis.

- *Data Integration and Validation*

The study first collects data and integrates data from multiple sources into one database for EODI. The major processing includes: (1) standardize measurement units; and (2) ensure that metrics are comparable. These steps are important especially given that this study is a country-comparison based study. Specifically, the unit of energy volume in the U.S. is in "million barrels", whereas the European based statistic system(IEA, OECD) and Chinese studies mostly use "million tonne". In this study the conversation factor[iv] is 7.33(1 tonne=7.33 barrel). In addition, the U.S. data covers a more than two decades period (1977-2009) was already in 2009 USD. However, the global sales prices (IEA importing cost by origin) during the period were not converted to 2009 dollar. Because it is a price factor, the study uses the (overall) consumer price

iv Note: The conversion factor is provided by BP: http://www.bp.com/conversionfactors.jsp factor[v] to convert sales prices to 2009 dollar value. Another inflation factor, the GDP deflator, is also frequently used to indicate price inflation. But the GDP deflator not only considers the price inflation of a basket of goods but also investment and consumption pattern changes. Using different inflation factors will lead to small changes in the pricing estimation. If the alternative GDP deflator is used, the real sale prices (in 2009 dollars) would be lower. Judging from historical data, the difference in real prices reached its highest point at approximately 20% (in 1977), but the difference narrowed over time. After 2000, the real prices (in 2009 USD) calculated with the GDP deflator would be less than 2% lower than the prices calculated with the CPI inflation estimator. Therefore, using the alternative price inflator (GDP deflator) may slightly downgrade the future price estimates and thus reduce the current value of profit accordingly.

To ensure the validity of data used in this analysis, the study also uses a process to reconcile inconsistencies across meta-data sources. This reconciliation process involves using different sources of information in order to increase the validity of a study. In this study, as described in section 2.1(Table 2.1), these sources include the data provided by: (1) State/Federal government: EIA-28 Survey, Statistical Bulletin of China's outward FDI; (2) International Government: OECD China Oil demand & Supply, IEA Energy Prices and Taxes Statistics; (3) independent think tanks: China Global Investment Tracker; (4) Companies: corporate annual reports/Form 10-K; and (5) analytical research summaries based on synergizing multiple data sources. These following bullet points describe how this study validates data from the five sources to increase the validity of this analysis.

(a) U.S. EODI data: examine the representativeness

As discussed in section 2.2.1, the U.S. EODIs data are mainly retrieved from U.S. EIA-28 Summary statistics, (EIA -28 Survey Summary Table 10: Size Distribution of Net Investment in Place Ranked by Total Energy Assets), top four account for 81.2% of foreign investments (Table 10 of this survey), and top fifteen account for 95.3% of total foreign assets. Therefore, it is valid to assume that net EODIs of the top 30 major producers could be close to 100% EODIs of all the U.S. oil producers.

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v Note: the BLS CPI index calculator can be found here: http://www.bls.gov/data/inflation_calculator.htm.

(b). Chinese EODI data: examine and improve validity

As discussed in Section 2.2.1, Chinese government also conducts a survey on FDI, but the data are not cleared to public comment[vi]. However, international databases, and analyses from published Chinese research reports on the aggregate investments are solid approaches to improve the validity of data. This study uses the Heritage Foundation data as the basic reference, and also fills data gaps and correct false data points by comparing with multiple data sources. First, five data points are imputed to this database based on IEA 2011 data and media coverage. For example, the share size of the $ 300 million investment in Russia (by CIC) is 45%. In addition, several uncaptured investment deals are included into this database, such as CNPC purchase of $ 240 million in Iraq in December 2009. Third, the study also corrects some inaccurate estimates about the value of acquisition based on company news release and media coverage. For example, the official deal of the PetroChina in Singapore Petroleum Company Limited ("SPC") was $1.02 billion (45.51%)[10], not the estimated $ 1.16 billion (50%) previously provided. Last but not least, one failed project is deleted from the database. That is, according to media report, the CNOOC (part of Bridas joint venture) withdrew from its initiative to acquire 60% BP Pan-American Energy ($ 4.26 billion) in Argentina[11].

- *Examine descriptive Statistics*

This descriptive statistics, along with literature review and expert interviews, characterize the two countries' EODI trends, in terms of investment size, share, and location of investment, average size, and proven reserves.

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vi Note: in the official report (China Foreign Direct Investment Cooperation and Development Report 2011-2012 中国对外投资合作发展报告2011～2012) to summarize the survey statistics, the government-sponsored researchers specifically avoided discussion of oil & gas sector FDI in the sectorial report section.

2.2.2 Identify Determinants and Goals of U.S. and Chinese EODIs

- *Review literatures and Conduct interviews*

The study in Section four uses literature reviews and experts interview to understand the rationales of EODI determinants and goals. Reviewing classical ODI theories, to this end, could help explain its general determinants, and discover principal ones. In addition, during the period of this study, several interviews were conducted to complement the perspectives from literature research. The interviewees included CSIS energy program director, Chinese Academy of Social Science, CNOOC researchers, ExxonMobil policy advisors, a Chevron economist, University of Southern California law professor, and Heritage Foundation China program researcher, Panelist discussion, a WRI Chinese FDI behavior study researcher, RAND China researcher, the U.S. and Chinese government officials, among others.

2.2.3 Partial Equilibrium (P.E) Analysis and Sensitivity Analysis

To understand the mechanism of U.S. and China's EODI interaction, the study will present the movements of investment and output factors, through a well-designed partial equilibrium model. The goal of this model is to test the validity of win-win EODI options, by examining whether such options lead to Pareto-improving outcomes. This model also will help predict the magnitude of payoffs for beneficiary stakeholders.

- *Partial Equilibrium Simulation Method*

To model the partial equilibrium, as a first step, major components of the problem were identified including the principal, objectives, instruments, constraints and major assumptions. To solve the P.E. model, the study uses a dynamic simulation method. The software used for this simulation is MATLAB. Note that Guobao Feng (my brother) wrote the MatLab code that underlies the PE model. He compiled the code, debugged the program, and ran the model under my direction. The detailed description of the model structure can be found in Section 5.3.

3 Current Positions: China and the U.S. EODI status and historical trends

In this section, the study will describe the characteristics of the U.S. and Chinese EODI in the past. Specifically, the study in this section will address the first set of research questions about the current EODI positions. In section 3.1, the study will describe the major characteristics of the U.S. and Chinese EODIs around the world (excluding their reciprocal investments), and then will summarize the factors that drive the evolving trends of their EODI over time. Likewise, in section 3.2, the study will describe the characteristics of their mutual EODIs in terms of size, investment types (equity or whole ownership investments), and success rate, and further summarize their evolving trends.

Analysis in the following sections mainly relies on the U.S. and Chinese EODI data tabulated in the Appendix Table 1-5. Appendix Table 1 and 2 lists the year, investment, and locations of their historical EODIs. Appendix Table 3 exhibits the financial yields of two U.S. EODI companies[vii]. Appendix Table 4 and 5 exhibit the operational outcome of their EODIs.

3.1 Chinese and the U.S. EODI positions around the World

China began to seek foreign energy investments mainly under its State-owned National Oil companies. Since the early 1990s, Chinese NOCs have expanded their EODI investments from neighboring central and south Asian countries to oil-rich regions all over the world. By contrast, U.S. energy businesses competed with other international oil companies (IOCs) as early as the 1980s when outbound energy investments exceeded inbound investments for the first time, by bidding against private multinational companies for energy investment deals. Unlike Chinese NOCs, these IOCs represent the interests of their individual or international corporate shareholders[viii], and thus are not subject to the direct oversight of the federal government.

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vii Note: Chinese overseas yields are not reported separately in their annual reports or 10-K forms.

viii Note: In U.S. Energy Information Administration statistics, the U.S. government treated these multinationals almost equally with domestic companies, integrating them into the EIA Financial Reporting System (FRS). Among the 30 major U.S. energy companies reporting to U.S. EIA FRS, six are multinational companies, with investments from foreign countries including France, Holland, the UK, and Venezuela. Established in 1998, the Chamette Energy Corporation is an equal partnership between ExxonMobil from the U.S. and PDVSA. Other foreign affiliates included BP America, Total Holdings USA, Inc. Alon USA, CITGO, (owned by Petroleos de Venezula) and Shell Oil (owned by Royal Dutch Shell).

- *After the oil crisis in the 1970s, the U.S. oil companies began to drastically increase investments globally. These oil companies steadily expanded EODIs into the 1980s, when the Chinese counterparts also began to cautiously explore global investment opportunities.*

Before the 1980s, there were more inbound investments to the U.S. than outbound investments from the U.S. companies, given that the U.S. was rich in energy reserves and flexible in energy development policies, as well as home to the biggest global market for energy demand. In 1982, for the first time, additions to petroleum-related direct investment abroad by U.S. companies exceeded additions to FDI in U.S. petroleum. After that, U.S. companies continued to invest steadily in upstream oil and gas development overseas[ix]. As shown in Figure 3.1, U.S. overseas investments in upstream oil wells(both exploration and development) were maintained at a steady level overseas from the 1980s to 1999. During this period, the upstream EODI investments averaged $21 billion annually (range: $16 billion to $ 34 billion). In addition, the investment fluctuation basically followed a ten-year cyclical pattern, which is possibly associated with the cyclical energy demand trends.

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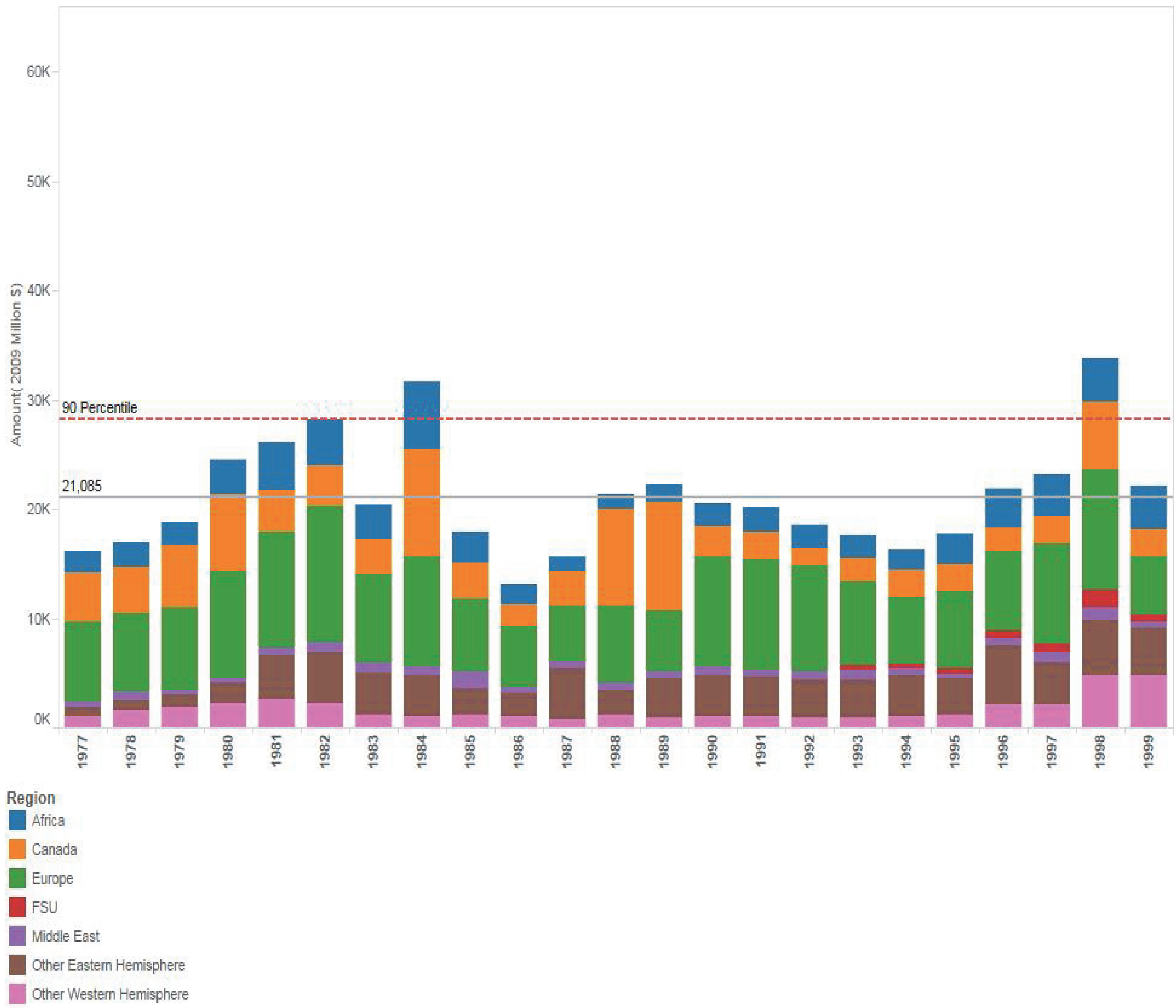
ix Note: During the same time, their foreign refinery operations (downstream) leveled off at around 10 per cent of the total refinery capacity (11% in 1989, 1990 10%).

Figure 3.1 The U.S. overseas exploration and development investment from 1977 to 1999



SOURCE: Analysis based on EIA FRS Form 28 Survey data

Since the 1980s, China began to realize its need to tap new energy resources. In 1985, China became a net energy importing country for the first time. Since the early 1990s, China has not only imported foreign oil, but has also begun to invest globally in the drilling and platform operations of energy companies worldwide, embarking on drilling oil in Africa, the Middle East, Central and South Asia (Table 3.1). In all these regions, Chinese NOCs focused on small equity investments. Compared to the overseas investments by the U.S. IOCs (Figure 3.1), China's EODI projects were too minor to influence the flows of global energy investment markets. And Chinese EODIs then mostly concentrated in neighboring central Asia countries such as

Kazakhstan (60% of $ 4.3 billion project), Mongolia, and Turkmenistan, and its long term supplier and also neighboring southern Asian regions(Indonesia, Thailand, Papua New Guinea). Also, because their technological capacity for exploitation and refinery was quite limited, Chinese NOCs were cautious about investing in high-value, high-risk projects. And CNPC and CNOOC are the only Chinese NOCs exploring EODIs during that time period. To minimize risk, Chinese NOCs chose the method of equity investments, either partnering with host country companies or participating in multinational consortia (MTC). Under most circumstances, Chinese NOC's rarely sought full ownership of foreign oil businesses.

Table 3.1 Selected Chinese NOCs' EODI during the 1990s

Year	Country	Description
1992	Canada	CNPC Canada purchased reserves for $ 6.64 million.
1993	Canada Peru Indonesia	CNPC Canada purchased reserves for $ 5 million. A subsidiary of CNPC bought Talara Block for $ 25 million. CNOOC purchased 33%(value unknown) share of Malacca oil field in Indonesia
1994	Papua New Guinea Thailand	CNPC joined a consortium with CITIC, Marubeni, and America Garnet Resource. (Amount unknown). –purchased Block 160. Purchase Banya Block.
1995	Indonesia Papua New Guinea	CNOOC purchased another 6% share of Malacca oil field in Indonesia CNPC purchased Block Kumusi
1997	Kazakhstan Iraq* Venezuela	CNPC purchased a 60% share (of an oil development project for $4.3 billion, and purchased a51% of the Uzen field for $1.3 billion (oil pipeline construction). CNPC and North China Industries Corporation consortium signed a 22-year contract to develop al-Ahab field (50% share.) Total estimate cost was $ 1.3 billion*. CNPC bought two fields (Caracoles-$ 241 million, Intercampo Oilfields-$ 118 million) for $ 359 million.
1998	Mongolia Turkmenistan	A joint venture of $29.7 million for oil extraction and refinery. China Oil & Building Corporation invested $ 14 million to restore oil wells.

SOURCE: Downs, 2000[12]; Wong, 2011[13]; CNPC Worldwide, 2014[14]; Kong, 2009[15]

Note: *the deal was postponed after UN sanction on Iraq. CNPC began to renegotiation this deal only after 2008.

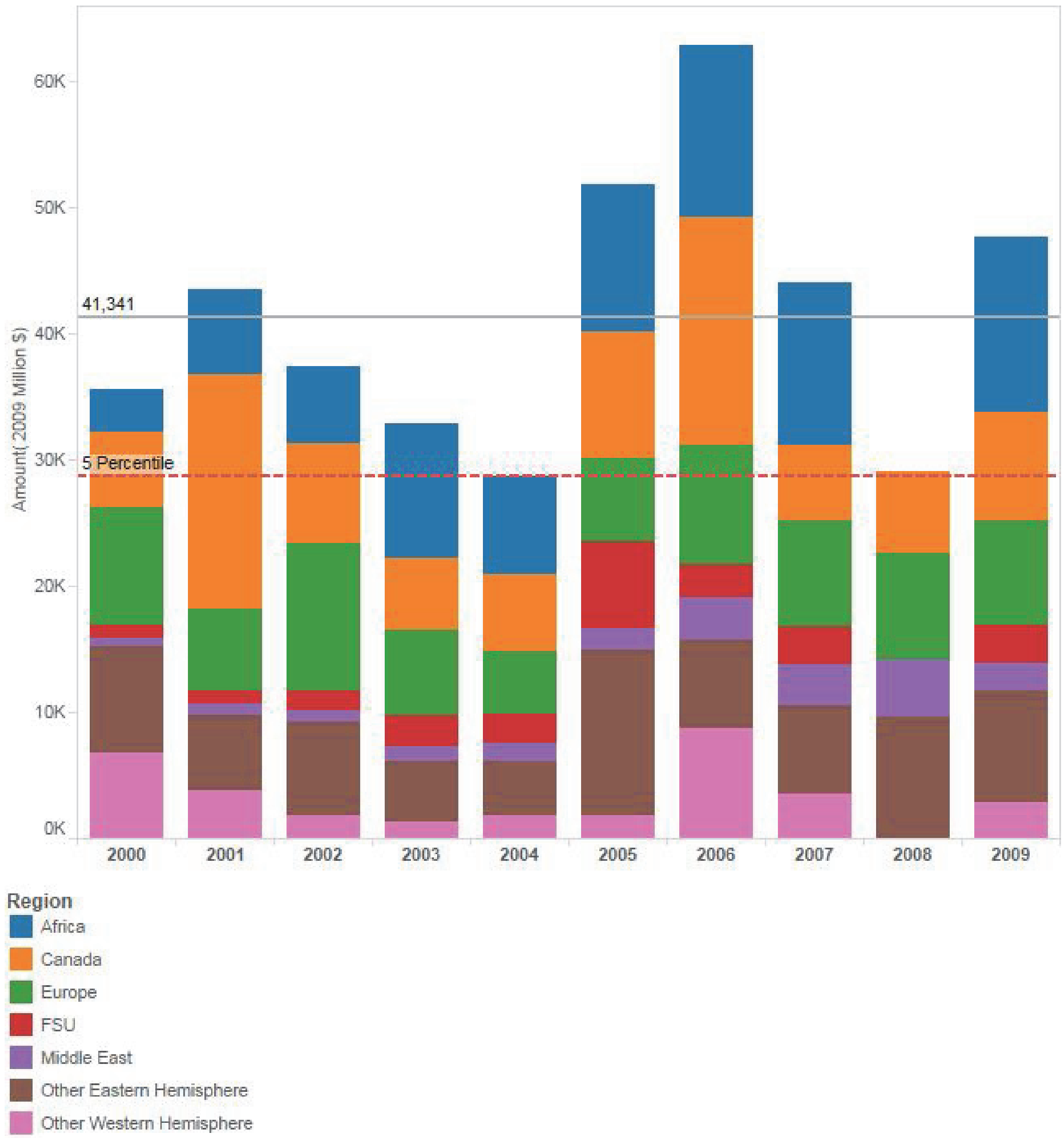
- *Both the U.S. and China oil companies increased their EODIs since 2000; they both chose the strategy of diversifying their investment portfolios. As a result, U.S. IOCs became more flexible and competitive by launching a more mixed portfolio of wholly-owned and equity investments, whereas the Chinese NOCs chose to invest in riskier deals with bigger shares, and wider coverage.*

Since 2000, U.S. EODIs evidenced a fast growth, compared to the two decades before 2000. In the beginning of 2000, the U.S. Congress passed Energy Act of 2000(Title I) already refocus the objectives to fulfill "U.S. obligations under international energy programs"[x]. In 2001, leading U.S. cabinet officials signed the Cheney Report (Cheney Report, 2001[16]) , which emphasized the importance of "deeper dialogues with major oil producers to work for greater oil production in the Western Hemisphere, Africa, the Caspian, and other regions with abundant oil resources.". The Report was further used to advise President Bush to direct the Secretaries of State, Commerce, and Energy to continue supporting American energy firms competing in markets abroad, and to make use of U.S. membership in multilateral negotiation platforms such as the WTO Energy Services Negotiations, to gain access to accurate information about financing sources, sales, and inventory – information for investment decision-making. Several subsidy and tax-incentive policies were subsequently introduced to encourage oil company investment overseas. Incentivized by these Presidential policies subsequent to the release of Cheney Report, the U.S. investor confidence in overseas investment was raised further. With such strong government policy orientation, the U.S. EODIs directly jumped from $ 22 billion in 1999(Figure 3.1) to $ 35 billion in 2000 (Figure 3.2). And as shown in the Figure 3.2, for the following decade from 2000 to 2009, U.S. overseas upstream investments averaged $41 billion annually (range: from $ 28 billion to $ 63 billion). It is almost double of the average annual investment ($21 billion) between 1980 and 1999. Moreover, 95 percentile ($ 28.1 billion) of annual investments during the two decades before 2000(1977-1999) is lower than the 5 percentile ($28.6 billion) of annual investments between 2000 and 2009. As shown in Figure 3.2, this increase was due mainly to growing investments in Canada and Africa. Meanwhile, the overall investment

x Note: H.R. 2884 (106th): Energy Act of 2000: Title I (Energy Act 2000) Reformulate the purposes of the Energy Policy and Conservation Act (EPCA) to grant the President specific authority to fulfill U.S. obligations under the international energy program" pattern during this time was similar to that of the previous decades, maintaining steady growth with five-year cyclical fluctuations.

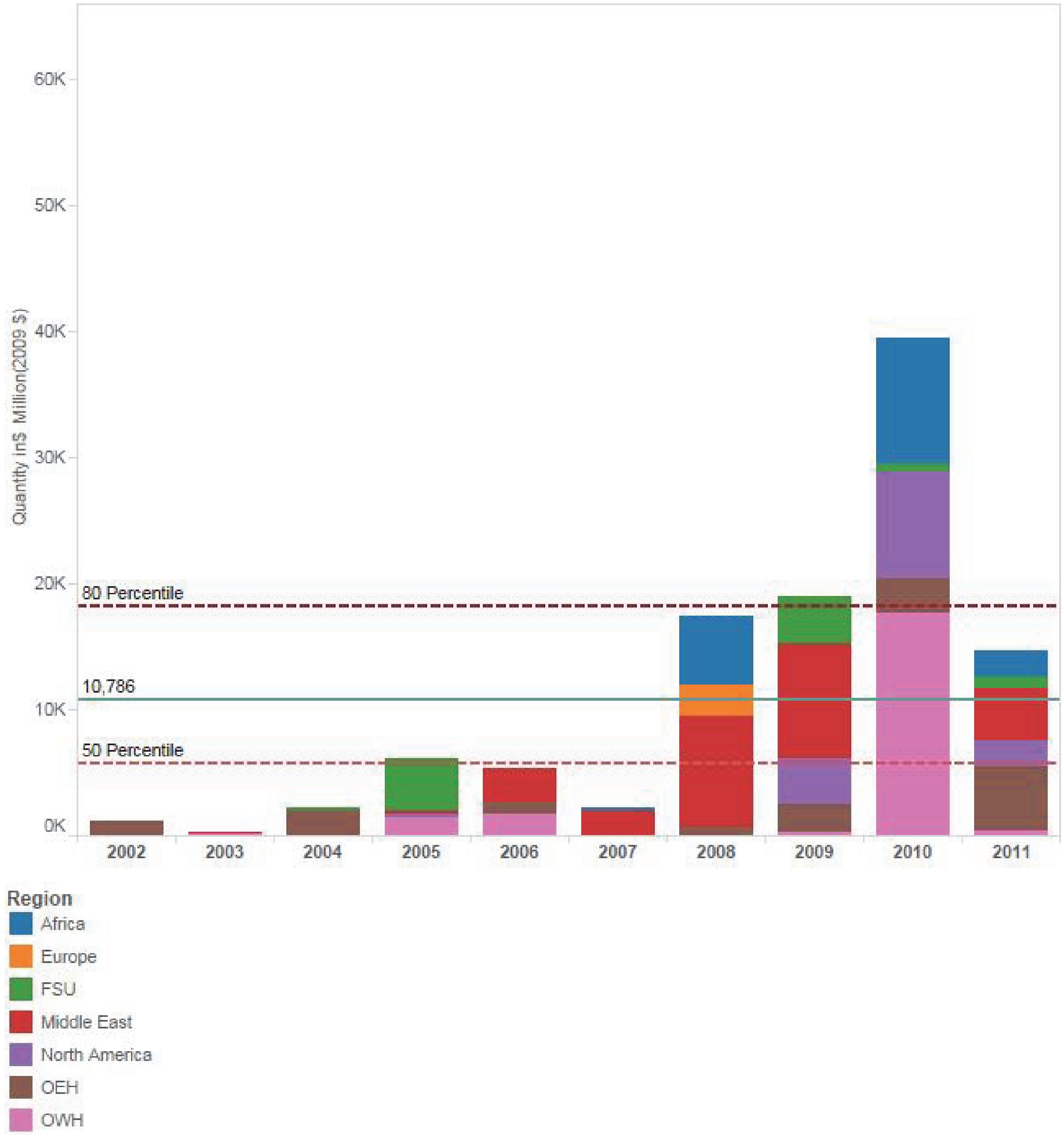
The Chinese EODI experienced a similar growth trend, except with a time lag. As shown in the Figure 3.3, between 2002 and 2004, there was not a sign of obvious EODI expansion, compared to the decade between 1990 and 2000. However, in 2005, Chinese central government launched the "going out" policy, encouraging Chinese State Owned companies to explore foreign markets. It was actually in that year (2005), Chinese NOCs responded instantaneously to the "going out" policy launched by the new Chinese leadership. As a result, the NOCs witnessed strong growth in overseas investment between 2005 and 2010 (with the exception of 2007). As shown in Figure 3.3, in 2005, China witnessed its biggest addition to EODIs in neighboring central Asian countries (FSU) such as Kazakhstan. Over time, Chinese EODIs have greatly diversified in terms of location choices. By 2011 they had expanded into fourteen countries around the world. In terms of growth trending, the annual investments averaged $17 billion (between 2005 and 2011) and averaged $ 10.8 billion over the ten year horizon (between 2002 and 2011). On the other hand, as their EODI experienced fast growth and diversification, Chinese NOCs were also exposed to the uncertainties of the "rogue" (politically unstable) regimes in the Middle East (Iraq, Iran), Africa (Sudan), and OWH (Venezuela), which became major destinations of Chinese EODIs. Due to these disruptive growth and diversification trends, the pursuit of EODIs by Chinese NOCs since 2005 has become a mixed blessing, promising both greater profits and increasing vulnerabilities.

Figure 3.2 U.S. overseas exploration and development investment from 2000 to 2009



DATA SOURCE: EIA FRS Form 28 Survey

Figure 3.3 Chinese EODI (Exploration and Development) from 2002 to 2011



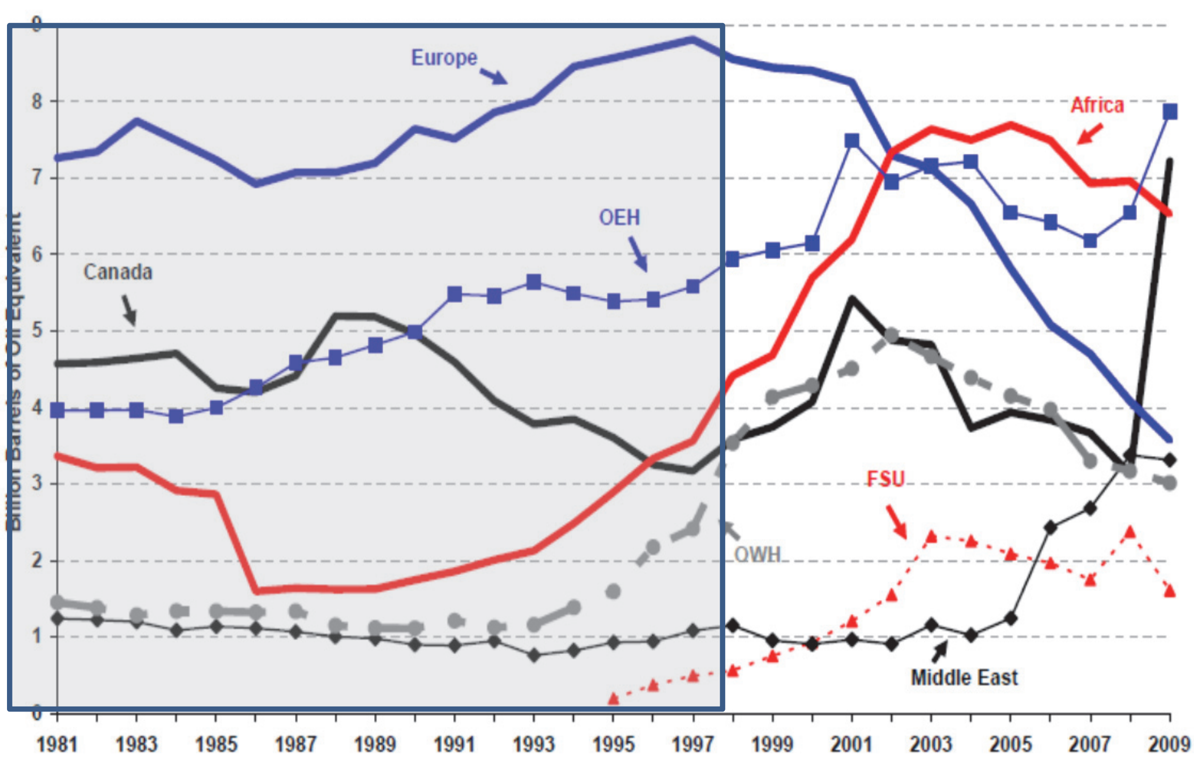
Source: Chinese EODI Metadata analysis

After about a decade of growth in EODIs, the comparative market powers of investments by U.S. IOCs and Chinese NOCs have undergone a revolutionary shift. In 2002, the total annual

EODI of the Chinese NOCs equaled only about 3% of U.S. EODI, but in less than ten years, Chinese NOCs' EODI had grown to almost 45% of U.S. EODIs in 2009.

During this period, the geographic focuses and investment portfolios of both countries also changed dramatically. Between 1980 and 2000, according to EIA (2011) statistics, U.S. multinational corporations held their foreign energy reserves mainly in Europe, maintaining at a level of between 7 and 8 billion barrels per year for twenty years. Since 2000, FRS reserves in Europe kept falling. In 2009, IT reached its lowest point to about 3 billion barrels per year. On the contrary, FRS reserves in Africa rose from under 2 billion barrels in 1995 to over 7 billion barrels in 2005. Similarly, FRS reserves in Middle East also rose from about 1 billion barrels in 2000 to more than 4 billion barrels in 2009 (Figure 3.4).

Figure 3.4 Oil and Natural Gas Reserves of FRS Companies in Foreign Regions, 1981-2009



Source: U.S. Energy Information Administration, Form EIA-28

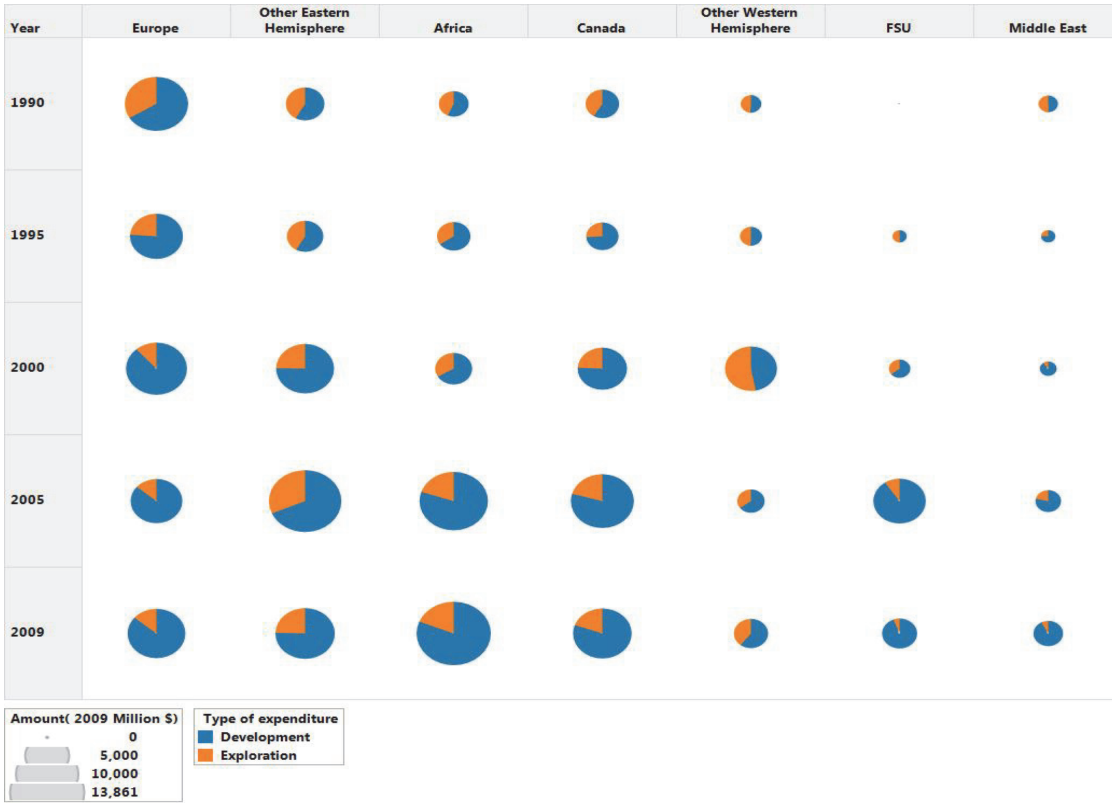
In terms of factors such as size per investment, the big U.S. IOCs pursued highly diversified investment portfolios, ranging from equity investment to whole ownership. ExxonMobil, the biggest oil company in the U.S, held over 50% of its total assets overseas. A similar pattern of diversification also applies to Chevron, which owns affiliate companies in 32 countries all over the world. Figure 3.5 below illustrates the overseas portfolios of two smaller yet significant U.S. IOCs—ConocoPhillips and Hess. Both companies hold various equity investment packages throughout the world, from minor equity investments (4%) in Algeria to principal equity investment (85%) in Russia.

Figure 3.5 EODI portfolios of two representative U.S. oil companies

SOURCE: Analysis based on ConocoPhillips and Hess Data, 2011

In terms of sectors, U.S. companies have invested more in development of oil, and less in the exploration sector. As shown in Figure 3.6, depending upon the region and time period, between 5 and 50% of foreign investments by U.S. oil companies went to exploration activity. Specifically, there are more exploration activities in Europe and Other East Hemisphere (mostly in the 1990s. Since 2000 exploration activities gradually leveled off in Western Europe, where documented energy reserves were largely depleted. Exploration efforts in Africa, however, gradually increased as more and more unexploited oil wells were found.

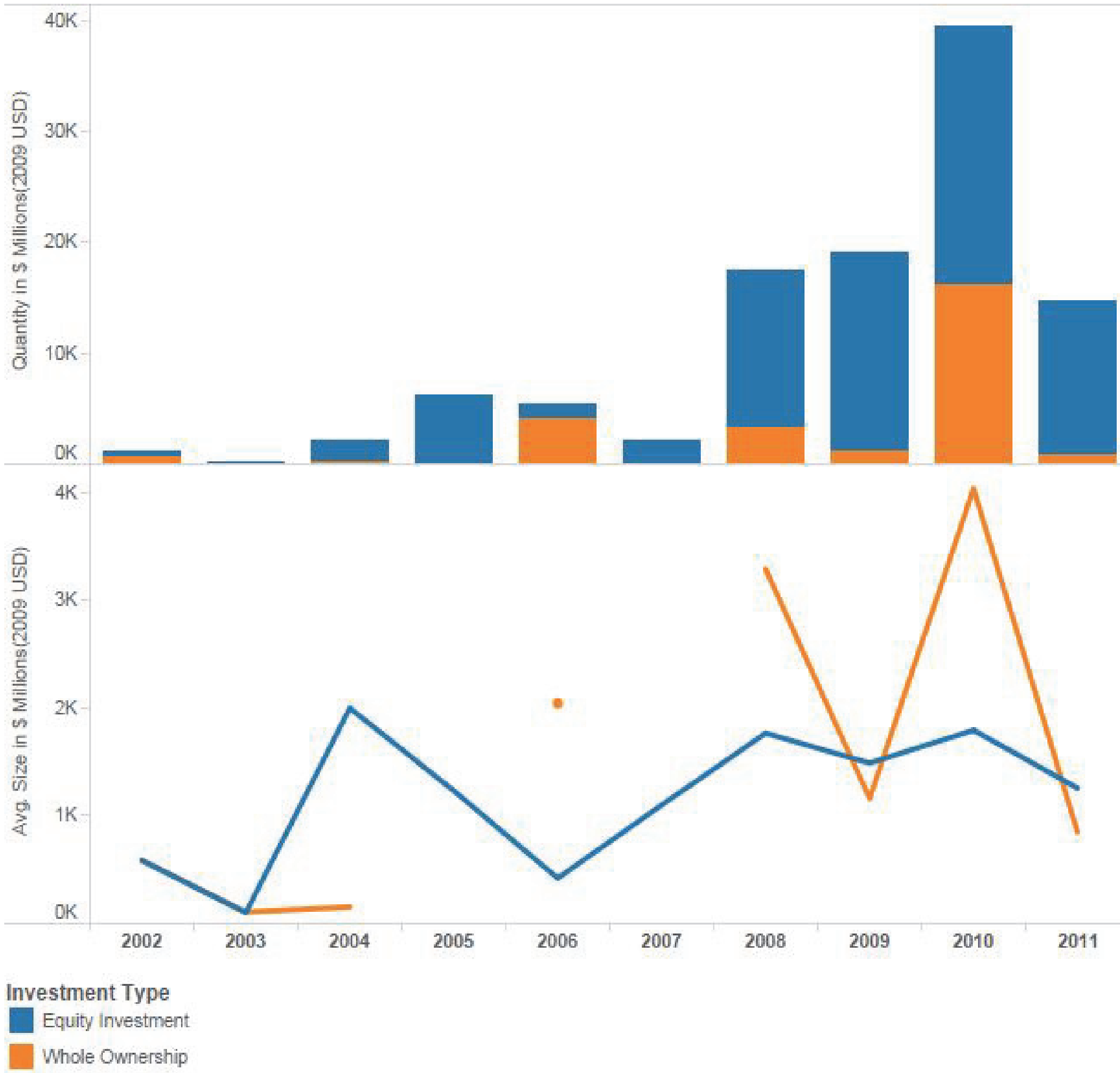
Figure 3.6 U.S. EODI by region and in selected years by types of investment



SOURCE: Analysis based on EIA FRS Form 28 Survey data

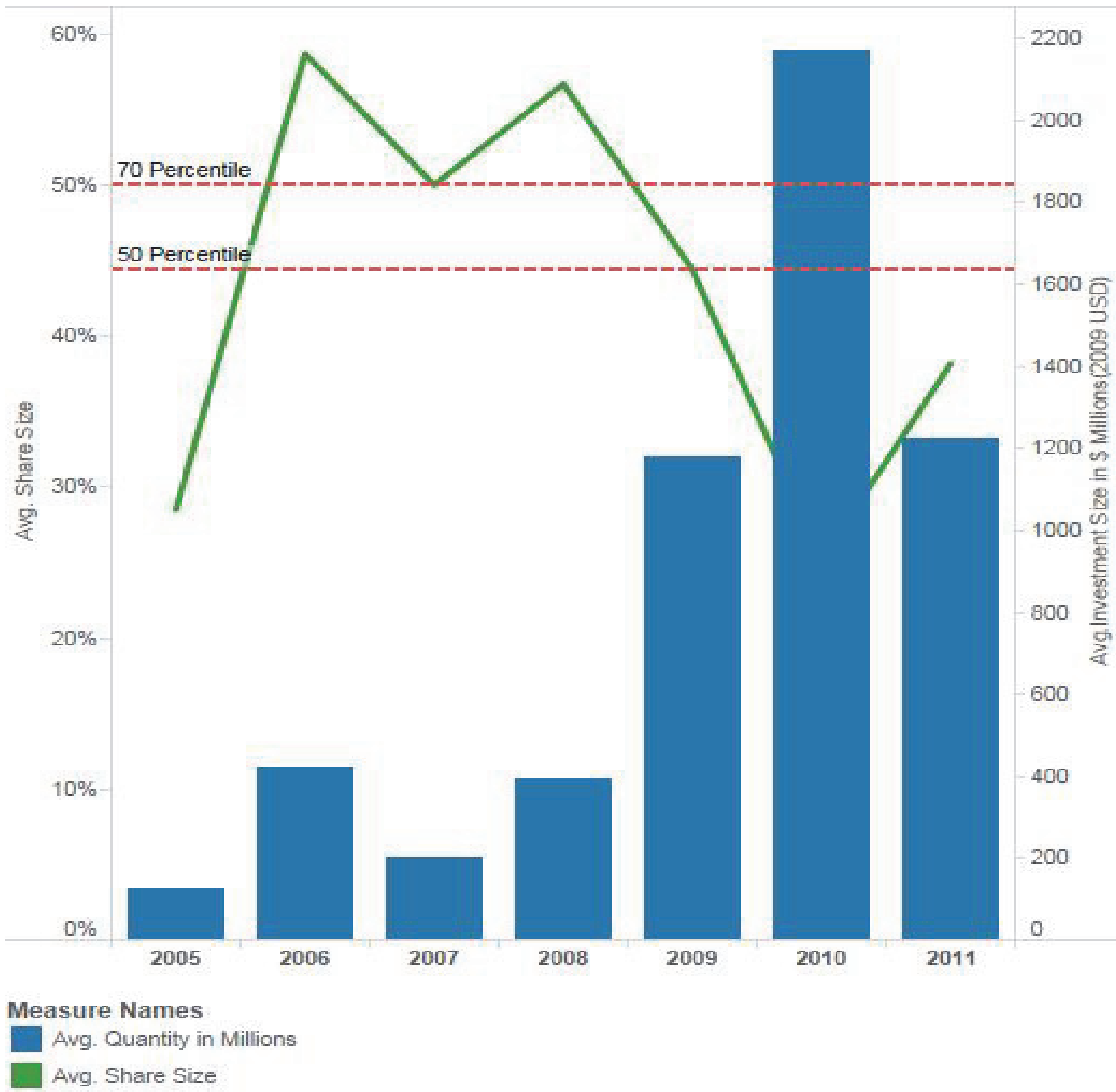
For China, EODI portfolio and geographic distribution shifted after 2005. Specifically, Chinese energy investors gained momentum to engage in larger investment and profit shares (Figure 3.7) and riskier deals (Figure 3.8) in the global energy investment market. This should be attributed to China's steady economic development, quick technological learning capacity, and increased international business experience. In terms of project investment patterns, Chinese EODIs are more concentrated in equity investment than in wholly- owned ventures (Figure 3.7). Since 2005, Chinese wholly-owned investments range in amount from $1 to $4 billion, whereas equity investments are smaller in range (around $1 billion per project). Compared to investments a decade ago (when they generally ranged between ten and several hundred million $), the project size of Chinese EODIs have more than doubled every year. For most of the equity investments, shares (Figure 3.8) range from 70 percentile of Chinese EODIs owned less than 50% shares. That is to say, in very few international projects are Chinese NOC's able to become the principal stakeholders.

Figure 3.7 Chinese EODI Investment Types from 2005 to 2011



SOURCE: Chinese EODI metadata analysis

Figure 3.8 Equity investment shares and amounts of Chinese EODIs from 2005 to 2011

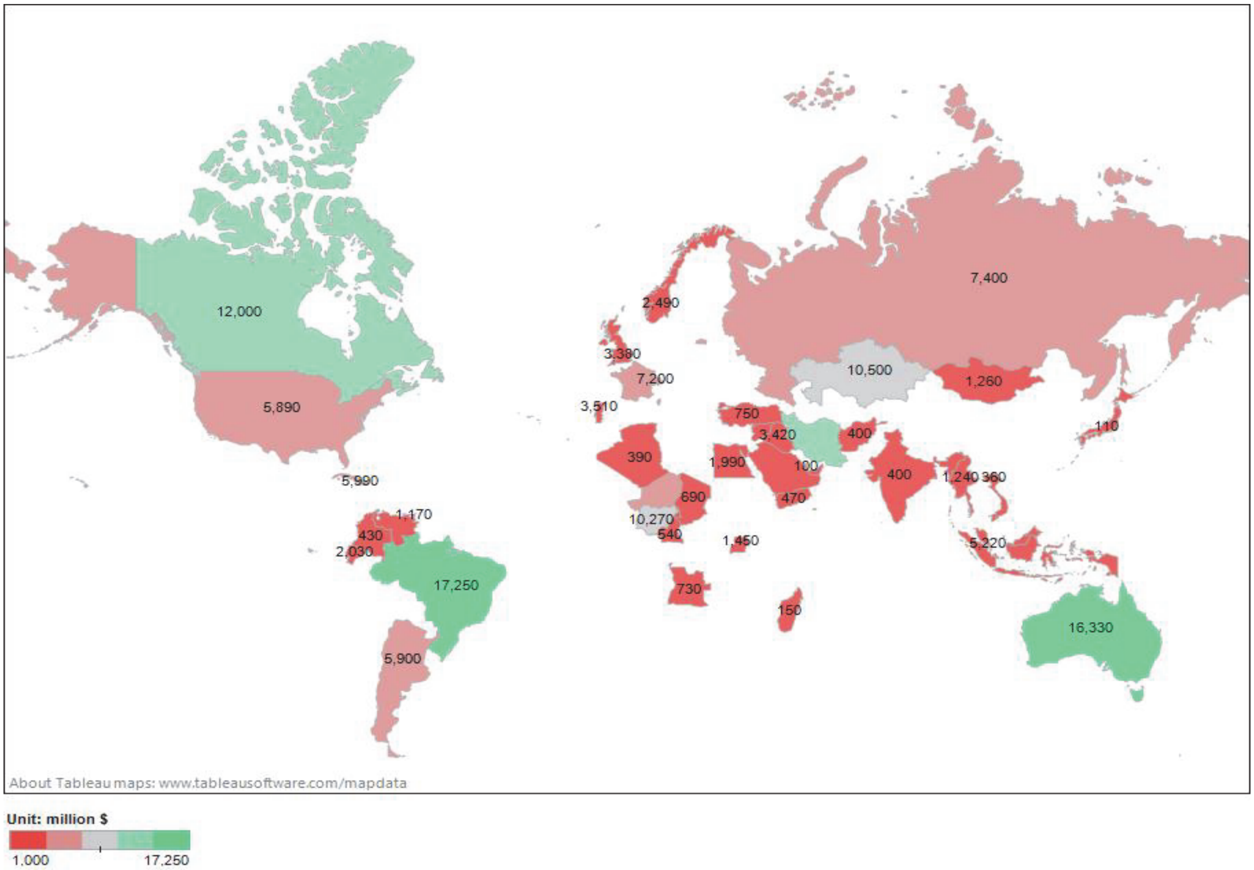


SOURCE: Chinese EODI Metadata analysis

Note: this is a statistic for equity investment only and does not include whole ownership. The investments between 2002 and 2004 are only whole ownership types.

Geographically, the global energy investments of Chinese NOCs represented wider coverage and bigger investment amounts in these overseas regions on the whole. On one hand, they continued to strengthen ties with adjacent oil-rich countries in Central Asia, such as Kazakhstan ($10.5 billion) and Russia ($7.4 billion), and South China countries such as Singapore ($5.2 billion) (Figure 3.9). On the other, they also extended further into untapped oil-rich countries, despite potential societal, political, and other uncertainties. These targeted countries ranged from African countries such as Nigeria ($10.27 billion), “rogue regimes” such as Iraq and Iran (Figure 3.3), and South American countries such as Brazil ($17.25 billion).

Figure 3.9 Geographic distribution of Chinese cumulative EODIs from 2005 to 2011



SOURCE: Chinese EODI metadata analysis

Among the OECD countries, Chinese NOCs were remarkably successful in their investments in Canada ($12 billion) and Australia ($16.33 billion). By comparison, Chinese EODI endeavors in other OECD countries in Western Europe were significant, but were limited partly because the natural resources of this region were gradually being exhausted, and partly because the thresholds of market access in these countries were comparatively high to Chinese investors. Chinese EODIs in the U.S. were especially limited ($5.89 billion) considering the huge U.S. energy producing potential[xi]. That is, to a great extent, attributable to "structural impediments to market access," as framed by Gilroy and Heginbotham (2012)[xii]. In the OPEC countries, Chinese

xi Note: The U.S. was ranked the third biggest oil producer in the world, right after Russia and Saudi Arabia.

NOCs also encountered market access impediments. In Qatar, one of the largest gas producing countries, Chinese NOCs contracted projects worth a mere $500 million. However, the market access difficulties of the OECD and OPEC countries may have very different and even contradictory causes.

- *The evolving trends of U.S. and Chinese EODIs were driven by the gap between domestic demand and supply, redistributed according to the geographic location of oil reserves and cost considerations, and incentivized by their national geostrategic positions.*

The U.S. has increasingly been engaged in global energy trading since the 1980s. With the increasing energy demand of rapid economic development, the U.S. oil demand and supply gap has grown over the past three decades. As shown in the following Figure 3.10, the gap between demand and supplies has increased from 750 million barrels in 1981 to 1.7 billion barrels in 2011. Thus the supply shortfall climbed from approximately 12% to about 25% of total consumption. In other words, if the U.S. had relied upon increasing domestic production alone to cut the oil supply deficit, it would have needed to increase its annual production capacity by 25% in 1981. By 2011, the annual production increase required to maintain U.S. oil self-sufficiency had grown to over 80%. However, there are so many practical barriers[xiii] to scale up oil well development (especially in the lower 48 states) that sole reliance on domestic production increase to meet the supply gap is not realistic. The U.S. has multiple options to reduce its supply deficits. In addition to increasing domestic production, it has also used complementary supply adjustment tools, such as oil futures, logistic management, and SPR releases. However, even these adjustment tools, together with domestic production increases, are insufficient when the deficit gaps exceed 80% of annual production capacity. Therefore, short of reducing total consumption trends, another important complementary tool is to increase total production capacity elsewhere — that is, invest in energy exploration and production globally.

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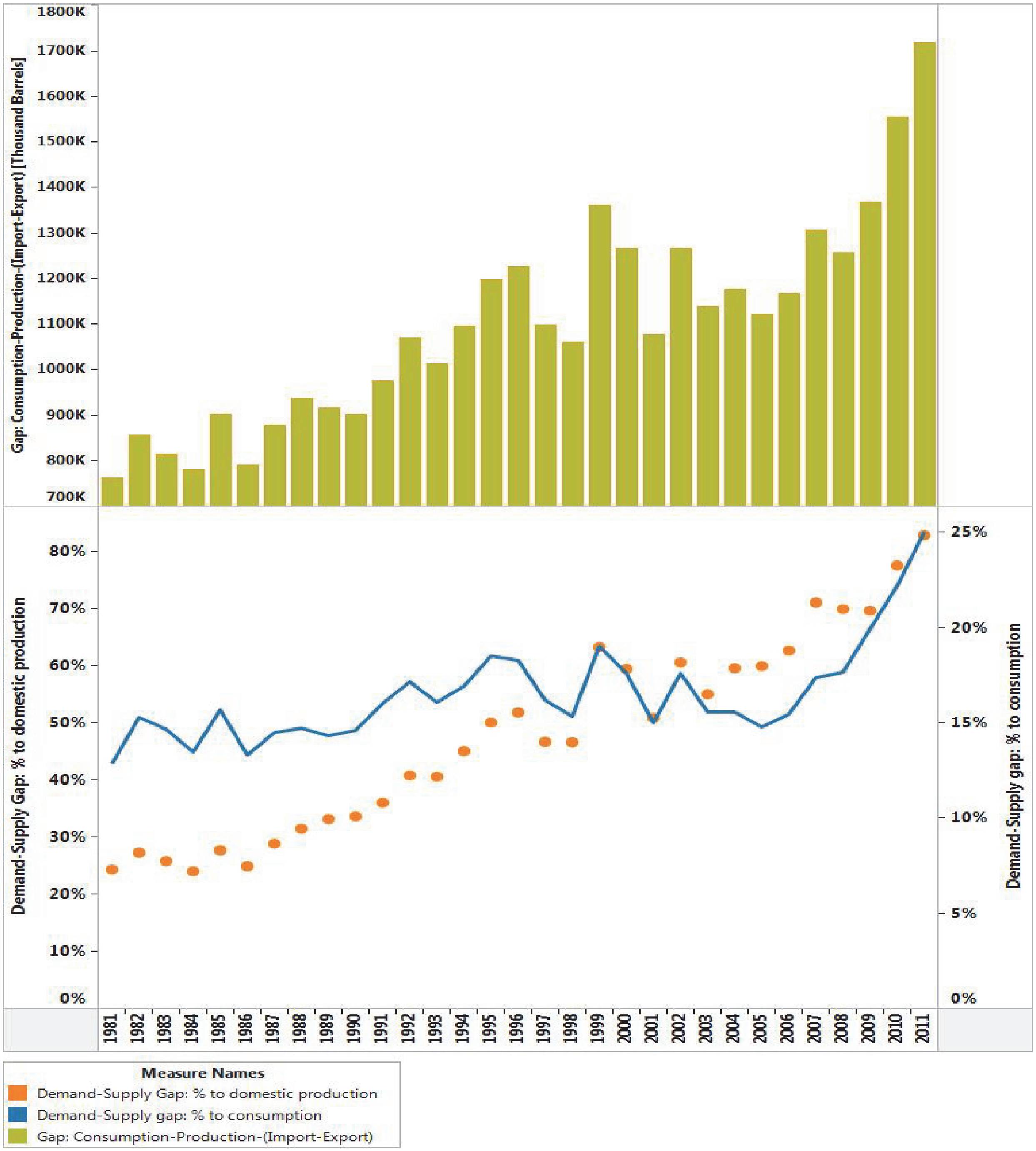
xii Note: Admittedly, the reasons why Chinese NOCs encountered difficulties in accessing U.S. markets are multi-faceted. The study will address this question explicitly in one of the following sections.

xiii Note: these practical barriers include factors such as environmental concerns, socio-economic debates, and human and logistic disposition capacity limits.

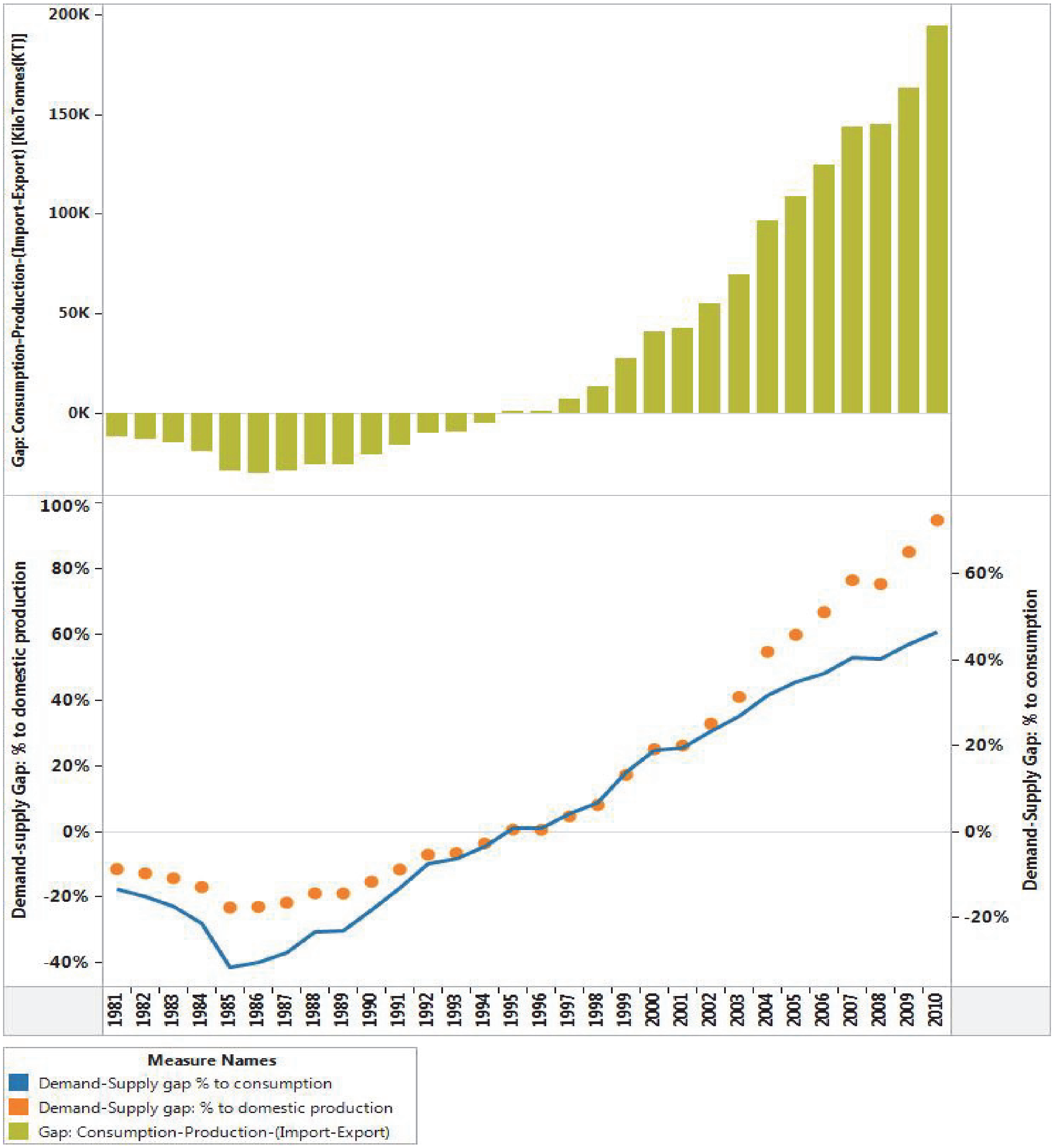
Figure 3.10 U.S. Oil Demand and Supply Gaps from 1981 to 2011



SOURCE: U.S.EIA, 2011

China has encountered a similar urgency to expand global energy investment, and indeed expects a more radical shift towards global energy exploration. As shown in Figure 3.11, from 1981 to 1994, China was still a self-sufficient energy economy, with sufficient supply surpluses. From 1995 to 2010, total Chinese oil supply deficits soared from zero to about 200 million tons (1.5 billion barrels), averaging an increase of 13 million tons (96 million barrels) every year. The shortage of oil supplies climbed from close to 0% to about 45% of total consumption in 15 years. In other words, if China had counted solely on increasing domestic production to cut its oil supply deficit, it would have needed to increase annual production capacity by 95% in 2011. It is just as unrealistic for China to rely solely on increased domestic production to contain supply deficits as it is for the U.S. However, in China, this is not mainly due to the practical barriers to scale up domestic production, but to the fact that China simply doesn't have sufficient exploitable oil reserves to meet its increased domestic demand. To complement the shortage, since 2005 Chinese NOCs and the Chinese government have also utilized multiple adjustment options, such as gradually entering international oil stock markets, improving logistic management, and even beginning to plan for national SPR operations. Despite these persistent attempts to diversify its supply portfolios, China would still fall short of its energy needs without resorting to more flexible production channels, including drastically expanding its energy production globally.

Figure 3.11 China's Oil Demand and Supply Gaps from 1981 to 2010



Source: OECD Data Library, 2011

3.2 U.S. and Chinese Reciprocal Investment positions: U.S.-Chinese EODI

- *U.S. multinational oil companies were welcomed to Chinese joint initiative exploration and development projects, although their investment potential there is limited in scale.*

Several of the top U.S. energy companies such as Exxon Mobil, Chevron, and ConocoPhillips, also entered the China investment markets since China opened up to foreign investments in the late 1980s. Although China does not have the advantages of Africa or the Middle East in terms of energy reserve potential and uplifting costs, its huge demand for downstream energy products makes it an ideal place to invest in refining. To illustrate, Exxon Mobil was mostly involved with production and sales of refinery products[xiv] (ExxonMobil. 2010[17]) and high-value chemicals such as lubricants in China. Chevron had an even longer history in developing Chinese energy markets, expanding operations in China in businesses, from exploration and production to marketing of fuels and lubricants. In 2007, Chevron signed a 30-year production-sharing contract with CNPC for the joint development of the Chuandongbei natural gas area in Sichuan Basin in central China. Chevron also joined the CACT (short for "CNOOC/Agip/Chevron/Texaco") joint operators' group to develop onshore energy resources in the South China Sea and in Bohai Bay. In 2010, Chevron also invested in three deep-water exploration blocks to cover an upstream exploitation of 5.2 million acres in the Perl River Mouth Basin (Chevron fact sheet, 2010[18]). A detailed description of these investments is summarized in Table 3.2.

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xiv Note: in 2007, ExxonMobil partnered with Saudi Aramco, Sinopec, and Fujian Province to form China's first fully integrated refining, petrochemical and fuel marketing venture with foreign participants. ExxonMobil owned 25% of the venture, and Fujian Petrochemical Company Limited, the leading stakeholder, 50%. The refinery capacity was estimated to be 240,000 barrels/day.

Table 3.2 the three largest U.S. energy companies' investment projects in China

US company	Partnering Chinese NOCs	Project Site	US company-Interest
ConocoPhillips	CNOOC	Penglai	49%
ConocoPhillips	CNOOC	Panyu	24.50%
Chevron	n/a	Sichuan Basin	49%
Chevron	CNOOC	South China Seas	59.2%, 100%
ExxonMobil	Sinopec	Fujian-Refinery	25%

SOURCE: ConocoPhillips, Chevron, and ExxonMobil worldwide fact sheets, 2012

In addition, for the U.S. oil companies, China is a perfect overseas base from which to outsource technology and technician development. Soon to be the world's leading producer of PhDs and engineers (Cyranoski et al, 2011[19]), compared to other EODI locations China has great human capital advantages for R&D in cutting-edge exploration and exploitation technologies. Not surprisingly, both Exxon Mobil and Chevron have established R&D centers in China: the Exxon Chemical Shanghai Technology Center, and several Chevron-Chinese oil company partnerships in joint research and training programs.[xv] The details of Chinese policies on foreign investments are summarized in Table 3.3.

xv Note: According to its China Fact sheet, Chevron began licensing vacuum residue desulfurization technology to Sinopec in 1985, and later hydro-processing technologies as well, to help improve refinery quality and quantity.

Table 3.3 Chinese laws and regulations on FDI in general and in energy sector

Law/Regulation	Content
Foreign Asset Management	For approved FDI projects in China, the government can provide up to 30% discount for land use expenditures; For FDI projects smaller than $300 million, the government has simplified the approval process, requiring approval from local governments only.
Income tax exemption for international labor transport	Provide income tax exemption for those companies which satisfy any of three conditions: 1) transport commodities or personnel into China; 2) transport commodities or personnel from China abroad; 3) Transportation within foreign countries.
Oil /Natural Gas exploitation	Provide value-added tax (17%) and customs exemptions on imported equipment, for all companies drilling offshore Chinese oil and gas wells.
Crude oil exploitation tax reform	For all energy businesses in Xinjiang all oil and gas processing companies(both domestic and foreign ones) are exempt from resource taxes; heavy oil and high-sulfur natural gas production qualifies for up to a 40 % resource tax deduction; advanced oil exploitation can receive up to a 30 % resource tax deduction;
Non-citizen enterprise income taxes	Non-citizen business may qualify for tax break under certain tax exemptions or tax treaties (up to 10%).

SOURCE: Multiple Chinese legal and regulative documents[xvi]

xvi
Note: these related regulatory policies include:
The State Council's guidance on furthering attracting foreign investments(2010)
《国务院关于进一步做好利用外资工作的若干意见》(2010)
Temporary Regulation on exempting import tax for offshore oil and natural gas(2001)
《关于在我国海洋开采石油（天然气）进口物资免征进口税收的暂行规定》(2001)
Temporary Regulation on exempting import tax for onshore oil and natural gas in certain regions(2001)
《关于在我国陆上特定地区开采石油天然气）进口物资免征进口税收的暂行规定》(2001)
Regulations on tax reforms for Xinjiang crude oil and natural gas extraction(2001)
《新疆原油天然气资源税改革若干问题的规定》(2001)
Regulations on non-residential corporate income taxes(2009)
《非居民企业所得税源泉扣缴管理暂行办法》(2009)
Notification on exempting operational taxes for companies exporting labor forces(2010)
《财政部、国家税务总局关于国际运输劳务免征营业税的通知》（2010）

- *Despite some failures, Chinese NOC's continue their efforts to tap into the investment potential of U.S. markets.*

Compared to its investments elsewhere, China's EODI in the U.S. followed a different trajectory. Before 2005, China's ventures into U.S. energy markets were minimal; U.S. energy companies except in 1994, when China participated in energy exploitation project in Papua New Guinea under a multi-national consortium including a single U.S. investor. In 2005, CNOOC, the Chinese energy company, was recognized as the first Chinese company to bid for U.S. energy deals: CNOOC offered a competitive bid against Chevron for the Californi Figure 3.11 China's Oil Demand and Supply Gaps from 1981 to 2010a-based Unocal. However, because of the opposition expressed by the Congress (CRS, 2005[20])[xvii], CNOOC had to drop the bid despite that its initial offer $18.5 billion[21]was higher than 2nd highest bid from Chevron ($ 17 billion). Since then, national security concerns, as reflected in many political debates, thwarted China's direct investments in all U.S. businesses, including energy companies. As a result, China's direct investments in the U.S. began to focus predominantly on the buyout of U.S. treasury bills and other government debt (Wolf.Jr et al, 2011[22]). From 2007 on, Chinese ODI in the U.S. gradually gained some momentum, reaching $25.8 billion at the end of 2010. Table 3.4 is a meta-analysis summary of the major energy deals that China made in the U.S. between 2007 and 2010. These new investments were mainly undertaken by Chinese NOCs, as well as through the China Investment Corporation (CIC) and some quasi-governmental organizations such as State Administration of Foreign Exchange (SAFE) and China International Trust and Investment Corporation (CITIC). Since 2010, U.S. national security concerns about domestic Chinese investments in the U.S. have been on the rise, and Chinese EODI investments in the U.S. and Canada together only reached $17 billion in 2012. Of all their North American investments, Chinese purchase of Canadian tar sands and pipeline construction projects further inflamed political tension with the U.S., because the U.S. oil companies also had a great interest in importing oil from Canadian tar sands to the Gulf Coast (Davenport, 2012[23]).

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xvii Note: on August 2 2005, the CNOOC announced that it had withdrawn its bid, citing political tension inside the United States.

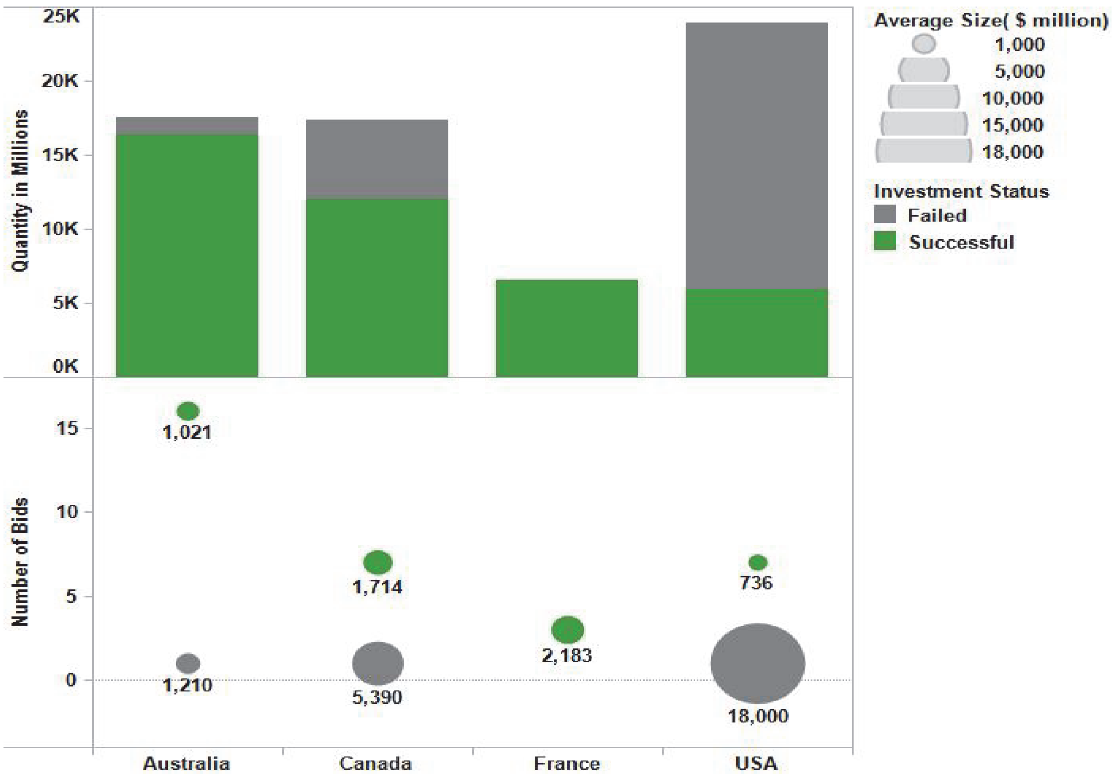
Table 3.4 A selected Chinese recent EODIs in U.S.

Year	Buyer	Seller	Investment ($ Million)
2009	CIC	AES	1,580 (15%)
2010	CNPC	Inova Geophysical Equipment (Energy)	180 (51%)
2010	Hopu	Chesapeake Energy (gas)	100 (1%)
2010	CNOOC	Chesapeake Energy (oil)	2,200 (33%)

SOURCE: Wolf Jr et al 2011, Nargiza Salidjannova, 2011

China failed attempts to invest in U.S. oil and gas sectors, in sharp contrast to its success in other major OECD countries (Figure 3.12). The reasons behind this are still unclear and under heated debate: some argue that the Chinese companies lacked in legal and executive experiences related to business acquisitions in the U.S.; another important argument is that Chinese NOC investments were a cause of tension for U.S. national security.

Figure 3.12 Successes and failures: Chinese EODIs in major OECD countries, 2005-2011



SOURCE: Chinese EODI metadata analysis

Given the concerns about their implications for U.S. national security and the impact on the competitiveness on local business, the Chinese FDI endeavors in the U.S. insofar have been largely unsuccessful. Several big Chinese energy investment bids for U.S. shares (such as CNOOC bid for Unocal) were disapproved by oversight process of the Committee on Foreign Investment in the United States (CFIUS). These Chinese EODI endeavors have gone through special scrutiny of CFIUS investigation, mainly because these investments exhibit heighted risks: (1) EODIs involve investment in energy sector-an important critical infrastructure in the U.S.; and (2) Chinese EODI bids were placed by NOCs, thus making them “foreign government-controlled transactions”. A detailed summary of U.S. laws and political process on foreign investments in the continental U.S. is summarized in the following Table 3.5.

Table 3.5 U.S. regulations and policies on foreign investments in the energy sector and FDI in general

Legal code/Debate	Restriction
Foreign Investment Act of 1975	The Act authorized the President to prohibit any significant acquisition as appropriate for the national security, to further the foreign policy, or to protect the domestic economy of the United States.
Foreign Investment and National Security Act of 2007(FINSA)	The Act required the establishment of CFIUS (Section 3), and authorized CFIUS to conduct risk analysis of foreign investment transactions.
Mineral Leasing Act (30 U.S.C. lSl)	Imposed conditions on foreign investment involving mineral leases in, or oil or gas pipelines through, the approximately one-third of US. Onshore land owned by the federal government.
FDI impacts on the competitiveness of small-modest size U.S. domestic drillers	FDI in U.S. petroleum makes it difficult for U.S. independent drillers to compete against low-cost foreign producers. This foreign investment may result in U.S. vulnerability to price disruptions and reliance on foreign oil.
FDI impacts on pricing polies	If U.S. producers were forced out of the market, foreign companies would be in a position to raise oil prices by decreasing their production.
Foreign government ownership concern	Since most foreign oil companies are state-owned, there is also concern that these companies may be guided more by political motivations than by purely economic considerations. Changes in foreign governments or politics may also mean changes in oil prices. Production and price fluctuations in the petroleum industry may be subject to social and political forces rather than market forces.

8 SOURCE: GAO, 1990[24] , Jackson 2014[25], and Fagan 2009[26]

3.3 Concluding Remarks

In conclusion, the characteristic of Chinese and US EODI's, and their evolving trends since the 1980s, can be summarized as follows:

- Chinese NOCs began their first overseas investments with several small–sized projects (with an initial investment in Canada of $6.6 million) in the early 1990s, whereas the EODI investments from the U.S. IOCs began a decade earlier and at a much larger scale ($25 billion in 1980).
- Over time, the U.S. EODIs presented a cyclical pattern (10-year period cycle), and maintained at a stable investment scale (average at $ 21 billion/year with less than 10% fluctuation range). By contrast, Chinese NOCs did not make noticeable progress until the mid-1990s. Their first venture was a $200million equity investment in a $ 788 million oil well development project in Kuwait. Since 2005 they have experienced disruptive growth, totaling $ 42 billion in 2010 at its peak moment. As a result of this, the relative global positions of U.S. and Chinese oil companies radically changed; China evolved from a minor player in the 1980s to a major US competitor in the current EODI market.
- In terms of investment portfolios, the Chinese preferred equity investments, usually as minor equity owners, rather than principal owners (owing 50% share or more). By contrast, their U.S. counterparts invested in a wide range of portfolios, from buyouts to a range of equity investments anywhere between 4 and 90%, and preferred a heavier level of engagement as controlling or participating partners in operations. In terms of geographic distribution, oil companies from China shifted most of their investments from Southeast and Central Asia to oil-rich countries in Africa, and U.S. companies also shifted major investments from Western Europe to Africa. Companies from both countries were generally unsuccessful in investing in the Middle East, another oil-rich region with comparatively low production costs.
- In terms of reciprocal investment, the outcomes are very different: U.S. investments were largely successful (with flexible investment portfolios and projects in areas with high strategic significance), whereas the Chinese NOCs into the U.S. market were less successful than those of other competing IOCs such as Royal Dutch, British Petroleum.

- These characteristics and patterns of EODIs are closely associated with major determinants including the domestic oil supply and demand balance, the changing geographic distribution of oil reserves, the lifting and transfer costs of oil production, and national energy security strategies.

4 Determinants and Goals: Similarities and Differences between U.S. and Chinese EODIs

In previous chapters, the study has analyzed the evolving positions of U.S. and Chinese EODIs in the global markets. In this chapter, the study will examine the economic and investment environments governing the EODIs of these two countries in the past, and address the question of what the goals of their energy companies should be for the future, i.e. for the short-, medium-, and long term. To what extent are their goals similar or different? To understand their goals for the future, the study will observe and examine the motivations behind their investment behavior in the past. This will allow us to interpret the essential values and goals of China's past foreign energy investment behaviors.

4.1 Determinants of U.S. and Chinese EODI: Similarities and differences

Thus both U.S. and Chinese EODIs, as described in Sections 2.1 and 2.2, present certain patterns across time. On one hand, they follow similar patterns in certain markets: for example, both have gradually shifted exploration and extraction focus towards Africa; and neither had achieved great success in accessing to the Middle East market. In other regions, however, the U.S. and China also present very different market strategies. For instance, Chinese companies have more heavily invested than U.S. companies in South American countries (with the exception of Venezuela); and Chinese companies have mostly invested as minor equity owners, whereas U.S. companies prefer diversified portfolios, and even operate proprietorship ventures in rival countries such as Russia.

In section 4.1.1, the study begins by reviewing the literature on the general determining factors of FDI and EODI, and in section 4.1.2 will examine these key determinants in the specific context of U.S. and Chinese EODI, to identify which are of special importance for the U.S. and China respectively. The study will consider whether these major determinants were generally shared by the two countries, or whether some of them were markedly different. And, finally, the study will summarize all my conclusions in section 4.1.3.

4.1.1 Classical Theories on EODI determinants

Studies on foreign direct investments (FDI) can be traced back to the 1980s, when ODI began to grow quickly. Dunning (1980)[27] claims that two overarching advantages drove FDI interests: (1) ownership advantage, and (2) location advantage.

The ownership advantage is determined by factors including investment motivations, diversification advantages, and resource availability. The investment motivation can be defined as the ratio of the investing country's domestic demand and its total production. The higher this ratio, the more motivated the investing country will be. In the case of energy investments, countries with high investment motivations are those whose demands far outweigh their production -- i.e., net energy importing countries. Both the U.S. and China belong to this category, since more than 50 per cent of their oil is imported. Diversification advantages measure the host country's receptiveness to foreign investments. In the case of energy investments, Iran, for instance, was an atypical destination for ODI, due to embargos and other sanctions that isolated it from the energy markets in many regions of the world. Kazakhstan, however, in contrast to its neighbors, whose energy resources were to a great extent dominated by Russia, implemented a series of economic and social reforms to embrace multinational investments from many countries, including China, Japan, Russia, France, UK and the U.S. Thus, Kazakhstan offered a stronger competitive advantage of diversification as a host country for EODI, and became a favorable EODI destination for international energy companies. Resource availability, another important dimension of ownership advantages, is of particular importance in the case of EODI. Most big multinational energy companies, such as Total, Chevron, Exxon Mobil, and CNOOC, have investments in energy-affluent countries around the world. The location advantage, associated with production and transfer cost factors, is another important determinant in decisions about investment portfolios. To illustrate, to develop a foreign project as principal operator, the investor should have a good estimate of production-incurred costs, including local labor, utility, and material costs, tax policies, and transfer costs, which include transport costs and both tariff and non-tariff barriers.

In addition to the economic factors described above, studies also found that several investment environment factors were crucial to ODI. Dunning (1994)[28], argued that host countries' valuation of inflow Transnational Companies (TNCs) had shifted in emphasis from value added to longer-term consequences for indigenous competitiveness In the special case of U.S. overseas ODI, research by Loree and Guisinger (1995)[29] also analyzed the key political and non-political policy factors that determine overseas site selection. Lorre and Gusinger believed that four major factors stood out from all others: the political stability of host country; cultural distance between the investing and host countries;, market characteristics;[xviii] and political institution. However, another study, NBER (2011)[30], comprehensively analyzed both the economic and policy factors of FDI, and found little evidence that policy factors affect FDI, with the exception of, those concerning bilateral investment treaties, customs unions, and trade and service agreements, all of which will have an impact on global M&A.

In addition to the political and non-political policy factors in the host countries, the investing countries' government support of their ODI is also an important factor in its success. Jackson (2008)[31] noted that some American politicians believed that U.S. direct investment abroad directly or indirectly shifts jobs to low wage countries. They argued that such shifts reduce employment in the United States and increase imports, thereby negatively affecting both U.S. employment and economic growth. Thus, some politicians propose tax policies to mitigate ODI incentives, such as reducing tax exemptions. In contrast, China's "going out" policies encourage big national oil companies (NOCs) to invest globally.

A full list of ODI factors is summarized in the following Table 4.1.

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xviii Note: market characteristics: open market, closed market, planned economy, or capitalist society.

Table 4.1 The constructs and measurements of major EODI determinants

Type	Sub-Type	Determinant	Measure
Economic Determinant	Ownership advantage Dunning(1980)	Investment Motivation	Investing countries' demand/supply ratio
		Diversification	Average no. of Multinational Enterprises(MNE)) operate in host country;
		Market concentration	c) percentile of output of industry accounted for by "largest firms";
		Efficiency	d)Wage cost (per man hour)
		Resource availability	e) % main resource imported; % of main material used in production
		Growth	g). increase in sales
	Location advantage Dunning(1980)	Production costs	a). Wage/man hour; energy costs; material costs; tax rates;
		Transfer costs	b).Transport costs; tariff; non-tariff barriers;
Investment Environment Determinant	ODI policy environment factors Loree and Guisinger (1995)	Performance requirements	a) Export /import constraints; local input mandates; local labor use requirements; limit on the proportion of equity that parent may hold in the affiliate; royalties.
		Investment incentives	b) tax concessions; tariff concessions; subsidies; trade treaties, other incentives; Net Investment Incentive Measure
		Tax rates	Foreign investment tax rate
	ODI politics environment factors Loree et Guisinger (1995)	Political Acceptability	a). International Country Risk Guide
		Cultural and Institutional Proximity	b) Cultural dimensions
		Infrastructure	World Atlas

SOURCE: literature research

4.1.2 Compare and Contrast: the determinants of the US and Chinese EODIs

U.S. and Chinese EODIs, similar to most other ODI types, will be either constrained or driven by one or several ODI determinants.

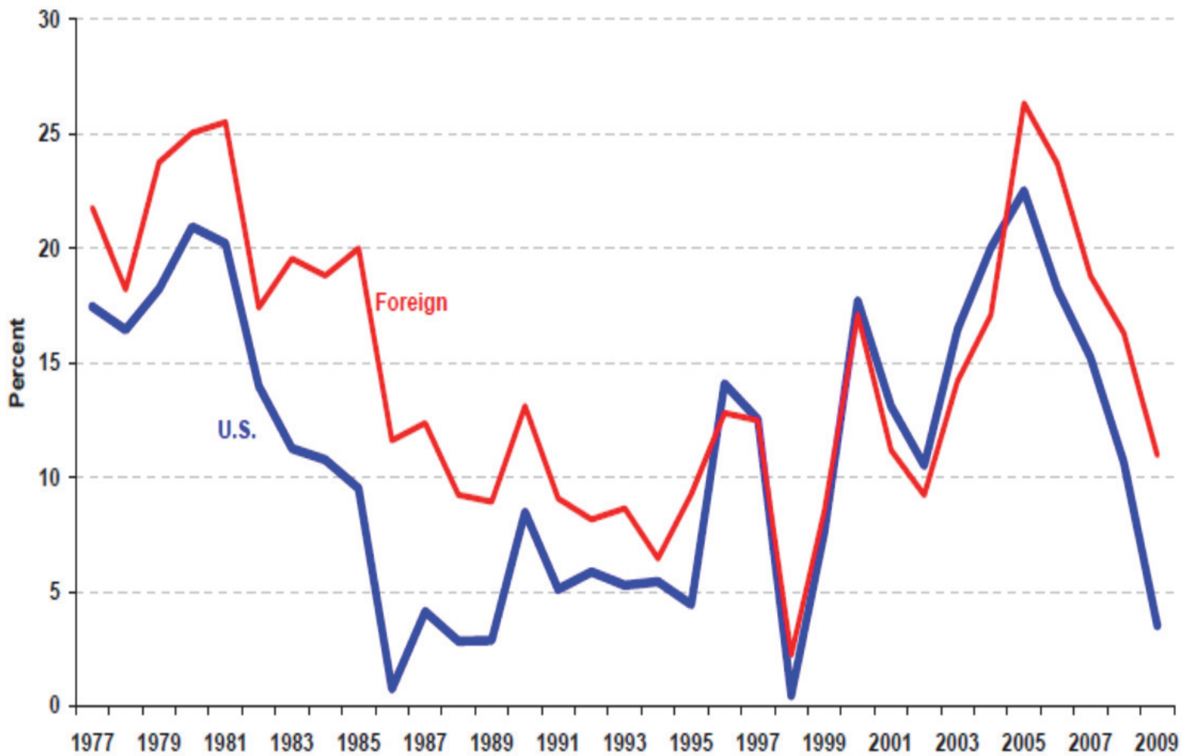
In terms of economic determinants, i.e., ownership and location advantage factors respectively, Chinese and U.S. energy companies have both similarities and differences. Specifically, on the ownership advantage factor side, both Chinese and U.S. companies are attracted by the abundant resources in the major oil exporting regions such as Africa, the Middle East, Central Asia including Russia, and South America. However, the energy economies in most Middle Eastern countries are not diversified, even if both the U.S. and Chinese governments have tried to liberalize their investment markets. Also, because the U.S. and China themselves have the greatest global energy demand, they present strong domestic investment motivation, especially in downstream refinery and high added-value chemicals production. On the location advantage side, as lifting costs in West Europe have risen/increased over the past decades, U.S. oil companies have gradually withdrawn their investments from that region, redirecting their efforts instead to cheaper and more easily accessible regions such as Africa. On the other hand, Western Europe and Canada are geographically proximate to the U.S., and thus the transfer costs from these regions should be lower and less vulnerable to global sea lane transport disruptions. For China, South Asia and Australia have been the primary investment targets since 2005, partly because of the low transfer costs and the low risk of transportation disruption. However, in some cases investors must weigh the tradeoff between ownership and location advantages. China's gradual expansion into African markets could exemplify the balanced strategies between the two. On one hand, the ownership advantage in Africa is obvious: all the ownership advantage determinants (low wage costs, affluent oil resources, and receptiveness to Chinese investments) are favorable for Chinese NOCs. On the other hand, the transfer cost, a major factor of the location advantage determinant, disfavors Chinese investors, given the high transportation costs across seas, the high disruption odds, and China's limited capacity to address sea lane disruptions in the East and South China Seas.

Driven by the energy supply deficits in both of their home countries, the U.S. and Chinese oil companies also shifted their geographic focuses and redistributed their investment portfolios to improve cost-effectiveness.

The big transition in the geographic distribution of U.S. EODI can be largely explained by the investment factors, especially the resource availability and exploitation costs. Figure 3.4 shows the transition of the global energy resource distribution over time. During the two decades from 1981 to 2000, the oil and gas reserves of U.S. IOCs were located largely in Europe and other western hemisphere (OWH) countries rather than in Africa and other eastern hemisphere (OEH) countries. Since 2000, however, the distribution has been reversed, and most of energy reserves held by U.S. IOCs have come to be located in Africa and OEH countries.

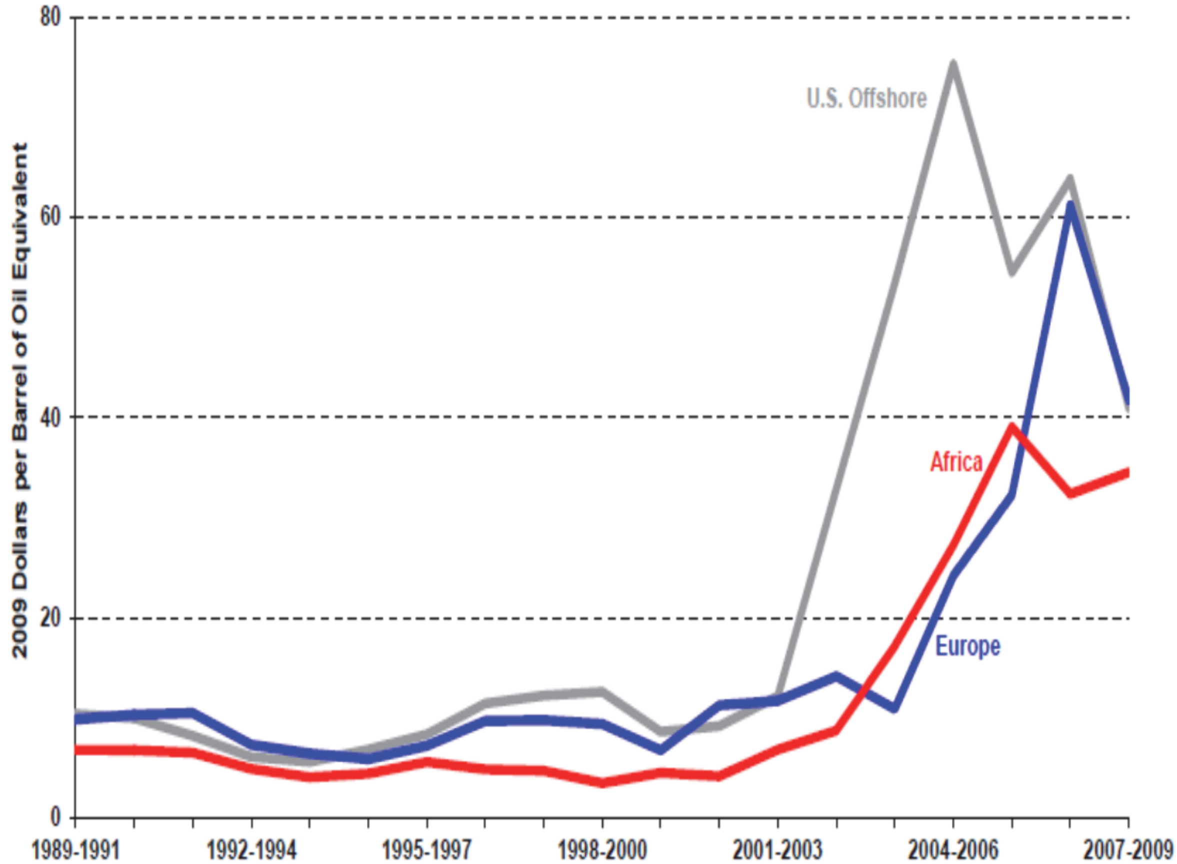
In the meantime, the trend of global energy investment during this period could also be attributed to the fact that it is cheaper to invest in foreign countries than in the U.S. As shown in Figure 4.1, for U.S. oil companies, the Rate of Return (RoR) on net investments over time is higher overseas than for domestic sites, especially after 2005. From 2005 to 2009, the gap in RoR between domestic and overseas investments sustain at approximately 5% level. For example, the finding cost, an important component of oil company profitability on the cost side, was lower for the U.S. IOCs in Europe and Africa than in the U.S. in recent years (Figure 4.2). In particular, the costs in Africa at their lowest point (in 2004-2005) were less than half of costs for the U.S. offshore wells. In this sense, the U.S. IOCs were greatly incentivized by profit spaces and cost-effectiveness to develop more overseas projects/increase their overseas investments. In one specific case, Exxon Mobil—the largest oil company in the world—followed precisely this trajectory, shifting investment locations and amounts in response to profitability variations. Obviously, the company invested much more in global than in domestic markets (Figure 4.3), primarily because international market returns are higher than U.S. domestic investments (Figure 4.4).

Figure 4.1 Returns on Net Investment in Place for U.S. and Foreign Oil and Natural Gas Production for the Major U.S. Oil Companies, 1977-2009



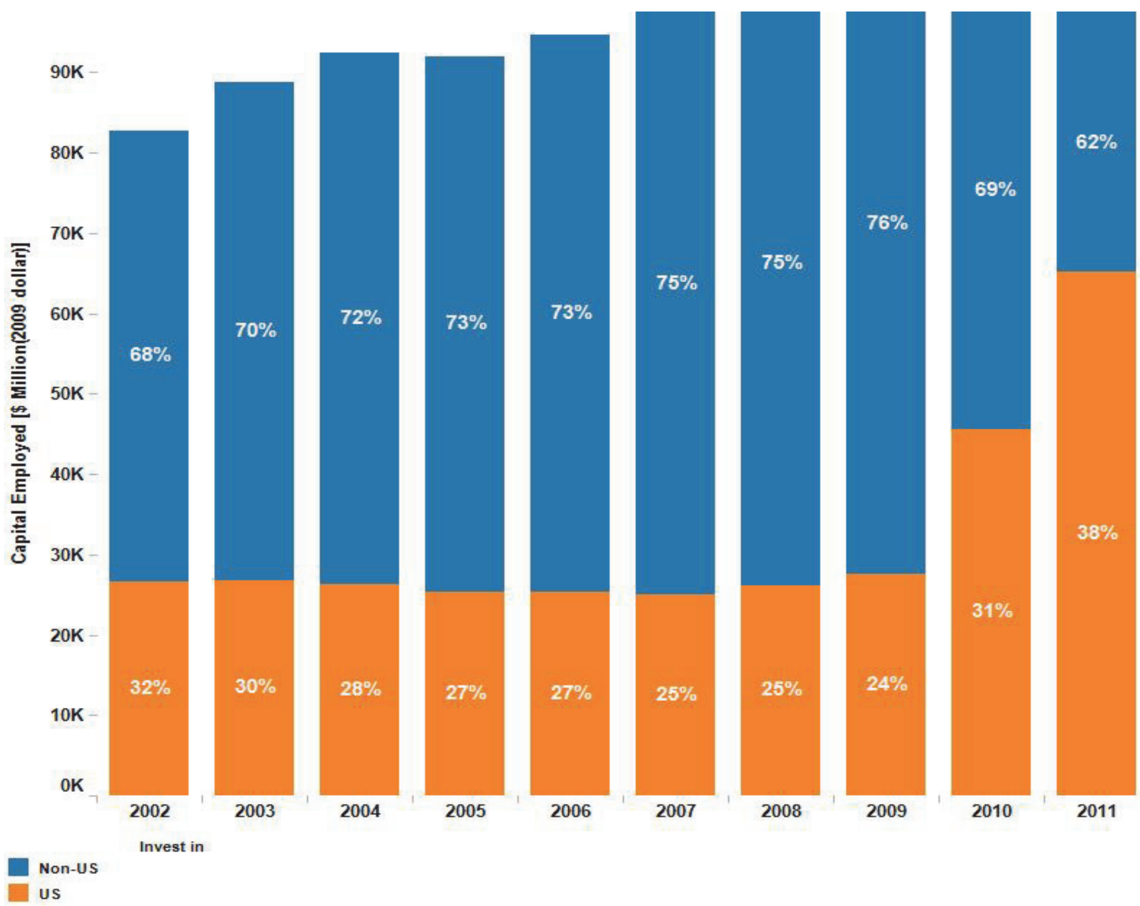
SOURCE: U.S.EIA, FRS 28 survey Data

Figure 4.2 FRS Company Finding Costs ($/barrel) in Selected Regions, 1989-2009



SOURCE: Analysis of EIA FRS 28 Survey by EIA, 2011[32]

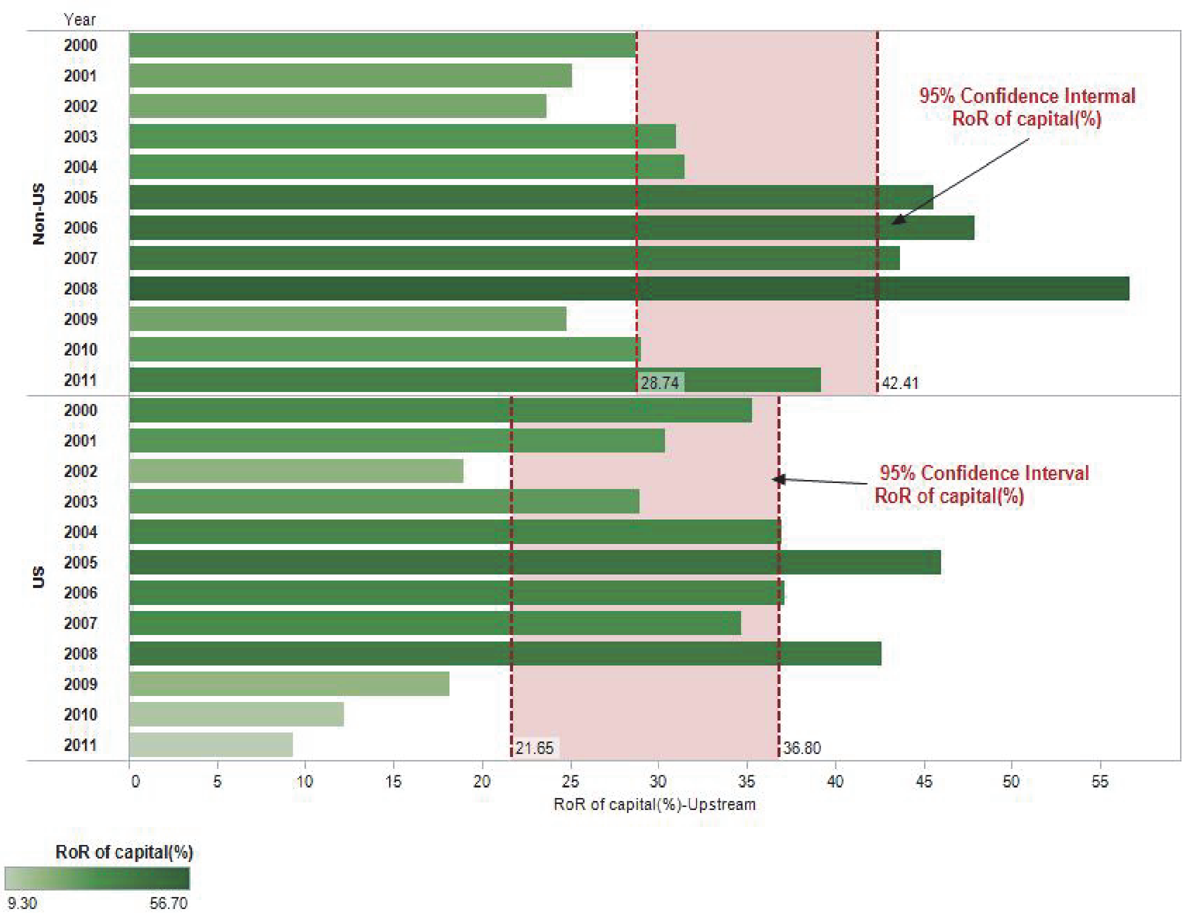
Figure 4.3 Exxon Mobil Capital Employed for US and non-US development



SOURCE: Data from Exxon Mobil Annual Reports

Note: "Upstream" refers to the production of crude oil and natural gas. "Downstream" refers to the production of end-use products including gasoline, diesel and kerosene. "Chemicals" refers to industrial products extracted from upstream products, such as industrial additives and lubricants.

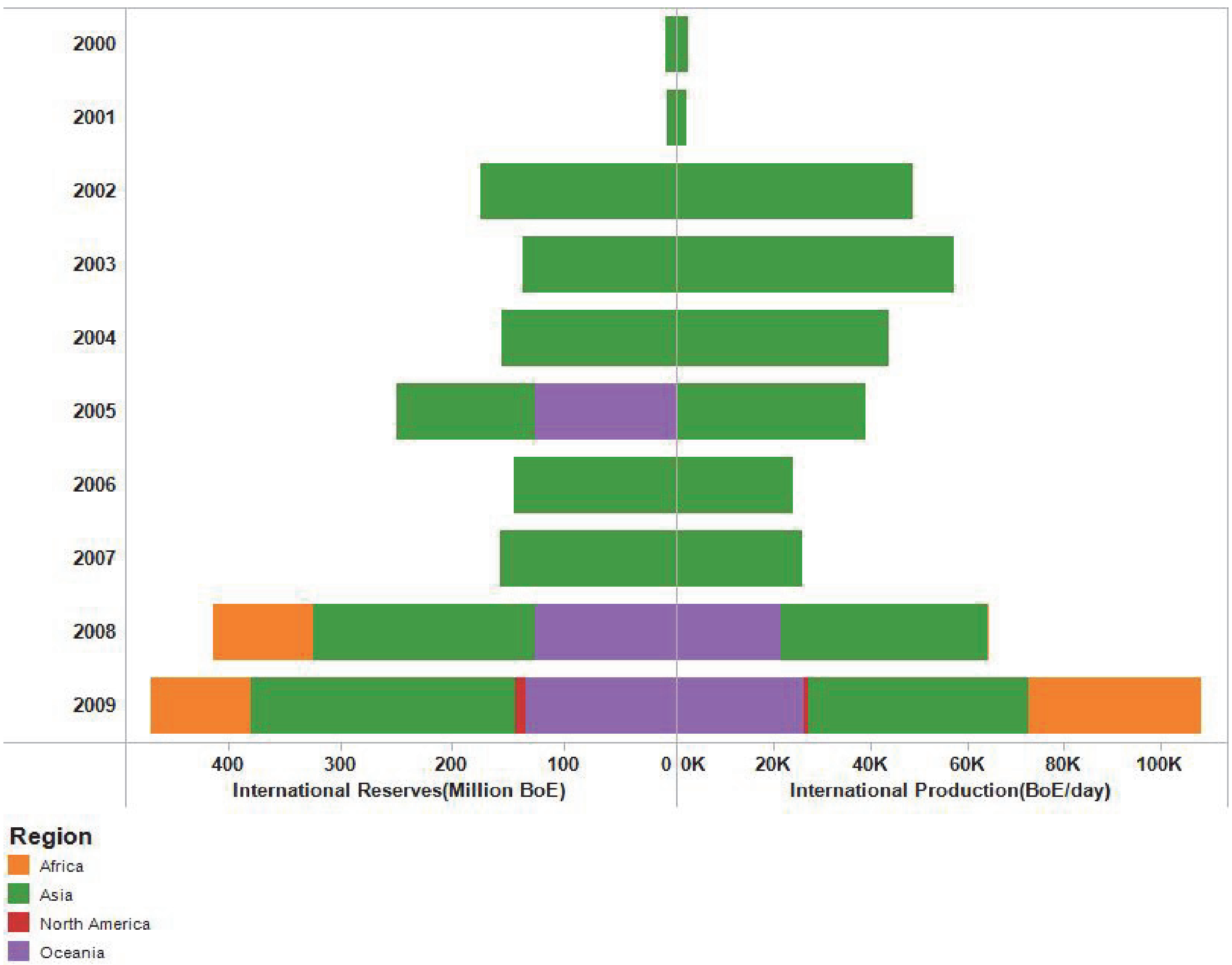
Figure 4.4 Exxon Mobil Rate of Return (RoR) on Capital Employed for Upstream Production Investments



SOURCE: Data Adapted from Exxon Mobil Annual Reports

In China, there are salient trends of geographic focus shifts towards energy abundant regions, and these trends were motivated by the cost factor--- it is cheaper to lift oil and gas from certain regions than from others. Where comprehensive data are not available about China's oil and gas reserves overseas, we can observe the trends of China's diversification strategies reflected in the global investment portfolios undertaken by its largest NOCs such as CNOOC. . As shown in Figure 4.5, from 2002 to 2009, the CNOOC's international reserves more than doubled, and the additional reserves in these years came mostly from energy abundant regions, including Africa and Oceania.

Figure 4.5 CNOOC EODIs from 2000 to 2009



SOURCE: Data Analyzed from CNOOC yearbooks

Besides, given the extraordinary growth of Chinese EODIs, it is anticipated that China will soon also own substantial reserves in the Middle East, home of what is known as "sweet light" oil. In fact, according to IEA estimates (*IEA, 2011*[33]), agreements between Chinese NOC's and three major Middle East countries (Qatar, Iran, and Iraq) since 2008 will add to China's Middle East oil reserves in the coming decades. For example, under one 2009 agreement with Iran, CNPC was expected to produce 75kb-150 kb/day for 25 years, yielding a total estimated reserve of 680 million barrels of oil and surpassing CNOOC's cumulative reserve for 2009. Table 4.2 below projected the totals of selected large contracts for future international oil reserves.

Table 4.2 the estimated reserves of selected Chinese contracts in the Middle East, 2008-2010

Time	Company	Country	Estimated Reserves	Years of supplies
2008	Sinopec	Iran	326 million barrels	7
2008	CNPC	Iraq	250 million barrels	7
2009	CNPC	Iran	1.10 billion barrels	25
2009	CNPC	Iraq	12.78 billion barrels	20
2009	CNPC	Iraq	3.9 billion barrels	20
2010	CNOOC	Iraq	985 million barrels	6

SOURCE: Data Analyzed from IEA (2011)

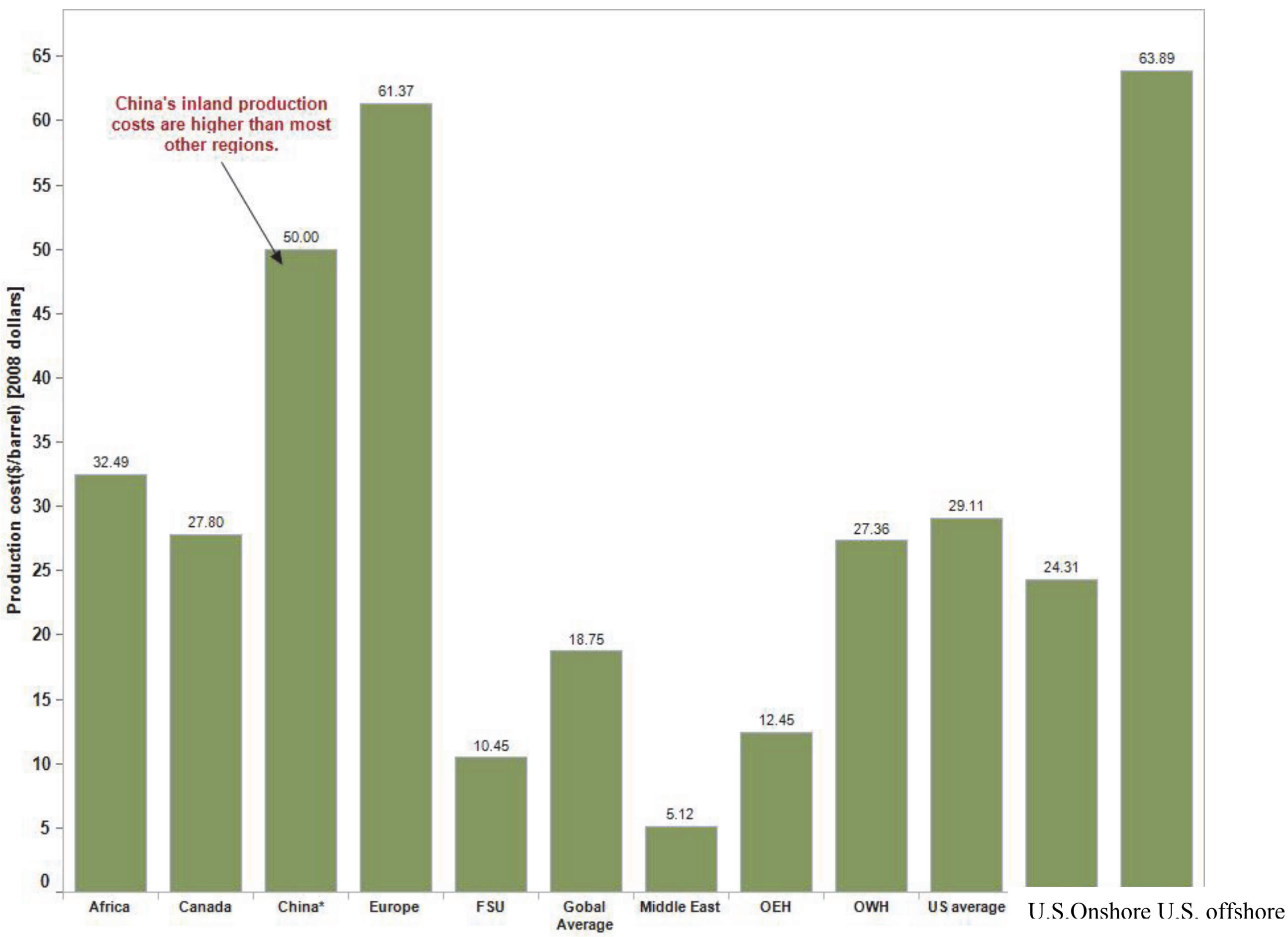
Domestic Chinese oil fields have higher lifting costs than most other international sites. While there are no official Chinese statistics on the finding and lifting costs of continental Chinese oil fields, major media and government reports show that these costs are much lower in other parts of the world than in China. According to the 2012 estimate of Mr. Feng Shiliang[xix], secretary of the Chinese Oil and Chemical Industry Association, Chinese inland oil production costs were as high as $50/barrel in 2008[xx], while production costs in other non-European

xixNote: Mr Feng Shiliang is the Associate Secretary of the Chinese Oil and Chemical Industry Association.

xx Note: ChinaDaily has a more optimistic quote, saying the average should be near 40$/barrel in China.

countries were much lower during this time (see Figure 4.6). In 2008, Chinese oil extraction costs were higher at $50/barrel, higher than almost anywhere else in the world except in Europe (where they were $61/barrel) and U.S. onshore (where they were $64/barrel). By comparison, the Chinese per barrel costs stood at more than twice the U.S. inland production cost. Therefore, considering current refinery costs, and absent the development of disruptive technological innovation, Chinese NOCs are more motivated than the U.S. IOCs to pursue global oil field investments.

Figure 4.6 Chinese and World Oil Production Costs, 2008



SOURCE: China Daily 2012[34]*, expert interviews*

In terms of investment environment determinants, i.e,. the political and non-political policy factors, the positions of Chinese oil companies differ from those of their U.S. counterparts in almost all investment regions. While most political factors (Table 4.1) are somewhat vague, difficult to measure, and usually debatable, the major non-political policy factors can more easily be measured. Specifically, in Africa, where China is expected to become the single largest trading partner, reaching a level of $400 billion/yr by 2015 (Aning, 2012[35]), the policy incentives for investment are very favorable to Chinese investors, especially Chinese NOCs. China has signed bilateral agreements with 33 African countries to promote and protect mutual investments, and has reached agreements with eleven African countries on tax exemptions designed to avoid double taxation (PRCGOV, 2012[36]). China has also established financial incentives for foreign investors—for example, the China-Africa Development Fund, which invests up to $5 billion annually in development projects in Africa. The United States, for its part, has signed free trade agreements with 19 countries[xxi], most of them on the American continent (Canada, Chile, Mexico, Peru, Columbia, etc.). The U.S. has also reached free-trade agreements with two oil-rich Middle East countries--Bahrain (in 2006)[xxii] and Oman (in 2009)[xxiii]. But in most oil-rich countries in Northern Africa and Middle East, the U.S. has not reached free bilateral trade agreements.

In terms of both cultural and institutional political factors, there are signs that Chinese investors are generally well-received than U.S. competitors in countries such as Singapore, Kazakhstan, Brazil, and "rogue regimes" including Iran and Cuba, than elsewhere; whereas U.S. investors generally meet with greater success in countries in Canada and Western Europe. Such cultural and institutional proximity could impose far-reaching effects on future EODIs of these countries, because over 60% of the world's proven oil & gas reserves are owned by governments and state-owned enterprises (Chevron, 2012[37]).

In addition to the profitability factors, including resource affluence and cost-effectiveness, the expanding EODIs were also assisted by their national government's geostrategic positions and energy subsidy policies. The Energy Policy Act of 2005 provided a tax deduction equivalent

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xxi Note: a full list of bilateral free trade treaties can be found at: http://www.ustr.gov/trade-agreements/free-trade-agreements

xxii Note: a detailed description of US-Bahrain FTA agreement can be found herehttp://www.ustr.gov/trade-agreements/free-trade-agreements/bahrain-fta

xxiii Note: a detailed description of US-Oman FTA agreement can be found here: http://www.ustr.gov/trade-agreements/free-trade-agreements/oman-fta to $2.8 billion for domestic and overseas fossil fuel production. In addition, export credit agencies and multilateral development banks (e.g., the Export-Import Bank of the United States) frequently provided subsidized credit for U.S. energy infrastructure projects overseas (*EIA, 2011*[38]). The IRS tax code was adjusted as well, to prevent double payments for U.S. companies that owned overseas investments. This tax code allowed a foreign tax credit for income taxes paid to foreign countries, which significantly benefited major oil companies.

The prosperity and diversification of Chinese NOCs after 2005 can be attributed to China's persistent promotion of its "going out" policy, under which the large Chinese national companies were pushed to seek global investment opportunities. This policy was a sharp contrast to the government's strong position in the 1990's to any foreign investments by the NOC's. According to IEA (2012), not even the CNPC's investment efforts in Peru (1992), Sudan (1996), or Venezuela (1996) managed to gain the approval of the Chinese government. But since 2005, the new level of approval and incentives for global investment that the Chinese government has given its NOC's will do much to enhance their overseas holdings, and thus will substantially increase their overall production capacity.

4.1.3 Summary of the key determinants for the US and Chinese EODIs

On the whole, the range of effects of the key economic and investment environment determinants of U.S. and Chinese EODIs can be summarized as follows.

- The leading economic determinant for both U.S. and Chinese EODIs is the investment motivation of their home countries. This investment motivation is seen in the size of the gaps between domestic oil supply and demand. The larger this gap, the more motivated companies will be to invest and produce overseas. On the Chinese side, the continuing disruptive growth of Chinese EODIs is significantly associated with increasing domestic supply deficits. On the U.S. side, EODIs follow a cyclical pattern over time, one that coincides with U.S. economic cycles--an indicator of the U.S. domestic oil supply-demand balance.

Two other economic determinants, the ownership and the location advantages, have mixed effects on the international investment choices of U.S. and Chinese investors.

- In response to global changes in oil reserve distribution, the U.S. shifted its investment focus from Europe to Africa and Canada. For much the same reason, abundant oil reserves in Africa were attractive enough to draw the attention of Chinese investors beyond Southeast and Central Asia (FSU).

- Also, the extremely low lifting costs of oil fields in Africa had a strong positive effect on the EODIs of both countries. This may have resulted in fierce competition between Chinese and U.S. investors, in which Chinese investors hold a slight advantage. However, the great geographic distance between Africa and China also had a mixed effect on Chinese investors, given the uncertainties and high transfer costs of sea lane transportation.

- In the Middle East, the effects of the investment and location factors were more mixed than in Africa for both the U.S. and China. Low cost and high quality oil is the obvious advantage for investment in this region, whereas the economies here lack diversity, and the markets are not free for foreign competition. It is interesting to note the contrast between the U.S. and the Chinese responses to these mixed conditions: Chinese investors plunged headlong into heavy investment with premium bids in countries such Iran, disregarding the risks and uncertainties, while U.S. investors expressed only limited interest in ventures there.

Similarly, the investment environment determinants had only a modest effect on EODI behaviors for investors from both countries.

- The "Pull" strategies of the Chinese government helped to create a favorable investment environment for their NOCs in Africa and the FTA between the U.S. and the previously mentioned oil affluent oil-rich countries in the Middle East could potentially increase U.S. access to EODI in this region.

- Partnership and rivalry, in the traditional sense, possibly affect mutual trust, and influence the business opportunities of both the U.S. and Chinese oil companies.

4.2 Goals of U.S. and Chinese EODI: Similarities and Differences

Chinese and U.S. energy investors explored global investment markets, motivated by multiple goals – of which some are similar; others are different or even contradictory.

- *Profit and reserves are the two goals shared by both Chinese and American investors*

Among the 30 major U.S. energy investors, there are six foreign subsidiaries, as well as additional leading international investors. One of them is Chevron, which has its own subsidiaries in more than 30 countries. For these internationalized U.S. private companies, profitability is the primary goal. Chinese NOCs, however, while seeking profits globally, also serve the government's geopolitical goals. In the last decade, the role of the Chinese NOCs as a geopolitical tool has decreased, while their transition towards a profit-driven company becomes more obvious through recent corporate restructuring arrangement by the Chinese government. In 2001, China established an important policy reform called "the separation of politics and enterprise" [xxiv]. Since then, Chinese NOC CEOs have not been assigned administrative titles, and thus are no longer subject to the direct control of the government. Up until the present, most Chinese NOCs were listed in both domestic and international stock exchange markets. CNOOC

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xxiv Note: more details can be found on the Chinese Party History Webpage: http://dangshi.people.com.cn/GB/165617/173273/10415397.html was first listed in the New York Stock Exchange Board in the last quarter of 2001, and for more than a decade, Sinopec affiliates have been listed in New York Stock Exchange, as well as in ETR (Energy Corporation Common Stock) and PINK[xxv].

- *Both Chinese and U.S. investors were eager to access the investment market in the Middle East*

Investors from both countries were interested in Middle East, because it is home to the single largest energy reserve in the world. The Chinese government does not place bans on trade with Iran, thus Chinese NOCs have already established a considerable investment there ($13,510 million between 2005 and 2011). On the U.S. part, after the Iraq war in 2003, U.S. oil company reserves in the Middle East almost tripled (Figure 3.10), partly because the war helped open the oil investment market in Iraq, formerly an isolated authoritarian economy. In addition, the U.S. government recommended instituting a policy initiative to open up the investment markets in other oil-rich countries, including Saudi Arabia and UAE (Cheney Report, 2001). This, in the end, will also raise investors' confidence in the opportunities in this region. In addition to their strong interests in the reserves of these oil-rich countries, both Chinese and U.S. companies are attracted by incentives from other Middle East countries to help promote their economic development, as well as other national infrastructure building. According to Donboli and Kashefi (2005)[39], major Gulf Cooperation Council (GCC) member countries have provided a favorable socio-economic climate for foreign investment in the region. Most countries have well-developed banking systems to attract investments to intended to diversify their economic structures. They have also removed tariff barricades, loosened mandates on foreign ownership, and impose no personal income taxes and limited corporate taxation outside the oil exploration sector, in order to attract high-skilled labor force. Following a history of trade with Europe and America, these countries also have free trade treaties or regional unions with Europe and the

xxv Note: OTC Markets Group Inc., formerly known as Pink OTC Markets Inc., operates OTC Link, an electronic quotation system that displays quotes from broker dealers for many over-the-counter (OTC) securities. "Market makers" and other brokers, who buy and sell OTC securities, can use the OTC Link to publish their bid, and request quotation prices. The terms "Pink" or "Pink Sheets" (as they were formerly known), stems from the color on which they were historically printed. Today they are published electronically today by OTC Markets Group Inc., a privately owned company. OTC Markets Group Inc. is not registered with the SEC in any way and it is not a Financial Industry Regulatory Authority (FINRA) Broker-Dealer.

U.S., such as the U.S.-Bahrain Free Trade Agreement and other duties exemption agreement in 2004, WTO entry and zero tariff in computer industries, U.S.-Jordan free trade agreement, Trade and Investment Framework Agreements (TIFAs) and Bilateral Investment Treaties (BIT) with the U.S.

- *Chinese and U.S. investments targeted both developing and developed countries*

Chinese EODIs were mostly made in developing countries with political constitutions similar to that of China. Before 2000, Chinese investors invested mostly in Non-OECD countries in the Middle East, Africa, and neighboring South and Central Asia. For instance, Chinese companies invested heavily in Iran, which now became its biggest single importing country, accounting for 15 per cent of China's energy imports. After 2000, Chinese investors tried to diversify their geographic investment distributions. But mostly, Chinese companies followed the principle of investing in developing countries. Between 2007 and 2010, the new markets with the greatest growth were developing countries in South America, such as Brazil and Argentina. The receptiveness of host country governments to Chinese investments during this time gave Chinese investors a comparative advantage. For the host countries, China's energy investments brought a greater benefit than merely the increase to local GDP alone from the added incomes. In Latin American countries such as Venezuela, for instance, Chinese investors also helped their host countries gain access to cheap telecommunication infrastructures, and then assisted the Chinese construction groups to navigate the infrastructure construction process affordably using mature technologies. Iran and Argentina, the other two important Chinese EODI targets, also benefited from the national security insurance provided by China through the sale of military weapons, which had been embargoed by from OECD countries, including the U.S.

While Chinese energy investors also made some progress in OECD markets such as France, Canada, and the U.S., Wolf et. Al (2011)[2] has cautioned that Chinese initiatives in developed countries such as the U.S. and the EU countries were highly limited due to the close scrutiny that Chinese investments aroused for national security reasons. In fact, it is almost certain that future Chinese energy-related investment will focus on China's partner countries in Asia, Africa and South America.

U.S. EODI, on the other hand, went mostly to host countries in the developed world. Jackson (2008[40]) noted that 75% of the U.S. ODI went to developed countries such as Canada. In comparison, the U.S. only invested 25% in developing countries and U.S. interest in investing in developing countries soon declined further. With respect to EODI in particular, American investors were very interested in entering developing markets obroad, but ovedrall U.S. institutional, geopolitical, cultural, and security positions made many host countries in the developing world reluctant/unwilling to accept U.S. investments. According to Klare (2004), U.S. companies were highly motivated to undertake oil exploration in Sub-Saharan and West African countries. The U.S. government was also very supportive of these development efforts. And since 2009, the U.S. government has provided military support to Africa, to reduce disruption risks to U.S. EODI investors. Oil development in Africa is a very attractive investment niche: Africa has very large reserves of high quality, low-sulfur oil. However, as Klare (2004) also claimed, several institutional, cultural, and security conditions make U.S. investments in these countries risky. These obstacles to U.S. investment in African oil ventures are: (1) corrupt bureaucratic systems; (2) intensifying military conflicts over oil revenue distributions among ethnic militias; and (3) disagreement over economic sanctions and human rights violations.

- *Chinese and American investors focus on different investment portfolios: operation versus equity*

Chinese ventures into foreign energy markets have to a great extent taken the form of equity investments. This is because Chinese companies have advantages in their financial capacity, but lack the necessary range of exploration and production technologies and operational management experience to run these companies. Chinese NOCs have always kept good records of their liquid assets, or cash flows. According to the Deloitte Report (Deloitte, 2009)[41], during the economic recession of late 2008, most oil companies in other countries experienced great pressure from the widespread liquidity shortage, but Chinese NOCs used their liquidity advantages during that time to acquire many high quality assets investments at discounted cost. Also, equity investments help Chinese NOCs access cheaper oil imports. In the most common scenarios (moderate share prices and wisely selected portfolios), equity oil[xxvi] is also much

xxvi Note: "Equity Oil" is a term widely used among EODI research or discussion articles. It refers to the oil purchased internally at lower-than-market-price by the oil company's equity owners.

cheaper than oil purchased directly from international markets (Abdrew-Speed, 2012[42]). In terms of the Chinese NOCs' interest in other types of investment, Deng (2006) also mentions China's interest in Green Field overseas investments, i.e. directly establishing affiliates of a Chinese company in another host country by constructing new operational facilities from the ground up. This strategy was allegedly guided by the Chinese government's call to promote Chinese brands internationally. Unfortunately, according to Deng(2006), the Chinese "brand going global" strategy using Green Field investments was not very successful in the cases of Hai'er, TCL or Lenovo. American investors, however, managed their investment portfolios quite differently. Because most major U.S. investors, such as Exxon Mobil and Chevron, have established well-known global brands, they usually set up their own subsidiaries in the host countries that contained the structures to manage all business operations, from financing through management, to production line technologies services.

4.3 Goals and Determinants: Implications for Collaboration or Competition

- *Similarities and differences in determinants and goals could lead to competition*

Because both Chinese and U.S. companies are interested in Middle East investment markets for reasons elaborated above, investors from these two countries may encounter aggressive competition in future. In 2002, when its domestic energy demand began to rise, China began to bid aggressively for energy sector investments in the Middle East – a trend described by Leveret and Bader (2005). This, according to the authors, could pose a threat to the markets the U.S. had already acquired in this region. China had initially established ties with Oman and Yemen, importing light crude oil in the early 1990s for its domestic refineries. After the U.S.-Sudan break in 1997, China immediately made overtures to Sudan, consistently utilizing lucrative market premiums, exchanging crude oil investment and advanced oil refinery technologies, developing imports of petrochemical products, soliciting investment, and improving its relations with Saudi Arabia, a traditional U.S. ally. Besides, to ensure sustained energy investment contracts in other Middle East countries such as Iran, China also provides bundles of infrastructure facilities to Iran, such as Tehran's subway system and broadband network. Chinese actions can reduce/diminish U.S.- Middle East energy supply resilience in several ways: 1) Strengthening China's ties with countries such as Iraq and Iran may bolster their political leverage against the U.S.; 2) Since September 11 and the beginning of the U.S. wars in Afghanistan and Iraq, the U.S.-Saudi alliance has weakened, given Washington's feeble defense of this relationship, while China continues to extend market premiums to strengthen China-Saudi ties; 3) China and Saudi Arabia have introduced the "currency basket" financial coordination, which greatly threatened U.S. dollar power and thus U.S. dominance in the Middle East energy market.

- *Similarities and differences in determinants and goals could also lead to common interests*

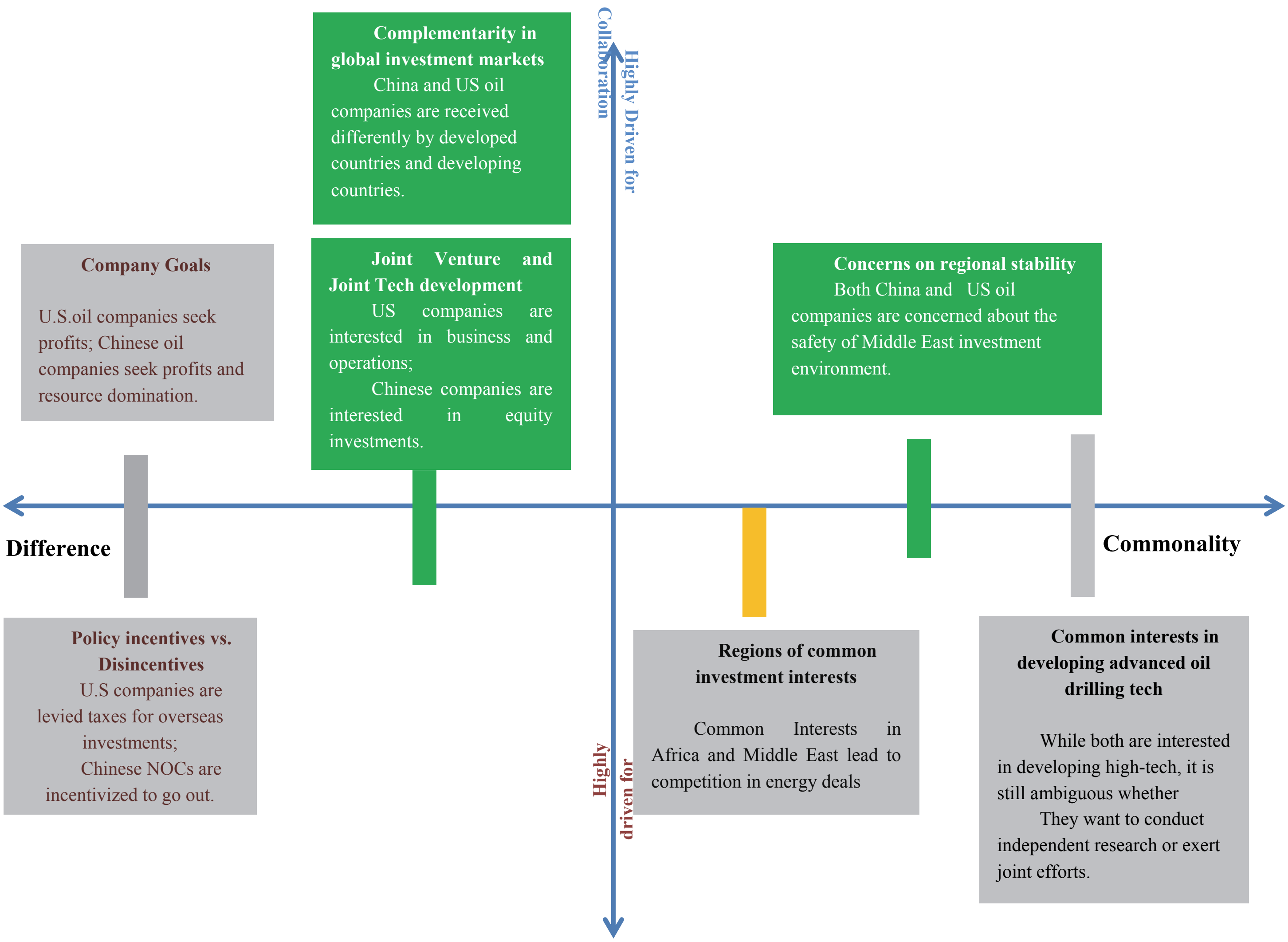
First, because China and U.S. have different advantages in investments of major developing countries and developed countries, they can complement each other in these markets accordingly. According to Chanlett-Avery (2008)[43], Chinese investors were very keen on Central Asian countries' investments. However, China also encountered competition from Japan for Russia's oil and gasoline pipelines, and needed to get rid of Russian's control in other Central Asian countries' investments in Uzbekistan and Tajikistan. Thus, an important strategy is to participate in multinational consortium including those of big U.S. companies, to strengthen its competitiveness against Russian investors. Similarly, in developing countries such as many Africa countries, U.S. oil companies can co-operate with Chinese investors, given the fact that China had entered these markets earlier and had established a strong investment network.

Second, it is possible for Chinese and U.S. energy companies to achieve win-win outcomes, joining forces on technology development and business ventures. As elaborated in the previous section, given the insurance of State-owned bank loans (IEA, 2011), Chinese NOCs had easy access to liquidity asset, while U.S. multinational energy companies mainly used international financing markets to fund their exploration or development activities. These international financing markets, however, are more vulnerable to the liquidity pressures and shrinking investments in times of economic recession. On the other hand, limited technological capacity greatly inhibited Chinese investors' choices of global energy production and refinery capacity. According to Zha and Hu(2007)[44], the key consideration for Chinese oil overseas investment and import was the technological match between China oil refinery capability and the types of crude oil available. Combining these two factors, if U.S. and Chinese investors cooperate in joint venture exploration, the outcomes might be mutually beneficial. Besides, China has more energy technological cooperation with U.S. more than any other country (Zha and Hu, 2007). Considering such a solid technological collaboration platform, the U.S. IOCs could be important partners with Chinese NOCs in future joint ventures of energy exploitation.

In particular, Chinese and U.S. joint development would be mutually beneficial in the area of South China Seas--one of the richest energy reserves in the world. According to Buszynski and Sazlan(2007)[45], trilateral energy exploitation could alleviate the regional clashes of sovereignty claims in this region, as well as help supply for growing energy needs of Asia-

Pacific economies. China and Vietnam have both claimed sovereignty to the South China Sea, based on incomplete historical occupation records, while other ASEAN countries, such as Philippines have claimed adjacent zones. With multiple countries involved in these maritime disputes, conflicts have tended to escalate as more and more countries have developed interest in this region. To alleviate tension in this region, China and the neighboring South Asian countries have gradually changed their strategies towards joint development of energy resources, which also helps quench a thirst for energy in the fast-growing economies in the region. In terms of the practical aspects of energy development collaboration, China was interests in seeking partnerships with operators with mature the ultra-deep-water operation experiences (e.g. Diamond Offshore Drilling & Baker Hughes from Texas). However, joint energy development, as strongly endorsed by Chinese leadership, may still encounter impediments due to lack of transparent benefit allocation mechanisms and sovereignty claims (Kate, 2011[46]).

Figure 4.7 The Goals of U.S. and Chinese EODIs: Implications for Competition and collaboration



4.4 Concluding Remarks

To summarize, U.S. and Chinese oil companies have both commonalities and differences in terms of their overseas investment goals.

- They share the goal to increase access to the Middle East. Common interests emerge in the Middle East, where plentiful and easily accessible energy resources make investments very attractive; common concerns also emerge in this region, where resistance to foreign investments could pose a great threat to the development of large-scale energy businesses.

On the other hand, U.S. and Chinese oil companies have different priorities.

- While they share the goals of acquiring essential resources and simultaneously maximizing profits, the Chinese oil companies place greater emphasis on the aspect of resource domination, whereas the U.S. companies are more interested in profit maximization.

- They also have different investment preferences. The Chinese companies, with abundant capital flow, but lacking both international management and operational experience, prefer to choose non-principal equity investment, i.e., they prefer to serve on the board of shareholders and to remain uninvolved in the day-to-day business operations. The U.S. oil companies, by contrast, due to their technological and operational advantages, are far more involved in operations.

These differences and similarities potentially create both competition and collaboration opportunities for the U.S. and China. They may compete fiercely in some regions, but in other regions may also consider participating in joint development efforts.

To further illustrate the mechanisms and the subtleties of competition and collaboration between the US and Chinese oil companies, the study in the following Chapter 5 uses a partial equilibrium model system to simulate their market behaviors in the day-to-day operations of their EODI activities.

5 Competition in Perspective: A Partial Equilibrium Model of U.S.-Chinese EODI operations

In Chapter 3 and 4, the study has addressed the major determinants and goals of both the U.S. and Chinese EODIs. In these two chapters, the study also analyzed the potential scenarios, in which some similarities and differences could lead to future competition, and others that may lead to future collaboration. Therefore, in this chapter, the study will fit these major goals, determinants and operational factors into a model—the EODI partial equilibrium model, in which the study will simulate and visualize the short-, medium and long-term patterns of their competitive positions.

5.1 The Partial Equilibrium Theory and application in energy modeling

Partial Equilibrium analysis, first proposed by the economist George Stigler, has been used to analyze a sectorial steady state, in which optimal objectives are reached and major interactive factors reach a balance. In this type of model, the analyses are based on a restricted range of data, in one particular market, which is considered as a closed system—i.e., all the stakeholders and activities outside the system are treated as exogenous factors. After Stigler, other economists also developed more comprehensive analysis methods to include the interaction with outside factors, and thus established a new analytical framework—***General Equilibrium***. General Equilibrium analysis seeks to explain the behavior of supply, demand, and prices in a whole economy with several or many interacting markets, by seeking to test whether a set of prices exists that will result in an overall equilibrium of all the pertinent markets and stakeholders.

In the energy research field, both P.E. and G.E. models have been used to analyze energy-related policy issues. The following table 5.1 provides examples of P.E. and G.E. applications from Stanford Energy Modeling Database. In this research, the study focuses only on one market—outward direct investment and does not consider the multiple-sector interactions such as energy-environment or energy-labor markets. On the contrary, the study details the behaviors of the business investors only and thus uses P.E. modeling in the following analyses.

Table 5.1 Applications of G.E. and P.E. Energy models

G.E. Energy Models	Application
Modeling Energy Markets and Climate Change Policy	Focus on the interactions of the firms and consumers in various sectors and industries, allowing for inter-industry interactions and international trade in non-energy goods.
Gemini Energy-Environment Model(DFI, 1993[47])	Gemini model: Focus on energy production and use in the U.S. and the associated impact on the global environment. The major components of the model include a simplified U.S. agricultural sector, a global environmental sector, and a detailed U.S energy-economy sector (resource sector, electricity generation and distribution sector, four end-use sectors.)
P.E. Energy Models	**Application**
Globalization of Natural Gas Markets –Effects on Prices and Trade Patterns	Explore how regional gas prices and trade patterns may develop until 2030 under different scenarios about future market conditions.
Perspectives of the European Natural Gas Markets Until 2025	GASMOD Model: this is a game-theoretic partial equilibrium model of the European natural gas market. In this model, exports to Europe and wholesale trade within Europe are represented as successive markets in a two-stage structure.

SOURCE: Stanford Energy Modeling Forum

Note: Stanford Model summary webpage: http://emf.stanford.edu/

Gemini Model was developed by was developed by Decision Focus Incorporated (DFI) and the U.S. Environmental Protection Agency (EPA).

GASMOD Model was developed by German Institute for Economic Research (DIW Berlin). Detailed description of the model can be found on its webpage: http://www.diw.de/sixcms/detail.php?id=diw_02.c.231874.de

5.2 The Partial Equilibrium Model System

5.2.1 General assumptions

Much as in other business investment behaviors, the Energy Outward Direct Investments (EODI) will also follow certain general principles of operations and rationales. Therefore, in this section, the study establishes general operational and decision-making assumptions for both U.S. and Chinese investors.

- *General business management principles*

In this setting, I assume that the big oil investment companies serve the interests of their shareholders, and there is no major split on investment decisions between the shareholders (represented by the board of directors) and the management. Therefore, in the case of Chevron, one of the largest U.S. multinational oil companies, for instance, its EODI decision-making should serve not only the interests of Black Rock which holds a 5.62% share and State Street Corporation which holds a 5.10% share (Chevron, 2011)[48]-the two single largest stockholders, but also those of its smaller stockholders such as non-employee directors and executive officers, who hold less than 1% of total shares. Likewise, Sinopec, one of the largest Chinese oil companies, should not serve only the interests of its largest shareholder-the State who holds75.84% of the total shares, but also those of smaller shareholders including foreign shareholders, which together hold 19.35% of the total shares and domestic public shareholders, who together hold 4.81% of the total shares (Sinopec, 2011[49]).

To best serve the overall interests of all shareholders, the companies will aim to maximize the aggregate profit for all its stockholders in the near (defined as 5-year period), medium (defined as 10-year period), and long (defined as 15-year period) term

- *EODI clustered into two heterogeneous patterns*

With the varying composition of their stakeholders, oil company EODI goals vary from company to company. Ideally, an accurate model system should represent how all the oil companies behave under different utility functions and interactions with each other. However, taking the modeling complexity into consideration, this study will model the EODIs of the U.S.

and Chinese companies respectively. The rationales behind this modeling approach are that the oil companies within each group: (1) have similar, if not identical, objectives; (2) are bonded by similar, if not identical, constraints; and (3) function under similar, if not identical, mechanisms, such as the allocation of profits, human resource flows, and technological mechanisms. In the following sections, this study will provide justifications for the clustering in terms of objectives, mechanisms and constraints.

5.2.2 Objectives of EODI for the U.S. IOCs and Chinese NOCs

- *U.S. IOCs targeted maximized profits*

As discussed in previous sections, large multinational oil companies such as Chevron are owned by a mix of private stockholders. These private stockholders, making investment decisions based on market approaches to seek maximal profits. Theoretically, then, the objective of EODI for U.S. IOCs is to minimize costs and maximize profits. Also, such objectives of profit maximization and cost minimization can be explained by the recent U.S. EODI historical trends. Specifically, between 1991 and 2003, the domestic drilling costs were almost equivalent to that of foreign drilling, and accordingly the domestic drilling investments dominated during that time frame. By comparison, as discussed in previous Section 4.3, after 2003 the U.S. IOCs switched the focus of their intense oil drilling investments from domestic to African oil fields. The crucial reason for this transition was that over time overseas drilling became less costly and thus more profitable. In the past decade, both the drilling costs (well development costs) and finding costs (well exploration costs) at home rose much more quickly than those in foreign countries. Specially, in 2007, the domestic drilling costs were 25% higher than foreign drilling costs. Meanwhile, the exploitation costs (production costs) were also much lower in foreign countries (especially non-OECD countries) than the exploitation costs in the domestic U.S. fields. In 2006, for instance, the per Barrel Oil Equivalent (BOE) finding costs of FRS(Financial Reporting System) companies in U.S. offshore fields were as high as $60, whereas the per BOE finding costs of FRS companies in Africa oil fields were only a little over $30 (EIA, 2011[50]).

Therefore, the objectives of U.S. IOCs, as reflected in the historical trends of their EODIs relocation, were minimizing costs to serve the end of profit maximization.

Therefore, the objective of U.S. IOCs can be expressed as maximizing the aggregate profits, i.e.

Aggregate profits=Gross Earning-Production & Maintenance costs-Storage Cost.

The gross earnings came from two major sources: the first was from sales to global market and the other was from domestic sales. Therefore,

Gross earnings=Earnings from Global market + Earnings from the domestic market.

This can be mathematically described in Formula 5.1.

$$\text{Max } \pi = \sum_{i=1}^{n} \sum_{j}^{2010-2025} (EG_{ij} + EI_{ij} - I_{ij} - OM_{ij} - SC_{ij})$$

Formula 5.1

- i: host country/region; j: year;
- EG: earnings from global market sales of oil and gasoline;
- EI: earnings from sales to the domestic market;
- I: EODI exploration investments ;
- OM: operation (production) and maintenance costs;
- SC: storage costs.

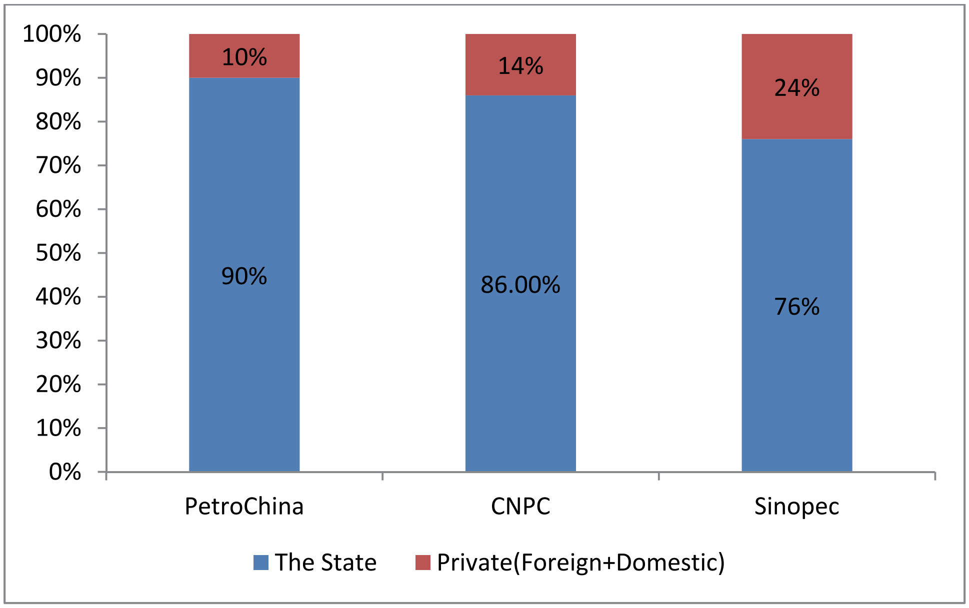
- *The Chinese NOCs served a mix of objectives*

Compared with U.S. IOCs, Chinese National Oil Companies (NOCs), served a mix of EODI interests.

First, the Chinese NOCs followed closely with their State government strategies when making any big investment decisions, including EODIs. This is due to the fact that their single largest stockholder is the State. In the case of Sinopec, as mentioned in previous section, 75% of its stock was owned as a State asset. And the State stakeholders showed strong interest in global energy resource domination. Such a strong interest in energy resource control can be indicated by the fact that in recent years Chinese NOCs had pursued costly and high-risk overseas M&A initiatives. For instance, Leveret and Bader (2005)[51] noted that Chinese NOCs bid with premium prices, so as to expand access to Sudan's upstream investments. Dreyer (2007)[52] also noted China's investments in central Asian countries such as Turkmenistan, despite suspecting that these countries had made export commitments in excess of their energy reserves. Chinese NOCs had also signed agreements with Russia at high prices despite the political uncertainty there and vague timelines. All these acquisitions, without exception, reflected the State's interest in the control of energy resources commissioned by way of the EODIs of NOCs. Such commissions, however, might be justified by the fact that China can only guarantee access to energy supplies through control of resources.

Moreover, the objectives of Chinese NOCs' EODI also evolved as these companies restructured their assets and readjusted their practices to operate more successful in the global context. Since 2001, the national asset restructuring, as elaborated in the previous section 4.1, changed the strategic landscape of Chinese State monopolies, among which are the large NOCs such as Sinopec. Currently, these NOCs are owned by a wide range of stockholders-- foreign and domestic, private and governmental stockholders (Figure 5.1). Therefore, another important objective of Chinese NOCs, though not the primary one, is to meet the earnings expectation of minor shareholders.

Figure 5.1 Share ownership breakdown of three leading Chinese NOCs



In consideration of the two major objectives of the Chinese NOCs, the study in this research integrates the two objectives under a weighted aggregate utility function (see Formula 5.2 below). In this formula, γ is the weight coefficient reflecting the relative importance of capturing energy resources abroad.

With regard to resource domination, the Chinese government audited resource domination in terms of the total amount of investment value (SASAC, 2004[53]), which could be used as a proxy to reflect the State control of a certain market such like foreign direct energy investments. On the other hand, from practical economics perspectives, the production capacity should be another good proxy[xxvii] for energy resource domination.

Therefore, the objectives of Chinese NOCs are to maximize the sum of aggregate profits and weighted value of controlled resources. Depending the choice of proxy for resource control, there are two possible ways to describe Chinese NOCs' objective functions:

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xxvii Note: discussion with RAND Economist Krstina Kumar.

Aggregate utility=aggregate profit +weight investment value*

=Gross Earning-Production & Maintenance costs-Storage Cost

+ Weight aggregate investment flows…………..... (i)*

Aggregate utility=aggregate profit +weight production value*

=Gross Earning-Production & Maintenance costs-Storage Cost

*+ Weight*production capacity*price …………..... (ii)*

Here, the weights are decided by regressing the historical ratios of profits and corresponding values (investment values or productivity values).

(i) and (ii) are mathematically expressed in Formula 5.2 and 4.3.

$$\text{Max } U = \sum_{i=1}^{n}\sum_{2010}^{2025}(EG_{ij} + EI_{ij} - I_{ij} - OM_{ij} - SC_{ij})) + \gamma\sum_{i=1}^{n}\sum_{2010}^{2025} I_{ij}$$

(Formula 5.2)

$$\text{Max } U = \sum_{i=1}^{n}\sum_{2010}^{2025}(EG_{ij} + EI_{ij} - I_{ij} - OM_{ij} - SC_{ij})) + \gamma'\sum_{i=1}^{n}\sum_{2010}^{2025} PC_{ij} \times P_{ij}$$

(Formula 5.3)

- i: host country/region; j: year;
- EG: earnings from global market sales of oil and gasoline;
- EI: earnings from sales to domestic market;
- I: energy ODI fixed investments ;
- OM: operation (production) and maintenance costs;
- PC: production capacity of Chinese NOCs in corresponding region and year;
- P: global oil sale prices in corresponding regions and years;
- SC: [fill in definition]
- γ, γ' weight of resource domination for Chinese NOC decision-makers;

However, it is still debatable whether and to what extent the Chinese policy to acquire resources. One Chinese report (Yin, 2011[54]) claimed that, as of 2010 Chinese overseas oil industry investments lost in excess of 400 billion RMB ($60 billion) every year and that more than two thirds of its total EODI projects hadn't made a profit. According to this report, the two major reasons for losses were: (1) the foreign oil wells invested didn't have the production capacity as predicted originally; or (2) the production operations were suspended due to regional turmoil. In the setting of this model, the parameters (γ, γ'), used to decide the relative importance between profit maximization and resource domination objectives, are simulated based on the three Chinese NOCs' historical Profit/Exploration Investment ratio. The intuition of this setting is to assume that the Chinese NOCs places equal importance on profit maximization and resource domination.

All the values in the Formula 5.2 and Formula 5.3 are represented in terms of net present value (NPV). The study also considers the different discount rate (IRR) expectations from Chinese oil companies and U.S. oil companies.

5.2.3 Identify and compare decision makers & decision variables

- *Decision makers*

In the case of EODI, generally only large oil companies invest substantially in global oil exploration, development and production. In the U.S., there are 27 big oil companies (responsible for approximately 80% of total U.S.-owned production) that are required to file their financial reports to Energy Information Administration (form EIA-28). These oil companies are also the main stakeholders of U.S.EODIs (See Section 2.1 Data Collection). In China, the NOCs are responsible for close to 100% of Chinese EODIs. While the business decisions of both the large U.S. oil companies and the three Chinese NOCs are influenced by external factors such as national politics, this analysis assumes that the business decisions of oil firms from both countries are made by their executive officers, driven by the objectives to maximize the utilities of their stockholders. Admittedly, in the case of Chinese NOCs, the largest stockholders are the State government. However, the State government stakeholders, under most circumstances, still convey their decision through the company investment project's board of stakeholders.

- *Decision variables*

By comparing the financial reports of U.S. and Chinese large oil companies, the study finds that there are four major decision variables for their EODIs respectively:

i. Exploration(& Development)

The life cycle of oil well starts with exploration and development. The exploration process is to discover and estimate the oil reserves in a site. The major activities in this process include early stage wildcat (or exploratory) drilling activities such as seismic surveys, drilling test, and other miscellaneous in-house activities such as reserve appraisal and early-stage production (Devold, 2013)[55]. Often times, the early stage wildcat activities involve more uncertainties than the later stage in-house activities, due to their high technological requirements, geological conditions and other environmental conditions. Depending on the type of exploration activities, the exploration projects may have different performance outcomes. In the U.S., large IOCs invested in a wide range of exploration activities, and thus the success rate of the investments varies project by project. For instance, while the Chevron exploration projects had an average drilling success rate of 57% in 2010, (Chevron 2010[56]) some exploration projects such as the Australia gas discovery projects were more successful than others, with an average success rate of 74%. In contrast, most exploration activities conducted by the Chinese big oil companies[xxviii]such as CNOOC mostly focused on later-stage well appraisal projects and thus achieved a higher success rate of 67% in 2012 (CNOOC, 2013[57]).

After exploration activities are completed, a well needs to be developed to prepare for production. These activities include full-scale drilling, setting up operation platforms, and construction activities (such as perforation) to complete a well.

Before the oil well is completed for production operations, both exploration and development will affect the production capacity of a well. Furthermore, the development and

xxviii Note: Chinese NOCs' exploration costs constitute a relative small part of "Operating costs". In the case of Sinopec, its exploration expenditures account for about 2% annual operating expenses (excluding production expenses).

exploration activities are not independent from each other. In fact, the exploration outcome will affect the development activities and thus further affect the production capacity of a well. For instance, in the U.S., the success rate of exploratory well is around 50% in 2005. That is to say, only 50% of the exploratory wells can be further developed. Therefore, this model system assumes that development investment as an implicit function[xxix] of exploration investment, and thus the total EODIs (exploration and development) can be expressed as a function of exploration investment.

ii. Production

Production is the leading activity that both Chinese and the U.S. oil companies conducted to increase access to international energy reserves. Production should include both upstream crude oil extraction and downstream refining activities. However, major Chinese and the U.S. big oil companies based only a small portion of their refinery production in the case of their EODIs. Thus, this study only focuses on upstream oil production, i.e., the crude oil extraction. The costs incurred during the oil extraction process include: personnel costs, host countries' production and income taxes, equipment depreciation, and maintenance costs. As long as the daily oil extraction of a well is within the production capacity limit, the decision makers can make the optimal decisions about production based on cost factors and other objectives.

iii. Stock

Maintaining stock is necessary in the case of the EODIs. This is because: 1) the volatility of international oil prices may motivate them to save stock when the market price is low and sell off inventory when the market price is high; 2) big oil companies may also respond to the government decisions to fill or release State-owned Strategic Petroleum Reserve (SPR). As of 2010, the U.S. federal government owned 727 million barrels of oil in the SPR storage sites(approximately 10% of annual total oil consumption in the U.S.); in China, the government sector(NDRC) also owned oil reserves of 475.9 million barrels(approximately 15% of annual total oil consumption in China) as of 2005 (China Daily, 2005[58]).

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xxix Note: based on historical U.S. EODI data, the analysis later in this study uses a linear equation to express the relation between exploration and development investment.

iv. Sales

Sales are typical business decision variables. In this model, sales are composed of two major parts: (1) sales in the international market at international oil prices; and (2) sales to domestic markets at domestic prices, either in response to federal subsidies in the U.S.(Loris and Dubay, 2011[59]) or import quotas required in China (Li, 2010[60]). Therefore, the aggregate sales can be formulated as an explicit function of inventory and production:

Sales to domestic market+ Sales to global market=Inventory by the end of last year-Inventory by the end of this year+ production of this year,

which is mathematically expressed as Formula 5.4 below. Also, a lower limit constraint should be applied to the sale by region. This is for practical reasons: (1) for continuous service, there should be a lower limit of sales; and (2) for local logistic capacity:

In this case, this model uses the lowest sales as the lower limits for sales by region (see Formula 5.5 below).

$$s_{ij}^{D} + s_{ij}^{G} = S_{i,j-1} + p_{i,j} - S_{i,j}$$

(Formula 5.4)

$$s_{ij}^{G} \geq s_{j_{historical} low}^{G}$$

(Formula 5.5)

- s_{ij}^{D}: sales to domestic markets;
- s_{ij}^{G}: sales to global markets;
- $S_{i,j-1}$: Inventory by the end of previous year;
- $S_{i,j}$: Inventory by the end of current year;
- $p_{i,j}$: Production in current year.
- $s_{j_{historical} low}^{G}$: lowest amount sold to global markets

v. Other Miscellaneous Factors

Aside from the three important decision variables previously discussed, corporate management must also make other miscellaneous decisions on nonstrategic assets and troubled assets sales, system upgrades, marketing and distribution, which may incur additional transaction costs. This study assumes that such miscellaneous decision variables, and corresponding costs incurred have been in part or fully factored into one or more of the above three decision variables.

5.2.4 Establish and compare mechanisms

In a structured system composed of decision mechanisms, corporate management can make decisions regarding exploration, production and inventory, to best serve the utility maximization objectives. . Therefore, in this section, the study will identify the key mechanisms, in order to link these business decisions to the realization of objectives of the oil companies.

- *Production capacity and cost functions*

A corporate management can decide upon the production level of current year between zero the company's maximum production capacity. The production capacity of current year, in turn, is affected by historical production, exploration, and well development efforts in the production sites and adjacent wells in that host country. According to research studies (Liu Zhibing, Jia Minhui, et Kang Xiaojun, 2006[61]; Bianco, et al, 2007[62]), the oil output capacity is contingent upon historical production and previous year(s) exploration investment.

Production Capacity = function of (cumulative production, cumulative exploration)

mathematically expressed in Formula 5.6

$$PC_{iJ} = f\left(\sum_{j}^{J-1} p_{ij},\ \sum_{k}^{J-1} e_{ik}\right)$$

(Formula 5.6)

- p: actual production;
- e: exploration investments in the region.

As shown in the Formula 5.6, there are two major contributing factors for production capacity (PC_{iJ}). They are: (1) cumulative production; and (2) cumulative exploration investment. These three factors impact the outcome of production capacity through three major mechanisms:

First, as shown in the Formula 5.6, as a key contributing factor, cumulative production, in other words, the aggregate production from previous years ($\sum_{j}^{J-1} p_{ij}$) directly impacts the production capacity (PC_{iJ}) of current year.

Second, cumulative exploration investments from previous years ($\sum_{k}^{J-1} e_{ik}$) also have an impact on the production capacity. However, depending upon the types of exploration investment portfolios, the impact of cumulative exploration investments from previous years ($\sum_{k}^{J-1} e_{ik}$) on the production capacity may vary. Historically, if the company chooses an exploration investment portfolio targeting short-term payback, cumulative historical exploration investments($\sum_{k}^{J-1} e_{ik}$) have an immediate impact on productivity in the following year; if the company chooses a historical exploration investment portfolio targeting medium to-long term payback, cumulative historical exploration investments($\sum_{k}^{J-1} e_{ik}$) don't have a direct impact on production capacity until many years later (seen in the following Table 5.2). The exploration costs e_{ij}(as shown in Formula 5.1 and 4.2) for U.S. and China are different:

$$e_{ij} = \begin{cases} e_{ik}^{CN}, & for\ the\ Chinese\ NOCs \\ e_{ik}^{US}, & for\ the\ U.S. MNCs \end{cases}$$

In addition, the partial derivative of production capacity (PC_{iJ}) with respect to exploration investment (e_{ik}^{CN}, e_{ik}^{US}) should satisfy these conditions: $\frac{\partial PC_{iJ}}{\partial e_{ik}^{CN}}$>0, , $\frac{\partial PC_{iJ}}{\partial e_{ij}^{US}}$>0. Considering that the U.S. exploration is more efficient than that of Chinese oil companies (*Luo 2008*[63]), it is also true that $\frac{\partial PC_{iJ}}{\partial e_{ik}^{US}} > \frac{\partial PC_{iJ}}{\partial e_{ik}^{CN}}$>0.

Table 5.2 short-long haul oil exploration activities

Exploration Activity	Description	Payback period
Progressive oil & gas field development	CNPC research group discovered oil-bearing structures at Sudan Block 3/7 in 2003, adding 300 million tons (previous reserve: 2.253 billion barrels) of proven oil in place.	1 Year
Carbonate Reservoir—Sinopec technology research	These developments supported reserve and production capacity buildup, while reducing cost and increasing efficiency. The research was initiated in 2008 and made major breakthroughs as of 2011.	3 years
Deep water operation demonstration	More than 70% of Chinese offshore oil wells are less than 300 meters (shallow water) below the sea. CNOOC initiated the deep water drilling tech research in 2005, and made breakthroughs in 2010 and 2012. Particularly the “Seawater Oil 981” project established a production platform from over 3,000 meters below the sea level, and the maximum drilling depth reached 10,000 meters. The technology was soon patented as CNOOC propriety.	5-7years
Advanced Enhanced Oil recovery methods	After one and a half year’s research, in 1976, the National Petroleum Council estimated that, by applying the advanced EOR method, the production would increase between 500,000 and 1.5 million barrels daily.	1.5 years
Developing environment-friendly working fracturing fluids	The industry use millions of gallons of water as the fracturing fluid to clean up the wells, but GASFRAC developed a new method to use LPG as a fracturing fluid, and demonstrated its first waterless LPG stimulation treatment in 2008. Three years later, in late 2010, Chevron licensed the LPG fracturing fluid technology to GASFRAC Energy Services Inc.	3 years

SOURCE: CNPC Annual Report 2003, CNOOC Annual Report 2005, Sinopec Annual Report 2008, Chevron Next Issue 4, 2010, New York Times, 1976, Dec 11th.

In summary, the explicit form of the function can be simulated based on historical data of valid production capacity estimates, and previous years' production, exploration investments, and OM costs. After situation, the explicit form of the f (.) function in this study is as follows:

$$f\left(\sum_{k}^{j-1} p_{ik},\ \sum_{k}^{j-1} e_{ik}, UOM \times\ p_{ij}\right) = \mu * \frac{\sum_{j}^{J-1} p_{ij}}{J-1} + \lambda * \sum_{k=T}^{J-1} e_{ik};$$

$$T = J-1, J-3, J-5;$$

- μ Coefficient estimated by historical data.
- λ: Exploration -production coefficient.

- *Technology advancement and Exploration Capacity*

As discussed in the previous section, the partial derivative of production capacity with regarding to exploration investment is always positive ($\frac{\partial PC_{iJ}}{\partial e_{ik}^{CN}}$>0, , $\frac{\partial PC_{iJ}}{\partial e_{ij}^{US}}$>0), meaning the more a company invests in exploration, the higher its production capacity will be. However, feasible exploration investment is not limitless. It is bounded by the investor's technological capacity. In fact, the upper boundary for exploration investment is contingent on the past exploration efforts and outcomes. As described in the classic technological learning model (Yelle, 1979[64]), exploration technology capacity A_{ij} (i.e., exploration investment required to successfully drill another new well), as shown in Formula 5.7, can be expressed as an exponential function of historical exploration investments.

$$A_{ij} = k\left(\sum_{j}^{J-1} e_{ij}\right)^{\frac{\log(\emptyset)}{\log(2)}}$$

(Formula 5.7)

Note: the current year's technological capacity, measured as the unit exploitation cost, is an exponential function of the cumulative exploration investments of previous years.

Here $\emptyset$ is the technological learning rate. In one meta-analysis, McDonaldand Schrattenholzer (2001)[65], found that the estimated learning rate for oil extraction in the North Sea is approximately 25%[xxx].

Further, under certain circumstances, multinational companies also tend to partner with each other to conduct joint research and exploration. This is especially true for the highly uncertain and costly exploration initiatives. For example, Chevron, ConocoPhillips, ExxonMobil, and Shell together committed over $ 1 billion for deep-water operation platform exploration. Likewise, in 2010, Chevron China affiliates partnered with CNOOC in the exploration projects in the South China Sea's Pearl River Mouth Basin (*Chevron Press Release, 2010*[66]). Admittedly, under most other circumstances, companies would rather initiate exploration projects independently, in order to appropriate technological property and gain technological edges for the future.

Thus, the upper limit of exploration investment of the companies will be also contingent upon their choices for exploration collaboration or competition. If companies choose to collaborate, then the exploration investment (e_{ij}) for companies from both countries are the same and equals to the sum of the Chinese and U.S. investments in the region, i.e.,

$$e_{ij} = e_{ij}^{CN} + e_{ij}^{US}.$$

Conversely, if companies (U.S. and Chinese oil companies) choose to compete (develop independently), their exploration investment are dependent only upon their individual historical exploration investment in this region. i.e.

$$e_{ij} = \begin{cases} e_{ij}^{CN}, \ for\ Chinese\ NOCs \\ e_{ij}^{US}, \ for\ the\ U.S. MNCs \end{cases}.$$

In section 5.3(sensitivity analysis section), this study will compare the different outcomes under the collaboration and the competition scenarios.

Here, $\sum_{j}^{J-1} e_{ij}$ represents cumulative exploration and development investments of the past periods. Accordingly, the current year's exploration capacity E_{ij} should be a function of technological capacity A_{ij}, labeled as $E_{ij} = \varphi(A_{ij})$. Here $\varphi(.)$ is the inverse function of

xxx Note: The learning rate is defined as unit costs decrease by a constant percentage, called the learning rate, for each doubling of experience. In this context, when the cumulative investments double, the exploration cost decrease by 25%.

exploration technology capacity as illustrated in the above Formula 5.7. Apparently, $\varphi'(A_{ij}) > 0, \varphi''(A_{ij}) < 0$. To simplify, in this research, the explicit form of the exploration potential function $\varphi(A_{ij})$ is as follows:

$$E_{ij} = \varphi\left(k(\sum_j^{J-1}(e_{ij}))^{\frac{\log(\emptyset)}{\log(2)}}\right) = \frac{(\sum_j^{J-1}(e_{ik}))^{\frac{\log(\emptyset)}{\log(2)}}}{J-1};$$

(Formula 5.8)

- *Demand, supply, SPR and the price function*

The three factors (demand, supply and SPR) affect the objectives not only by determining the cost functions and production capacity limits, but also by influencing sale prices.

First, increased supplies (thanks to EODI production) contribute to the increase of oil supplies in the two countries respectively. This further creates imbalance between supply and demand, and could lead to price fluctuation. In turn, the domestic oil demands also respond to fluctuating prices in the long run. In several research studies, such interactions between oil prices and demand have been modeled. In particular, EIA developed two versions of revenue function through a system of *EIA Oil Market Simulation Model*[xxxi], which considered estimations of world oil market prices and demand from 1979 to 2010 in all major market economies. In another research study, Dées and Karadeloglou (2007)[67] modeled oil demand as a log-linear function of real oil prices amongst other major factors (real GDP, and technical change rates).

In addition, the State government's Strategic Petroleum Reserve (SPR), as the leading oil inventory, also influences the oil pricing markets. Historically, since the oil crisis in the 1970, almost every U.S. SPR release or purchase decision led to either spikes or falls in oil prices.

Therefore, considering both the impacts on price of EODI supplies and the SPR policies, a theoretical framework for price function can be defined as following Formula 5.9:

$P_{ij} = g(D_{ij}, S_{ij}, SPR_j) = g(D_j^{US}, \sum s_{ij}^{US}, SPR_{j\_US})$….(U.S. price function)

$P_{ij} = g(D_{ij}, S_{ij}, SPR_j) = g(D_j^{CN}, \sum s_{ij}^{CN}, SPR_{j\_CN})$….(China price function)

xxxi Access: http://catalogue.nla.gov.au/Record/1001077

(Formula 5.9)

Here, $\frac{\partial P_{ij}}{\partial s_{ij}} < 0, \frac{\partial P_{ij}}{\partial SPRj} > 0.$

--D_j^{US} D_j^{CN} is domestic demand from US and China in year J respectively;

--$\sum s_{ij}^{US}$, $\sum s_{ij}^{CN}$is the aggregate EODI production in the U.S. and China respectively from all the foreign wells in year J;

$-SPR_{j_{US}}$,SPR_{j_CN} is the SPR volume of U.S. and China in year J respectively.

In this analysis, the study will use the Formula 5.9 as the rationale foundation for the purpose of sensitivity analysis of these three factors (supply, demand, and SPR policy) in the section 5.3.4.

However, for the purpose of efficient equilibrium calculation, instead of providing an explicit form for the g(.) function, the study processes the historical price data based on the *Moving Average method*[xxxii] to predict future global oil prices in the steady state analysis(*Formula 5.10*).

$$P_{ij}=(0.6 \times P_{i,j-1} + 0.3 \times P_{i,j-2} + 0.1 \times P_{i,j-3}) + \Delta\pi$$ [xxxiii]

(Formula 5.10)

where, $\Delta\pi$: is maximum likelihood estimate from fitting historical data to the moving average regression model (1977-2009).

This simplifying method is valid given several considerations: (1) despite the development of oil market simulation models including the above-mentioned EIA and Dées and Karadeloglou model, thus far none has claimed accurate oil price predictions in the middle-to-long term. Further, the diversity of global oil market stakeholders (Kaufmann, R.K.,Dees, S., Karadeloglous, P.,Sanchez, M.,2004) [68] set further barriers to accurate price oil predictions; (2) the demand is less elastic to price fluctuation in in the short run, which is also the time frame of

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xxxii Note: A moving average is commonly used with time series data to smooth out short-term fluctuations and highlight longer-term trends or cycles. It is often used in economics including projecting the trend of price data. Mathematically, a moving average (3 year intervals) is a type of convolution and so it can be viewed as an example of a low-pass filter used in signal processing.

xxxiii Notes: the weights are chosen based on experiences and historical observation. However, the variation of the weights can be discussed through sensitivity analysis.

this study. Therefore, observation and historical regression could be used a solid approach to predict prices for the purpose of this study.

- *α-factor: the discount effect of investment environment factors*

Aside from the variables discussed above, other variables, measuring the EODI environment in both the host and investing countries, also affect the outcome of the profit objectives. According to several research studies (Dunning, 1980; Loree and Guisinger, 1995; Tsai, 1994; Dunning, 1994), the most influential variables for the EODI environment in the host countries are: the political stability of the host countries, openness to foreign direct investment, and the infrastructure development level. Besides, in the context of China—the investing country, the NOCs are required to go through a lengthy administrative approval process. And as more Chinese state businesses began "going out", the approval process becomes increasingly complicated and takes even longer time (*Sohu Finance, 2012*[69]). As a result, the time delay for EODIs by Chinese NOCs, might have reduced the effect of initial production, exploration and sale decisions on the final payoff, as represented in the utility objectives. In a nutshell, this study introduces the parameter of α-factor--a discount ratio to represent the bundled effects of both the effects of EODI environment in the host and investing countries.

5.2.5 Operationalize constraints

- *Basic Constraints: Technology, demand, supply, storage, and exploitation capacity*

As elaborated in the previous section, the technology, demand, supply, stock, and exploration capacity of both the Chinese NOCs and the U.S. IOCs are constrained by certain capacity thresholds. The following inequality formula systems summarize all these basic constraints: (Formula 5.11) for U.S. IOCs and Formula 5.12 for Chinese NOCs.

$$
\begin{cases}
I_{ij} = e_{ij}^{US} \le E_{ij}^{US} = \varphi(A_{ij}) = \varphi\left(k(\sum_{j}^{J-1}(e_{ij}^{CN} + e_{ij}^{US}))^{\frac{\log(\emptyset)}{\log(2)}} \right) \\
s_{ij}^{D} + s_{ij}^{G} = S_{i,j-1} + p_{i,j} - S_{i,j} \\
S_{i,j} > S_{j\_low} \\
p_{i,j} \le PC_{ij} = f\left(\sum_{k}^{j-1} p_{ik}, \sum_{k}^{j-1} e_{ik} \right) \\
P_{ij} = g(D_{ij}, S_{ij}, SPR_j) = g(D_{ij}, s_{ij}^{CN} + s_{ij}^{US}, SPR_j)
\end{cases}
$$

(Formula 5.11)

$$
\begin{cases}
I_{ij} = e_{ij}^{CN} \le E_{ij}^{CN} = \varphi(A_{ij}) = \varphi\left(k(\sum_{j}^{J-1}(e_{ij}^{CN} + e_{ij}^{US}))^{\frac{\log(\emptyset)}{\log(2)}} \right) \\
s_{ij}^{D} + s_{ij}^{G} = S_{i,j-1} + p_{i,j} - S_{i,j} \\
S_{i,j} > S_{j\_low} \\
p_{i,j} \le PC_{ij} = f\left(\sum_{k}^{j-1} p_{ik}, \sum_{k}^{j-1} e_{ik}, UOM \times p_{ij} \right) \\
P_{ij} = g(D_{ij}, S_{ij}, SPR_j) = g(D_{ij}, s_{ij}^{CN} + s_{ij}^{US}, SPR_j)
\end{cases}
$$

(Formula 5.12)

- *Additional Constraints*

While the basic constraints bound the choices of the corporate decision makers, the additional constraints embody the fluctuation range of exogenous environment variables, which may also impact the outcome of objectives.

Typical exogenous environment variables, as described in the Section 5.2.4, include hosting country environment variables (openness, political stability, and infrastructure development levels) and investing country environment variable (approval process efficiency, in the special case of Chinese NOCs). Overtime, these exogenous environment conditions will also change. Some environment variables, if changed, may even have a cut-off effect on the profit outcome. For example, if the Chinese government repeals the administrative approval process, the discount factor attribute to this process will immediately rise to 1.

In addition, other exogenous environment variables, indicative of policies or legislations on international trade or domestic energy regulations (though not directly imposed on FDI), may also impact the final outcome of profits and the aggregate utility. For the EODIs in the U.S., these non-FDI environment effects may come from: (1) the legislation stipulating the maximum and minimum federal SPR volume; and (2) the upper and lower limits of price subsidies for imported oil sales. Similarly, for the EODIs in China, these non-FDI environment effects mainly come from the regulation on annual import quotas.

5.3 Analysis and Outcomes

5.3.1 Analytic Method: Iterative Simulation and Data Preparation

- *Iterative Simulation*

To solve the equation systems, the study uses a dynamic simulation method. The study begins by identifying its major components including the actors, objectives, instruments, constraints, and major assumptions. The study then integrates these components into the partial equilibrium model. The Appendix displays the model system for Chinese and U.S. EODIs, and their interactions. After these preparations, the study conducts the dynamic simulation processes in the following steps:

- *Step 1: Based on the U.S. historical data, initiate a preliminary set of estimates for all the values of all U.S. decision variables;*
- *Step 2: Contingent upon the step 1 setup for the U.S., calculate the optimal value for the Chinese model; record the values of all the Chinese decision variables;*
- *Step 3: Contingent upon the step 2 setup for China, calculate the optimal value for the U.S. Model; record the values of all the U.S. decision variables;*

- *Step 4-n: reiterate the step 2 and step 3 processes until the changes of both model results are smaller than certain specified limits;*
- *Step n+1: step n will be the simulated steady state. Record all the dynamic processes of the variable values (including the steady state).*

The software used for this simulation is MATLAB. The coding is completed with the close collaboration of a programmer, also the author's brother, Guobao (Oscar) Feng. The programmer's roles include compiling the code, debugging, running codes, and sending the raw outputs to the author for further analysis. The author's roles in this process include preparing parameters and variable initial values, communicating the iteration methods, sorting the constraint and objective function matrices and vectors, confirming the logics of the code by walking through the codes with the programmer line by line, and annotating the final codes. The author is also responsible for sorting, analyzing, and visualizing data based on the raw outputs.

This simulation method, in the process of calculation, has both advantages and disadvantages in terms of algorithm rigor, feasibility, and policy implications. The advantages and disadvantages of this method can be summarized as follows:

- *Advantages*

The simulation clearly reflects the interactive process (gaming) between the U.S. and Chinese businesses in EODI markets;

The trajectory of the U.S. and China variables provides important evidence for understanding the inner drivers of competition and cooperation for the two countries;

- *Disadvantages*

This method is flawed because, in the simulation process, the U.S. and Chinese stakeholders do not respond simultaneously: in this model, Chinese oil firms respond after the U.S. oil firms make their corporate strategies (production, sale, storage, etc). However, this disadvantage may be offset by the fact that the major Chinese NOCs decisions may see a time delay due to the lengthy administrative process, and thus respond more slowly than the U.S. IOCs.

- *Data Preparation*

Table 5.3 below describes the sources of data, the metrics referenced in each of the databases, a brief assessment of the data quality, and how the data are used for the purpose of the analysis.

Table 5.3 Major Data Sources, Metrics, Quality, and Use

Database	Metric(s)	Type	Use
EIA FRS Survey	Form EIA-28 Schedule 5211 - Petroleum Segments Expenditure & Operating Expenditure	Government Census	U.S. Overseas historical investment, production, sales, exploration
	Form EIA-28 Schedule 5246- Petroleum Segments		
Heritage Foundation	China Overseas Investment Tracker	NGO Survey	China Overseas historical investment, production, sales, exploration
Statistical Bulletin of China's Outward Foreign Direct Investment	China Outward Direct Investment Directory	Government Report	China Overseas historical investment, production, sales, exploration
IEA Energy Prices and Taxes Statistics	Spot market and crude oil import costs	International government Database	Region-specific oil sales price projection
	IEA - Crude oil import costs by type of crude		

5.3.2 Equilibrium Analysis

This part of analysis discusses the interactive process of U.S. and Chinese oil companies towards steady state, for the short term (5 years), midterm (10 years) and long term (15 years), in order to understand how they react to each other's investment behaviors.

The major conditions are as follows: (1) Chinese NOCs currently follow a strategy of balancing between profitability and resource domination, whereas the goal of the U.S. IOCs has been to maximize the aggregate profitability; (2) the U.S. and Chinese oil companies conduct exploration activities respectively; and (3) their exploration payback period is set at one-year, meaning both invest only in the low-risk exploration activities. All the exogenous conditions such as the investing countries' regional stability and openness to foreign investment remain unchanged over time.

- *Profitability*

Figure 5.2 describes the model calculation of average annual profit. In this model system, both the profits from the U.S. and Chinese EODIs estimates are raw profits (i.e. "operating income"), excluding deductions from corporate income taxes, non-operation depreciations and other asset liabilities. As elaborated previously in section 5.2.2, the study uses two proxies to model the resource domination goals of Chinese EODI, i.e., cumulative investments and cumulative production capacity value. The results regarding the optimal values of the endogenous variables (decision variables) are not significantly different from each other. Henceforth, the following analysis only discusses the results of the models using the proxy of resource value flows.

In terms of the overall profitability, if planned for the period 2011-2015, as shown in Figure 5.2, the average annual profits of the U.S. EODI operation will reach \$ 116 billion or 24.8 % of their total annual profits (operating income) in 2009[xxxiv]. During the same period, the average annual profits of the Chinese EODI operations will reach \$65 billion or 15 % of their profits

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xxxiv Note: according to EIA (2011) report (or EIA Form 28 Survey Summary Table 5), the U.S. FRS oil companies earned a total raw profit (operating income) of \$ 467 billion from all their operations (2009 dollars).

(operating income) in 2009[xxxv]. Furthermore, if planned for longer periods (2011-2020, 2011-2025), both the average annual profits of the U.S. and Chinese EODI operations will increase: (1) in the medium term, the annual profits from U.S. and Chinese EODI operations will increase to $ 140 billion(+20%) and $ 86 billion(+32%) respectively; and (2) in the long-term, the annual profits from U.S. and Chinese EODI operations will increase to $ 199 billion(+ 72 %) and $ 144 billion(+121 %) respectively.

In terms of regional profitability trends, both the U.S. and Chinese EODIs will see steady growth in the short, medium and long run. Africa will be the most profitable future EODI region for both U.S. and Chinese EODIs. For this region, in the short-term (2011-2015), Chinese and U.S. oil firms will earn a total profit of $ 21 billion and $ 39 billion per year; in the medium term (2011-2020), Chinese and U.S. oil firms will earn $ 28 billion and $ 46 billion per year; in the long-term (2011-2025), Chinese and U.S. oil firms will earn $ 45 billion and $ 63 billion per year respectively.

In addition, EODIs in OECD-Europe, OEH and Canada also turn outs to be moderately profitable for both the U.S. and China. However, the profits of Chinese EODI operation in Europe should be interpreted with caution, due to the limitations of the model setup. In the model setup, due to lack of Chinese historical EODI operation data, the starting year production capacity of Chinese EODIs are imputed in this way: multiplying the China/US EODI ratio (exploration and development investment in 2009) by U.S. historical operation data by region[xxxvi].

By contrast, in the FSU and East Europe, and Middle Eastern[xxxvii] countries, home to the richest and easy-to-access oil reserves in the world, companies from both countries find it hard to make profits out of EODI operations. For example, under the best scenario (planning for the long-term), the U.S. and Chinese oil firms will only achieve a total annual profit of $ 21 billion

xxxv Note: by aggregating the annual operating income of the three Chinese NOCs (data from their annual reports), the Chinese oil companies earned a total raw profit (operating income) of $ 442 billion dollars (current exchange rate: 1 USD=6 RMB).

xxxvi Note: the accuracy of the simulation of Chinese EODIs in Europe can be improved by obtaining further information in: Chinese marginal productivity of EODI (exploration and development) in Europe.

xxxvii Note: In FSU& East Europe and Middle East, there are world’s single biggest reserve countries, Russia, Saudi Arabia, UAE, Iran, Kazakhstan, and so on.

and $ 13 billion in the two regions together. This, as elaborated in section 4.3, can be explained by the fact that these countries are not open to foreign investments, especially in the energy sectors, in which the State governments claim ownership to energy resources.

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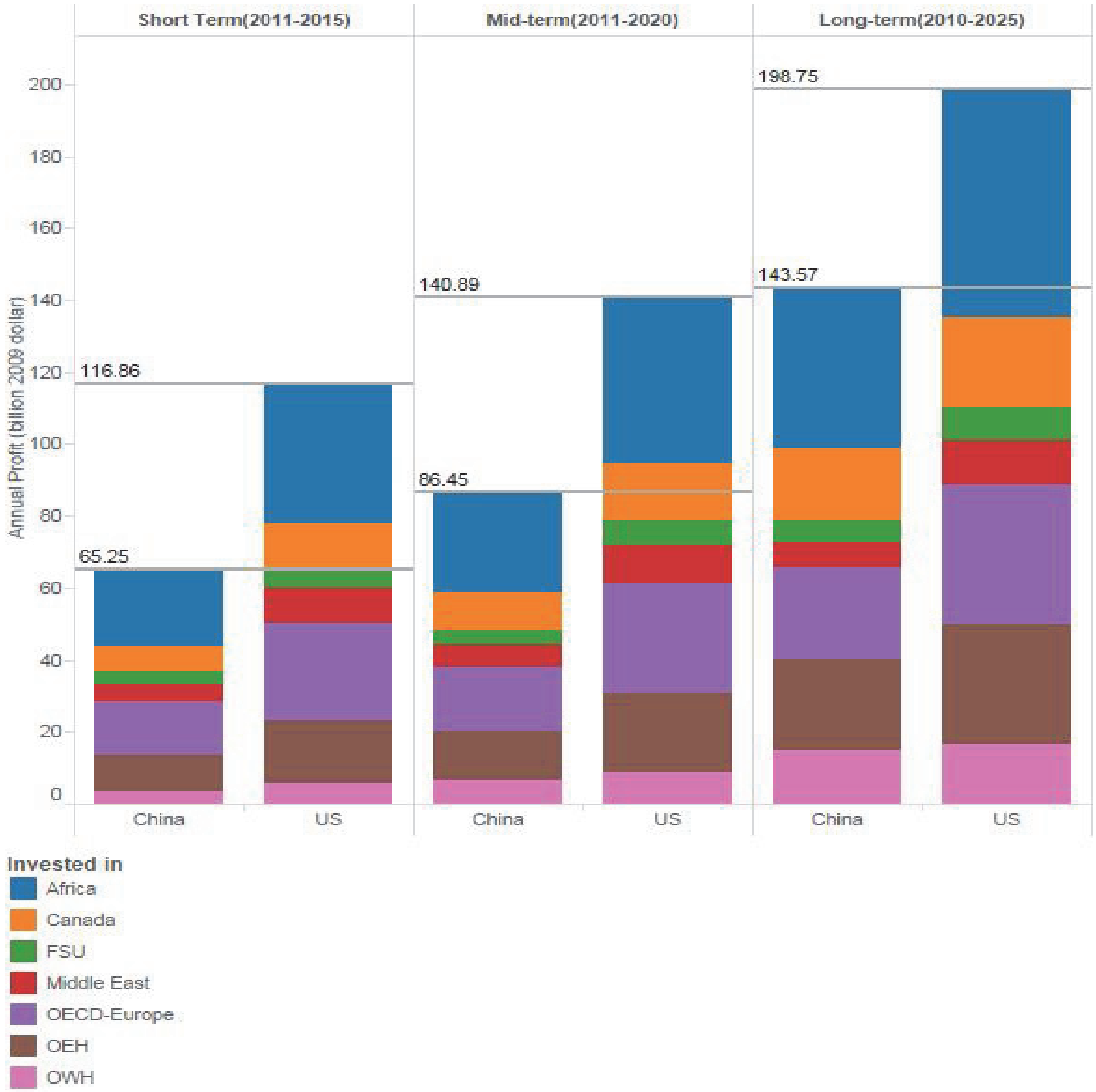
Figure 5.2 Annual Profits* for the U.S. and Chinese EODIs at different operation planning scenarios



SOURCE: Model Calculation

* The profits in this context are only counted as raw profits, excluding tax deductions, non-operation depreciation and asset liabilities. In other words, the profits in this context is "operating income".

In terms of the comparative advantages, the Chinese and U.S. profit ratio (the total Chinese NOC profits relative to the total US IOC profits) will range from 56 %(in the short term) to 72 % (in the long term). This may be explained by the fact that Chinese EODIs are expanding faster than the U.S. oil firms, and thus will see an increasing growth of profits.

To summarize, both countries will earn higher annual profits in the longer term, as they expand EODIs. Meanwhile, the profits of Chinese EODI operations will grow faster than the U.S. oil firms. In terms of EODI locations, Africa will become the most profitable destination for both U.S. and Chinese EODIs in the short, mid and long term. By contrast, in other regions with rich and easy-to-access oil but restricted market access,--the Middle East and FSU countries, both countries can only expect limited growth in profits of EODI operations.

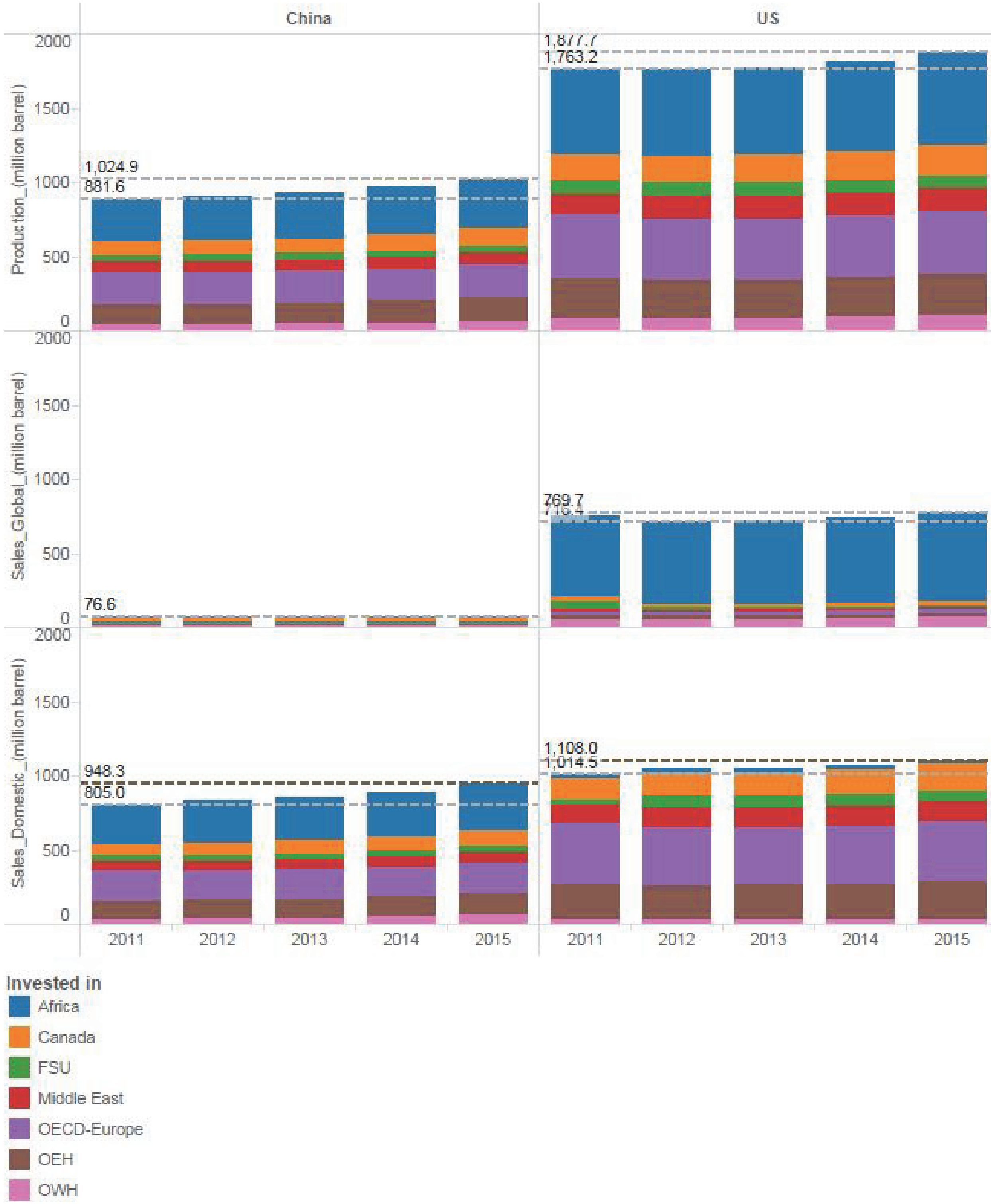
- *Production, global and domestic sales*

Figure 5.3, 5.4, and 5.5 show the results of steady states for the short-term, medium term and long-term operational strategies (production, global and domestic sales) for the Chinese and U.S. EODI operation respectively.

In the short term, both U.S. and Chinese production (Figure 5.3) from EODI operation will keep a slow and yet steady growth: Chinese EODI production will increase from 881 million barrels in 2011 to 1,025 million barrels (+3.85%/year) in 2015; U.S. EODI production will increase from 1,763 million barrels in 2011 to 1,878 million barrels in 2015(+1.59%/year). If compared with their domestic production in 2011, both the Chinese and U.S. EODIs can supply up to 50% of their domestic production.

The sale strategies of the U.S. and Chinese EODI outputs, however, will differ greatly. As shown in Figure 5.3, U.S. and Chinese companies will choose opposing strategies in terms of sales destinations. On average, the U.S. companies will sell approximately 40% of their annual production in the global market, and the rest directly to the U.S. By contrast, the sales of Chinese EODI production almost entirely (> 90%) supply the domestic market. These conclusions also concur with the observations of historical sales of Chinese EODI outputs (Downs, 2010[70]). This result further suggests that economic factors are important drivers for Chinese EODIs. As shown in the previous Figure 4.6, the oil lifting cost in China is higher than most other regions in the world.

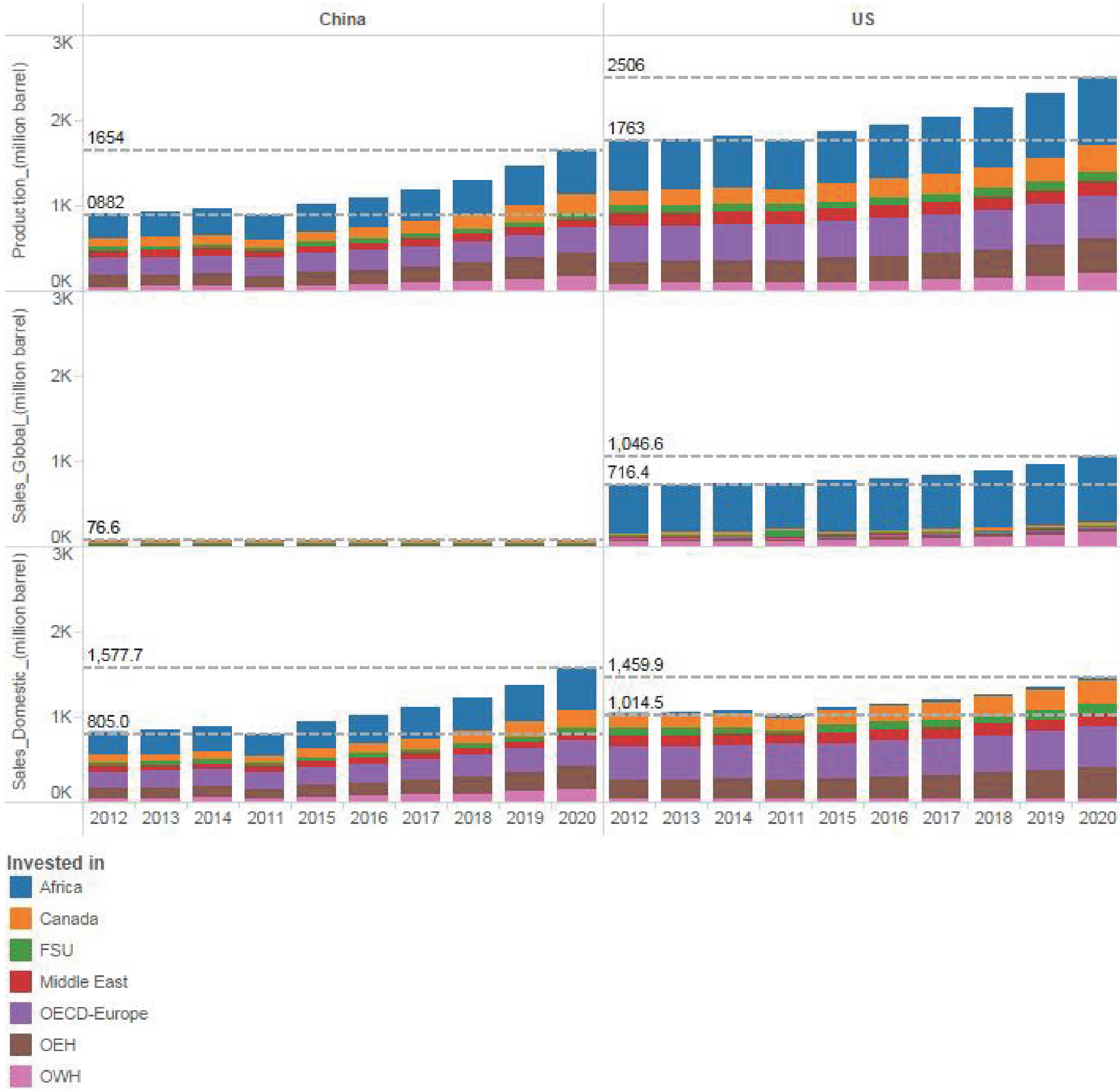
Figure 5.3 Productions, Sales to Domestic market, Sales to Global market: Short Term Scenario



Source: Model Calculation

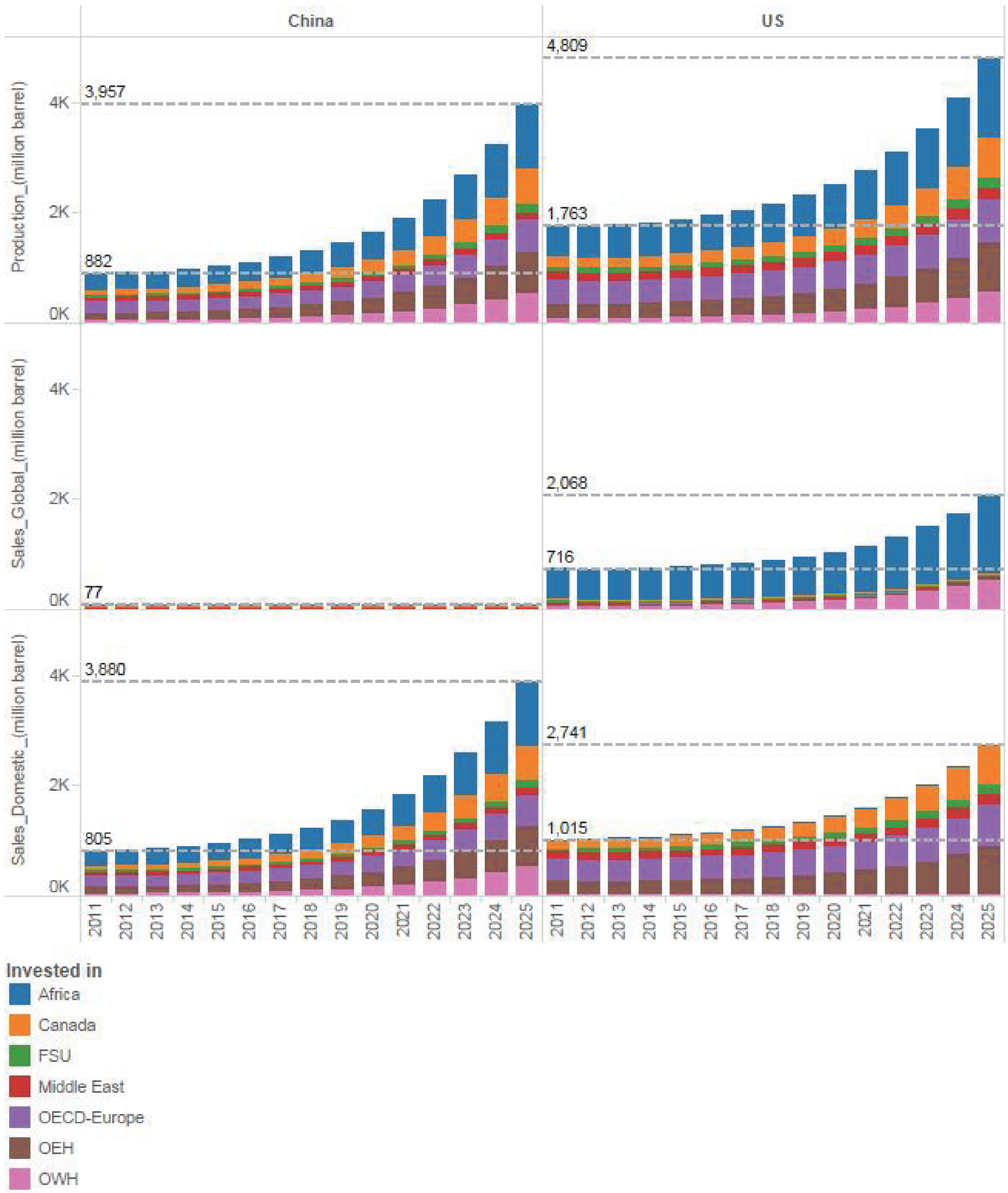
In the medium and long-term, the U.S. and Chinese companies use production and sales strategies similar to the short-term scenario. As shown in the following Figure 5.4 and Figure 5.5, both U.S. and Chinese production from EODI operation will maintain a slow and yet steady growth: (1) Chinese annual production will increase to 1,654(+6.5%/yr) and 3,957(+10.5% /yr) million barrels in 2020 and 2025; and (2) U.S. annual production will increase to 2,506(+3.5%/yr) and 4,809(+6.9%/year) million barrels. In terms of sales destinations, they both target their domestic markets over international sales. And yet, over time, the U.S. will sell increasingly bigger portions of its EODI production in the global markets. In the long term, the portion of U.S. EODI production sales in the global market will increase from 40% in 2011 to 43% in 2025. By contrast, Chinese oil companies tend to sell increasingly bigger portions of its EODI production directly to China. In the long term, the portion of the direct sales to China will increase from 91% in 2011 to 98% in 2025.

Figure 5.4 Productions, Sales to Domestic market, Sales to Global market: Mid Term



Source: Model Calculation

Figure 5.5 Productions, Sales to Domestic market, Sales to Global market: Long Term



Source: Model Calculation

- *Exploration Investment*

In this model, as explained in the decision variable setup section (Section 5.2.3), the exploration investment decisions of the two countries could affect the final operation and profitability outcomes in two aspects. On one hand, the U.S. and Chinese exploration investments in a certain region decides the future maximum exploration volume (exploration capacity) of this region. On the other, the U.S. and China conduct independent exploration activities in the region. Therefore, their production capacity in the region is determined by their exploration decisions, independent of each other's exploration decisions. The model calculation outcome for the short-, medium, and long term exploration investments are exhibited in the following Figures 5.6, 5.7, and 5.8.

For all the scenarios, in the steady state, the U.S. and Chinese oil companies will invest the same amount on exploration in the short-, medium, and long-term. This could be explained by two facts: (1) the exploration capacity in a region is a function of the aggregate historical exploration investment of the U.S. and China together[xxxviii]; (2) the marginal productivity of exploration (λ) is the same in the U.S. and Chinese EODI[xxxix].

Over time, according to the model results, both U.S. and Chinese companies will expand their exploration investment. In the short run, each country's firms will increase their annual exploration investment from $ 9 billion in 2011 to $ 18.7 billion (+27%/yr) in 2014; in the medium term, each country will increase their annual exploration investment to $ 68.8 billion (+29%/yr) in 2019; in the long-term, each country will increase their annual exploration investment to $ 252 billion (+29%/yr).

In terms of the profit/exploration

xxxviii Note: At steady state of Cournot equilibrium, all the parties will invest the same amount, and earn equal marginal benefits out of investments. Therefore, the results of exploration investment will concur with cournot equilibrium steady state: both the U.S. and China spending the same amount in exploration in each region.

xxxix Note: this model assumes that for example, once a company wins an EODI bid, they could hire the best available technology contractors to conduct the exploration activities. Therefore, the marginal productivity of exploration is the same across EODI investors. In practice, for example, in 2013, CNOOC (Chinese NOCs) actually contracted oil exploration activities to BP in Block 54/11 in Pearl River Mouth Basin of South China Seas. http://www.pennenergy.com/articles/pennenergy/2013/07/cnooc-signs-offshore-exploration-contract-with-bp.html ratios, Table 5.4 summarizes the Profit/Exploration ratios (can be interpreted as marginal profit of exploration) for the short-, medium, and long term. It (Table 5.4) shows Profit/Exploration ratio tends to decrease over time for both the U.S. and China, which concurs with the law of decreasing marginal benefit of investments. It is also apparent that the U.S. profit/exploration ratio is higher than that of China. Over time, the difference in profit/exploration ratio will narrow. Specifically, in the short term (2011-2015), the U.S. profit/exploration ratio (10.8) is 1.74 times of Chinese counterpart (6.2). In the mediumterm (2011-2020), the profit/exploration ratio of U.S (5.2) lowers to 1.63 times of Chinese counterpart (3.2). And in the long term, the profit/exploration ratio of U.S.(2.8) further lowers to 1.4 times of Chinese counterpart(2.0).

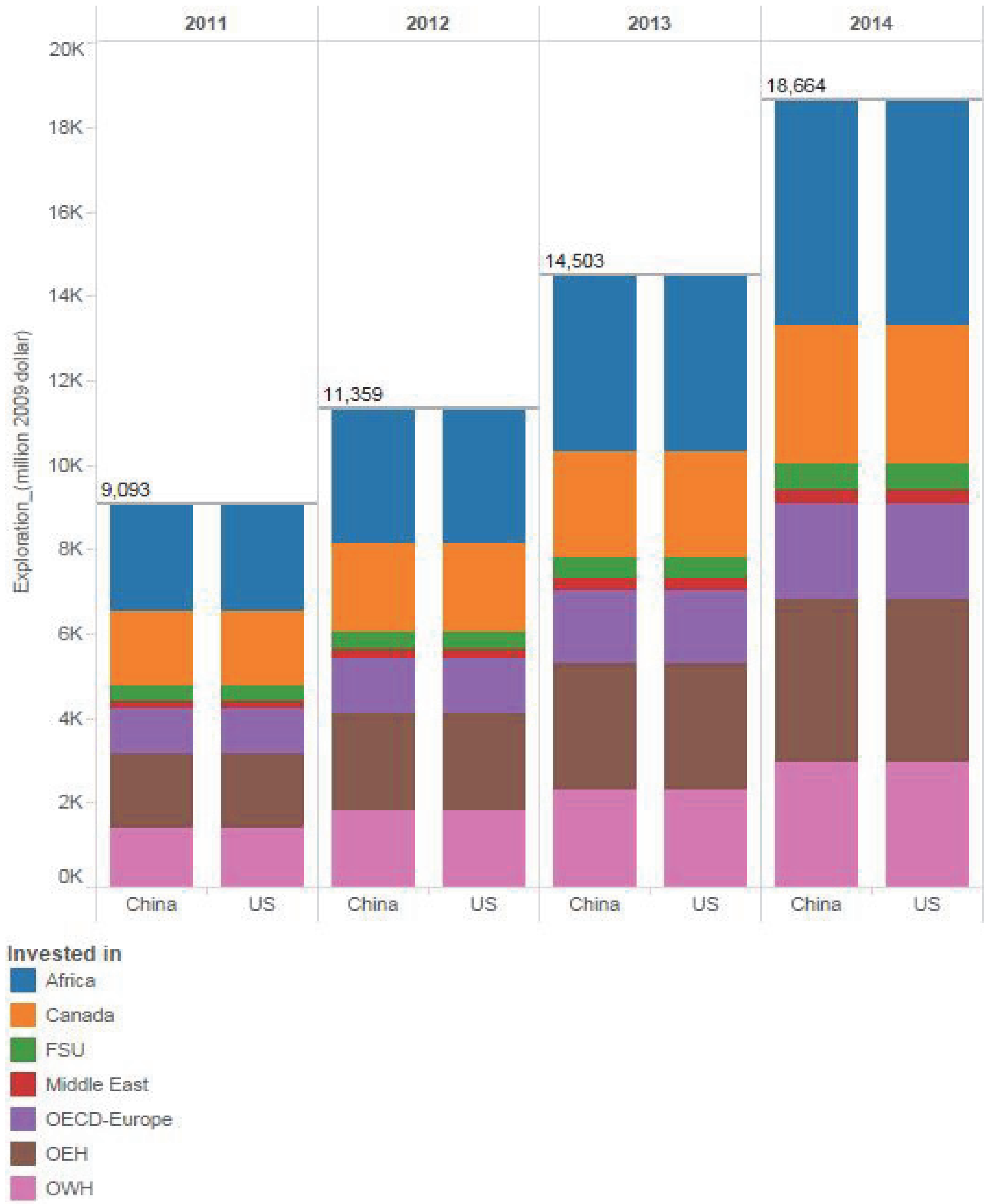
Last but not least, it should be very interesting to compare this estimate with the overall global exploration performance. According to EIA (2011), as of 2009, the total annual profits of all the FRS companies reached $ 30 billion, with a total exploration & development expenditure of $88 billion ($ 71 billion of production, $ 17 billion of exploration), thus the Profit/Exploration ratio of EODIs is approximately 2. Therefore, during all the time periods in discussion of this study, the overall exploration efficiency (Profit/Exploration &Development Ratio) is greater in the foreign markets than in the domestic market.

Table 5.4 Profit /Exploration & Development Ratios of the U.S. and Chinese EODIs

Profit/Exploration & Development Ratio / Period	U.S.	China
2011-2015	$ 584 billion ÷$ 53 billion= 10.8	$ 326 ÷$ 53 billion= 6.2
2011-2020	$1408 billion ÷$ 272 billion= 5.2	$864 billion ÷$ 272 billion= 3.2
2011-2025	$ 2995 billion ÷$ 1074 billion= 2.8	$ 2158 billion ÷$ 1074 billion= 2.0

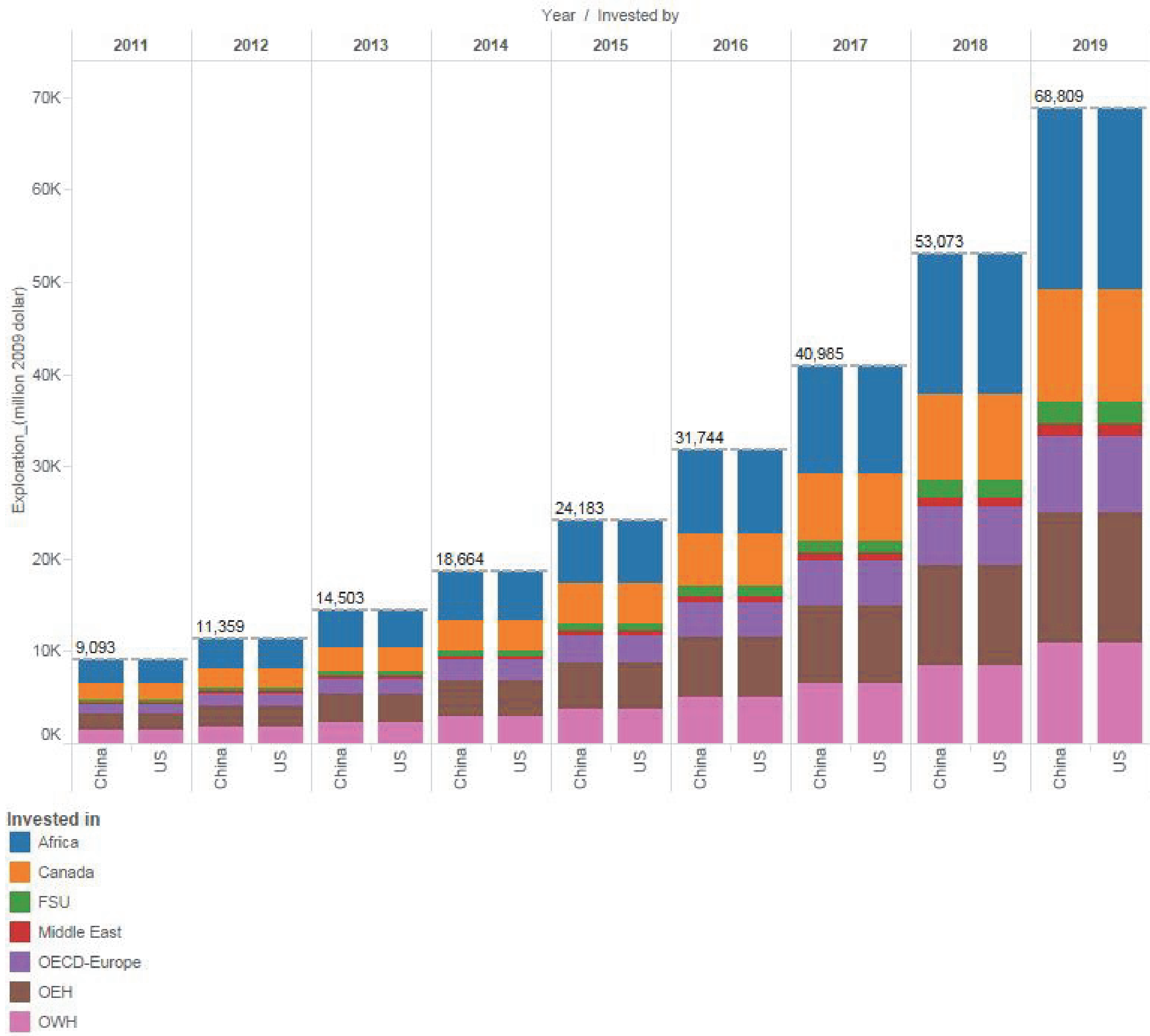
SOURCE: Model Calculation

Figure 5.6 U.S. and Chinese EODI exploration and development investments: the short-term



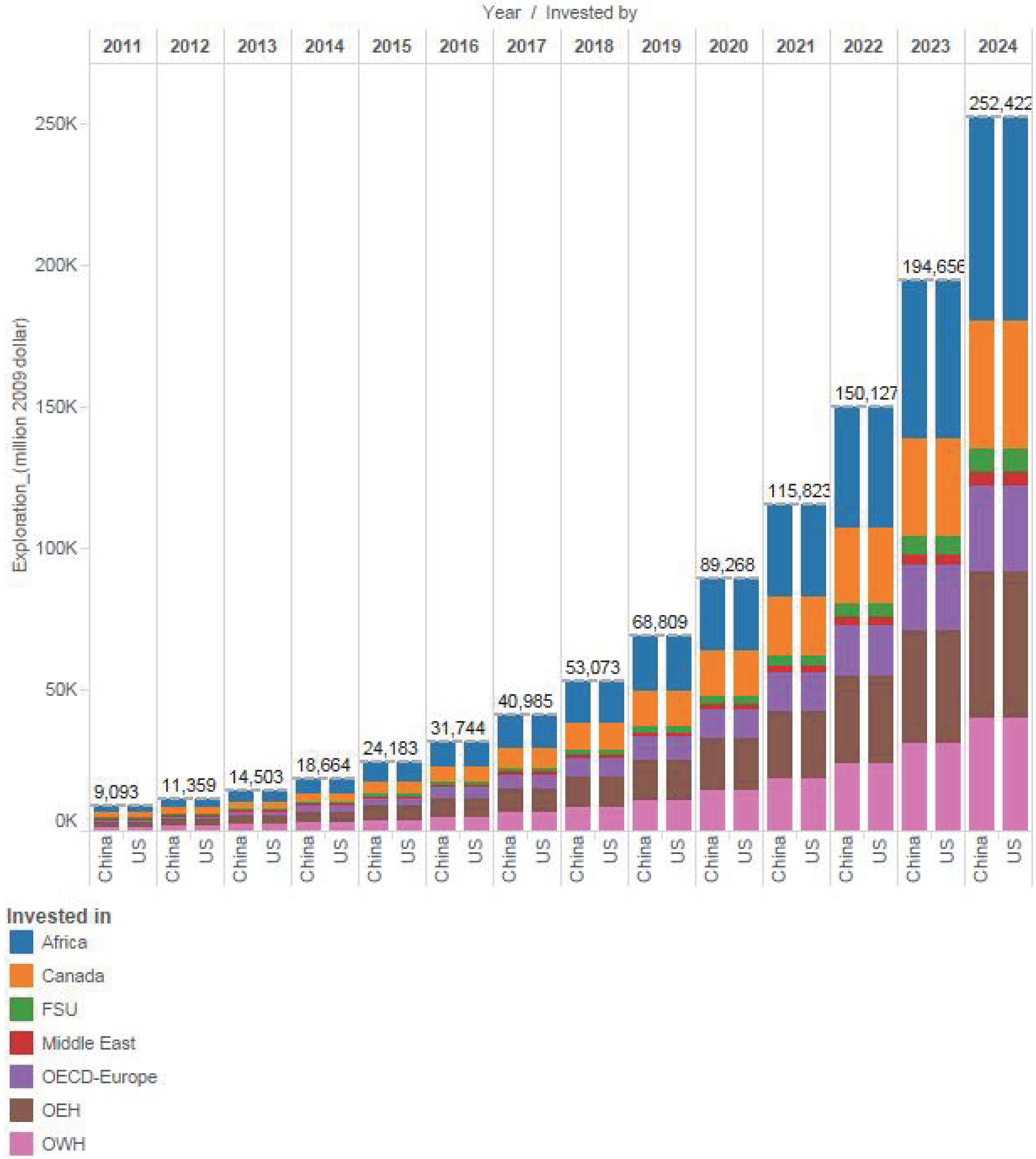
Source: Model Calculation

Figure 5.7 U.S. and Chinese EODI exploration and development investments for the medium term planning



Source: Model Calculation

Figure 5.8 U.S. and Chinese EODI exploration and development investments for the long-term planning



Source: Model Calculation

5.3.3 Sensitivity Analysis: A special look at system factors in Africa and the Middle East

In the previous section 5.3.2, the study has summarized the steady states and has explained their future trends in all regions. Further, the study determines that, for Africa and the Middle East, they require special discussion of the case in which the certain conditions outside the system change. This is because the two regions are similar in some dimensions, such as resource potential and stability status, but are very different in others, such as openness to investments, and technological requirements and availability. As a result, future EODIs in the two regions is sharply different: Africa is projected to become world's largest EODI destination, whereas the Middle East is projected to host much less smaller potential for EODI. In this consideration, study in this section will conduct a sensitivity analysis for these two regions in particular, observing if the evolution of certain environment factors (such as openness, stability, SPR policies) or system factor (such as technology choices and competitive strategies) will reshape the comparative advantages of investments in the two regions.

- *Technology Choice: exploration efforts in long payback or short payback technologies*

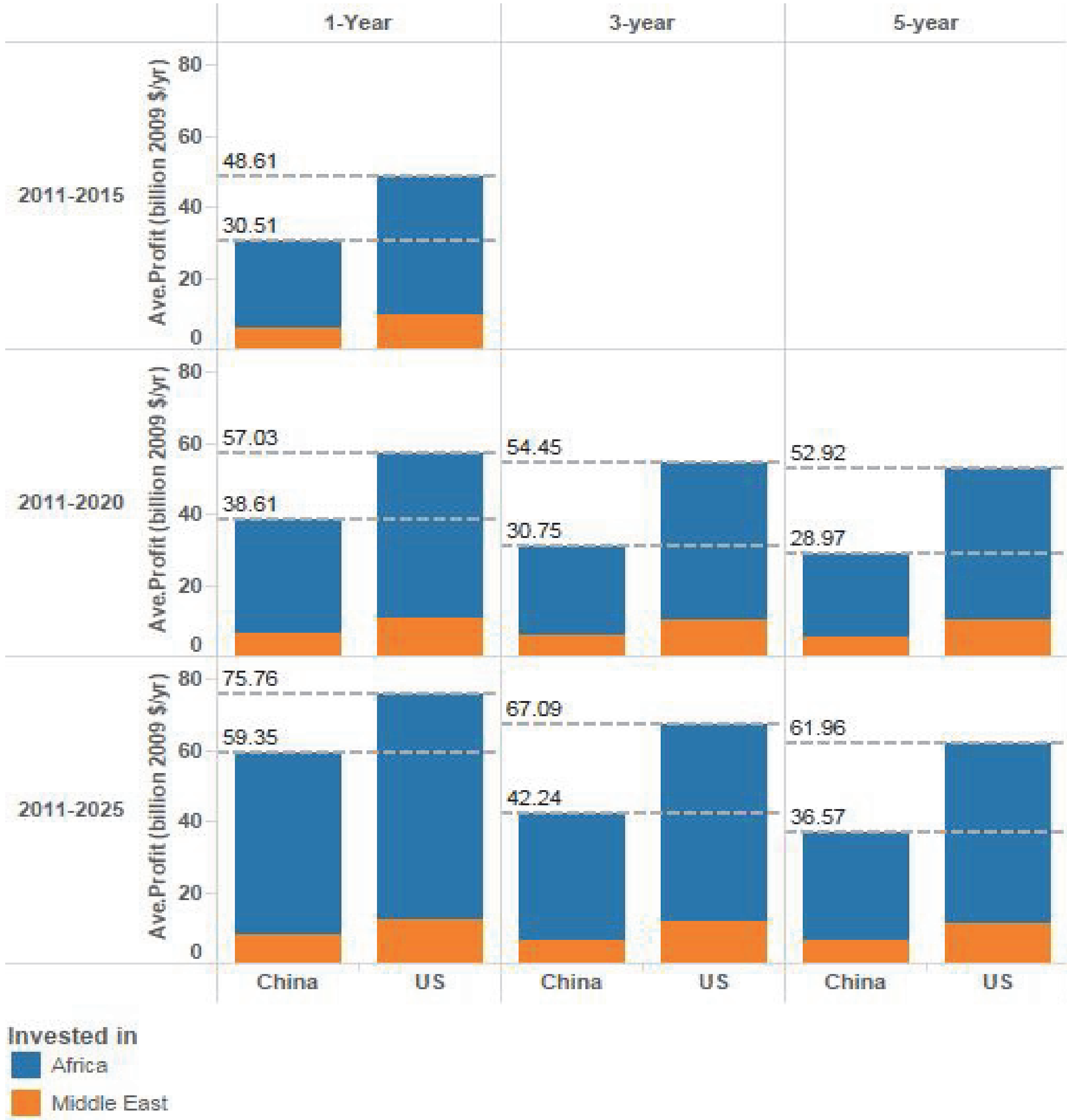
In the default setup, all companies invest only in one-year payback exploration activities, which, as shown in table 5.1, are the field testing components of basic exploration work. But as with investment in domestic wells, the U.S. and Chinese companies can choose to invest in more sophisticated exploration endeavors, which have longer payback periods. Therefore, I also considered two typical advanced exploration scenarios, as depicted in Table 5.1: 3-year payback exploration activities and 5-year payback exploration activities. The outcomes of all the two new scenarios can be found in the Figure 5.9 and Table 5.5.

First, as shown in Figure 5.9, investment in more advanced exploration activities (3-year payback and 5-year payback) will reduce the annual profitability performance of both the U.S. and Chinese EODIs. And the decline in profits is more apparent in Africa than in the Middle East. In the medium term (2011-2020), if switched to 3-year payback and 5-year payback exploration activities, the U.S. EODI annual profit in the two regions will reduce from $ 57 billion to $54 billion(-4.5%) and 53 billion(-7.2%) respectively. Similarly, if switched to 3-year payback and 5-year payback exploration activities, the Chinese EODI annual profit in the two regions will reduce from \$ 39 billion to \$ 31 billion(-20%) and \$ 29 billion(-25%) respectively. In the long term, the profit will shrink even faster, as shown in the Figure 5.9.

But why investing in advanced exploration decreases the profitability of the EODIs from both countries? As the study examines the changes of operations due to technology choices (Table 5.5), we can find enough supporting evidence. The marginal productivity of capital (MPK) decreases with investment volumes, thus longer payback-period (also larger in volume) exploration investments have lower marginal productivity ratio(i.e., $\tilde{\lambda}_5 \widetilde{<\lambda}_3 < \tilde{\lambda}_1$). As a result, the equilibrium exploration investment volume also decreases (show in column (4) in Table 5.5); and (2) in the steady state, as exploration investments decrease, the production(column (1)), sales to global (column (2)) and domestic(column (3)) market will also decrease accordingly. As a result, the total annual profits will decrease.

As above analysis already discusses the direction of equilibrium movement, the following Table 5.5 exhibits the scale of changes in production, sales and exploration investment. Particularly, Chinese annual production and sales of EODI in Africa drops more (percentage-wise) than that in the Middle East, while the U.S. result is the opposite. In addition, choosing more advanced exploration activities have different effects on the U.S. and Chinese sales strategies: it directly reduces the sales of Chinese EODIs to China in all scenarios, while it is not the situation for the U.S. EODIs.

Figure 5.9 Effects of Exploration and development (payback period) on the profitability of EODIs



Source: Model Calculation

Table 5.5 Choices of exploration and development type (payback period) effects on medium to long-term EODI operations in Africa and the Middle East

Invest in	Invested by	Year	(1) Production differences (million barrels)	(2) global sales differences (million barrels)	(3)domestic sales differences (million barrels)	(4)exploration differences (million 2009 $)
Africa	China	2011-2020	-21 (-6%)	0	-21 (-7%)	-2,077 (-48%)
Africa	China	2011-2025	-59 (-14%)	0	-60 (-15%)	-5,064 (-42%)
Africa	US	2011-2020	-19 (-3%)	-19 (-3%)	0	-2,077 (-48%)
Africa	US	2011-2025	-58 (-8%)	-57 (-8%)	0	-5,064 (-42%)
Middle East	China	2011-2020	-1 (-1.3%)	0	-1 (-1.5%)	-144 (-48.2%)
Middle East	China	2011-2025	-4 (-5 %)	0	-4 (-5%)	-349 (-42%)
Middle East	US	2011-2020	-15 (-9.2%)	0	-15 (-10.1%)	-144 (-48.2%)
Middle East	US	2011-2025	-4 (-2.6%)	0	-3 (-2.1%)	-349 (-42%)

SOURCE: Model Calculation

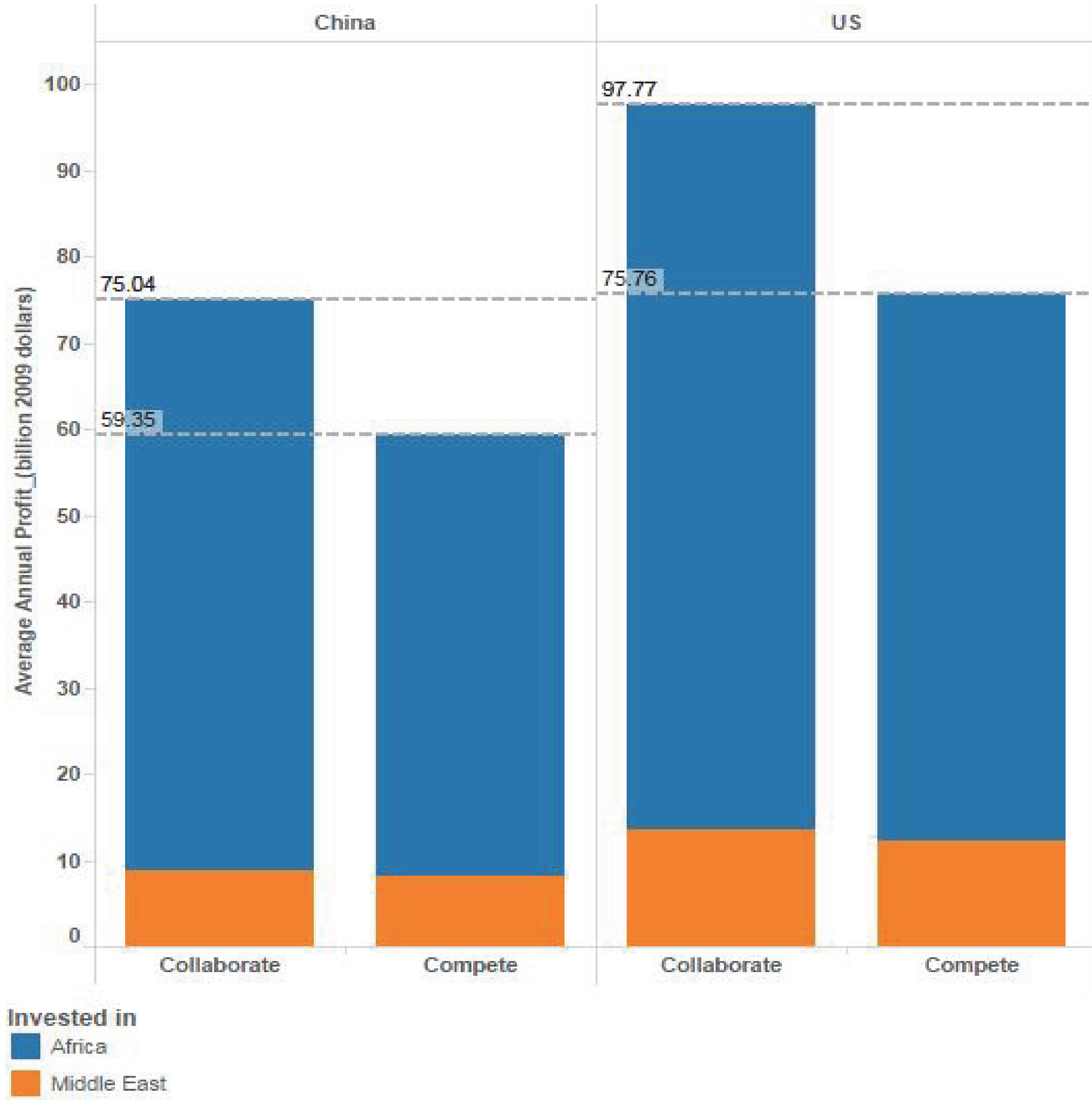
Note: The differences = the values (production, global sales, domestic sales, exploration investment) in the 5-year Payback scenario - the values (production, global sales, domestic sales, exploration investment) in the 3-year Payback scenario

- *Exploration Strategies: Collaboration versus Competition*

In the initial model setup, the study assumes that the U.S. and Chinese EODI conduct their independent exploration initiatives respectively. However, if the U.S. and Chinese companies change their strategies to collaborate in certain strategic regions such as Africa and the Middle East, will both parties be better off or worse off in terms of profits, productivity, and sales? To answer this question, the study also takes into consideration a cooperative scenario, in which the two groups of companies share exploration resources.

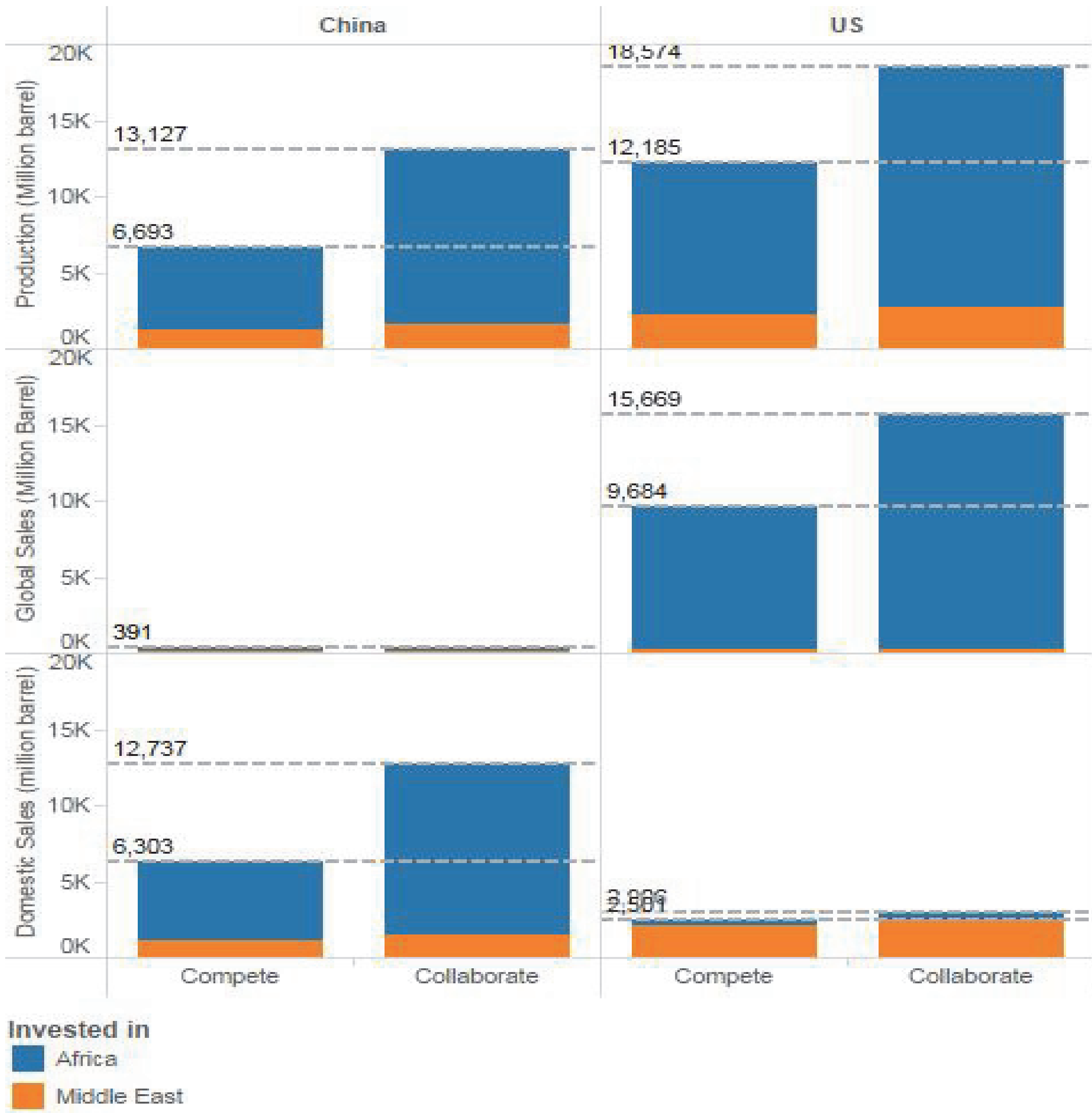
The results of the cooperative scenario are plotted in Figure 5.10. It is obvious that if the two could openly share their exploration and development resources, their aggregate profits would increase: specifically, the Chinese EODI profits in Africa would increase by $15 billion (+30 %); the U.S. EODIs profits in Africa would increase by $ 21 billion (+33 %). Figure 5.11 details the impact of competition and collaboration on production and sales. Specifically, a strategy for collaboration would allow the Chinese companies to increase production and sales to the domestic market. And for the U.S. companies, it would increase their production, domestic and global sales.

Figure 5.10 2011-2025 Profits for the U.S. and Chinese EODIs under Competition and Collaboration Scenarios



Source: Model Calculation

Figure 5.11 2011-2025 Production and Sales to Global and Domestic Markets



Source: Model Calculation

- *Resource Domination versus Profit Maximization: Different Scenarios of Chinese NOCs Objectives*

As discussed in Section 5.2.2, the Chinese NOCs place considerable importance on acquiring resources through placing direct investments. Under this assumption, the model implies that Chinese NOCs place equal importance on profit maximization and resource domination. As the weight parameter changes (an indicator of relative importance of resource domination against profit maximization), the equilibrium outcomes will also vary under the following three scenarios:

a. Within certain limits of movements, higher importance put on investment (higher weights) will lead to more investment, because the marginal utility of investment (γ-1)[xl] is positive. As a result, more investments lead to more production, and sales to domestic market and thus profitability.
b. However, increasing importance of investments beyond certain limits might not increase the production, profits, and sales of Chinese NOCs outcomes. This is because investment in a region is also bounded by the investment capacity. In an extreme case, if NOCs placing infinitely positive (+∞) weight on resource domination, the NOCs in one region can only invest up-to-maximum investment capacity in that region. As a result, the production, profits, investments, and sales will not increase after investments have reached their maximum capacity.
c. At a third scenario, exorbitant importance on resource domination may even reduce the profits, productions, and sales of NOCs. This is because as the investment expands tremendously, the marginal return on investment (profit/exploration ratio) will diminish. In an extreme case, that may lead to negative marginal utility of investment (γ-1<0). In that scenario, exorbitant weight on investments will lead to reduced profits, production, sales and investments of NOCs.

[xl] Note: γ is profit/exploration (investment) ratio. Historical data and our model calculation results (in Table 5.4) both indicate that$\gamma > 1$, thus $\gamma - 1$>0.

5.3.4 Effects of Environment Factors: Discussion of the additional Constraints

- *Strategic Petroleum Reserves (SPR) policies*

The national/federal SPR policies will influence the future prospects of EODI primarily through their impact on global and domestic oil sale prices (as modeled). Specifically, strong SPR policies can protect domestic oil sale prices from extreme fluctuations, thus reducing the risk inherent in planning for future production and sale. The U.S. EODIs, given the stabilization effects of SPRs, tend to: 1) sell a greater proportion to domestic markets, rather than relying on global energy traders; 2) plan for increased production in the future. For the Chinese, whose national SPR mechanisms did not exist before 2005, SPR resemble another allocation mandate: the regulation of the investment sizes and import quotas.

- *Regional Openness to Foreign Investments and Trade*

As discussed in section 4.3, regional openness to foreign investment is one important factor of FDI success for both the U.S. and China. This is especially true for the case of EODIs, i.e. FDI in the energy sector—a sector usually defined as a strategic sector in many oil-rich and developed economies. In specific, openness to investment and openness to trade--two significant aspects of openness to EODIs will directly affect the outcomes of U.S. and Chinese EODI as discussed in this analytical model. The following Table 5.6 summarizes the most current FDI and trade policies in oil and gas extraction in selected oil-rich countries of each of the six regions. By and large, there are three clusters of countries by the easiness of investment and trade environment:

- Oil-rich countries in the regions of Europe, Canada, Africa, Other Eastern Hemisphere, and China are open to EODIs and exports of EODI productions, whereas some in these regions may require principal equity ownership and partnerships (usually through Profit-Sharing Agreement[xli]) in the form of profit of oil companies from hosting countries.
- Oil-rich countries in the region of FSU, Middle East, and Other Western Hemisphere countries exhibit contrasting patterns of openness to EODIs and exports of EODI

xli Note: Production Sharing Agreement (PSA) requires foreign oil companies should participate in joint venture with local oil companies in oil extraction projects, but the foreign oil companies alone should bear the costs and risks pertaining exploration and development activities, and will receive proportionate profit shares during the production stage.

productions. At one extreme, Kazakhstan, Columbia, and Iraq are wild open to EODIs and exports of EODI productions. At the other, Russia, most other oil-rich countries in the Middle East, Venezuela and Brazil are almost close to EODIs of any form.

- The U.S. is unique in that it is open to EODIs, with possible effects from political processes. On the other end, the U.S. law Title 42 U.S. Code § 6212 specifies that crude oil produced in the U.S., whether by U.S. or foreign oil companies, cannot be exported, only with a few exceptions.

The effects of current status of the openness of these regions can be observed in the historical EODI volumes in these regions. For instance, Africa, both rich in oil and open to EODIs and trades of productions, has witnessed increasing investments and output from both Chinese NOCs and U.S. IOCs. On the other hand, the Middle East (with the exception of Iraq), though rich in oil reserves, has not witnessed increases of EODIs from neither the U.S. nor China.

More importantly, the trends of regional openness to EODIs and trades of productions in these regions, on the other hand, may have far-reaching effects on several constraints and outcomes of EODIs in each region.

- First, as debated heatedly by scholars, lawyers and policymakers within the U.S., a possible lift of export bans on the crude oil produced in the U.S. may tremendously liberate the investment constraints of EODIs within the U.S.. This possibility will not affect the U.S. IOCs' EODI outcome, but it will affect the foreign oil well investors, including the Chinese NOCs' investment interest in U.S. oil wells, where the lifting costs are still much cheaper than domestic wells.
- Second, several countries in the FSU and Africa might set more restrictions on EODIs. For instance, under Russia passed Strategic Investment Law of 2008, energy production sector was classified as strategic resources for national security, and thus evidenced more restrictions on investment. Before 2008, in the 3rd quarter of 2007, investment in energy production producing products accounted for a significant 16% of total FDI inflows to Russia (Vinhas de Souza, 2008[71]). Consequently, the U.S. and Chinese oil companies, though not principal investors in Russia, may still be vulnerable to shrinking potential for EODIs in Russia. Meanwhile, Algeria, an oil-rich country in Africa, also exhibited tendencies to impose more restrictions on FDI inflows in all sectors, including the energy

sector. Different from the case of Russia's restrictions on EODIs, the higher threshold set to inhibit EODI, will directly affect the U.S. IOCs investment, production, and international sales potential in Algeria, whose economy is extremely dependent on EODIs from the U.S. and sales of oil productions (98% of foreign trade incomes) to the U.S. (Bock and Gijón, 2011)[72].

- Finally, against all odds, recent trends may also imply long-term policy transitions to lift bans on oil and gas related FDI in the Middle East. Post-conflict Iraq passed Private Investment In Crude Oil Refining Law No. 64 of 2007[xlii], allowing any domestic or foreign energy producing companies to invest in crude oil extraction (without land ownership). Kuwait, the least receptive to FDI in the region, for instance, recently signed a $14 billion refinery project with a Dutch investor for oil well development (Dahlia, 2012[73]). Iran, known for oil nationalism, required foreign oil investors to sign the stringent buy-back contracts [xliii](Bunter, 2009[74]). However, it has recently revised the contract protocols three times to reduce foreign investors' risks and costs (Vakhshouri, 2014[75]). And according to information provided by current political leaders (Bozorgmehr, 2013[76]), Iran may launch a new type of "win-win" protocol (details to be publicized) to replace the buy-back contracts, to attract western investors in the oil extraction business. Such transitions to open up EODI in the energy sector in the Middle East, if happens, will directly reshape the distribution of the U.S. and Chinese EODIs, the production and sale strategies of both countries. In specific, oil companies from both countries will place higher proportions of EODIs in the region. More importantly, the sale strategy of the U.S. IOCs will also shift drastically from the current model analysis result. Since the lifting cost in the Middle East is cheaper than the U.S. domestic, the U.S. will sell a higher proportion of her EODI productions back to the U.S. In addition, in terms of U.S.-China

xlii Note: a full English version of the law can be found here: http://investpromo.gov.iq/wp-content/uploads/2013/06/Law-of-Private-Investment-in-Crude-Oil-Refining-En.pdf

xliii Note: The buy-back contracts require IOCs invested in Iranian oil wells to undertake exploration, development and production work. After completing an agreed scope of work, the IOC will transfer the operation to Iranian National Oil Company (INOC), and INOC will reimburse the IOC, including cost recovery and an agreed RoR. However, the IOCs do not allow foreign investors to take equity shares.

interaction in the region, the U.S. IOCs and Chinese NOCs will tend to compete or develop investment separately, given the higher-than-world-average profit margins and lower-than-world-average exploration risks and lifting costs in the region.

Table 5.6 A selected list of countries with restrictions on FDI (inflow) and trade in energy sector

Region	Country	Restriction on Investments and Trade in crude petroleum exploration, development and production
The U.S.	The U.S.	No restriction on the Oil & Gas FDI; but politics does have an effect on the bidding process; Title 42 U.S. Code § 6212 bans exports of oil produced in U.S., with a few exemptions.
China	China	No restriction on Oil & Gas FDI; but a foreign company is required to participate in joint venture with a subsidiary of Chinese NOC; foreign investors alone should carry out and fund exploration operations; No restriction on exports of production due to foreign investors.
Africa	Angola	Foreign investors must partner with Sonango—the NOCs of Angola
	Algeria	Foreign investors are allowed to own up to 49% of company shares
	Nigeria	None
Canada	Canada	None
Europe	Norway	None, but require foreign investors to transfer technology know-hows
FSU	Russia	More than 10% equity investment in oil & gas sector needs the approval of Russia government approval procedures; Foreign investors may not own more than 20% shares of a Russian energy production and distribution company.
	Kazakhstan	None
	Azerbaijan	Foreign investors should sign Production-Sharing Agreement(PSA)
Middle East	Saudi Arabia	Foreign investment in the oil business is disallowed
	UAE	Foreign investment in the oil sector is disallowed
	Iraq	Open to foreign direct investment in oil and gas sector since 2007
	Kuwait	Not receptive to FDIs, only has a few contracts for development infrastructure setup.
	Iran	Buy-back contracts
Other Eastern Hemisphere	Indonesia	Foreign companies must cooperate with Indonesia government to produce oil and gas within the country.
	Malaysia	Foreign investors should be licensed by Petronas (Malyasia national oil company) to invest in the country; Maximum FDI allowed in Oil and Gas equity share vary from 30% to 70%.
Other Western Hemisphere	Colombia	None.
	Brazil	Oil and Gas Production are closed to private and foreign investment. Under a few exceptions, foreign investors should partner a Brazilian company to bid competitively in response to public invitation to bid.
	Venezuela	Exploration activities are restricted to the State, thus closed to private and foreign investors; Foreign companies are allowed to participate in joint ventures with Venezuela oil companies in development and production, but should not own more than 49% of company shares.

SOURCES: World Bank (2012)[77]; Van, Shedd, and Murrill (2013) [78]; Bock and Gijón (2011)

- *Regional Stability and Market Transparency*

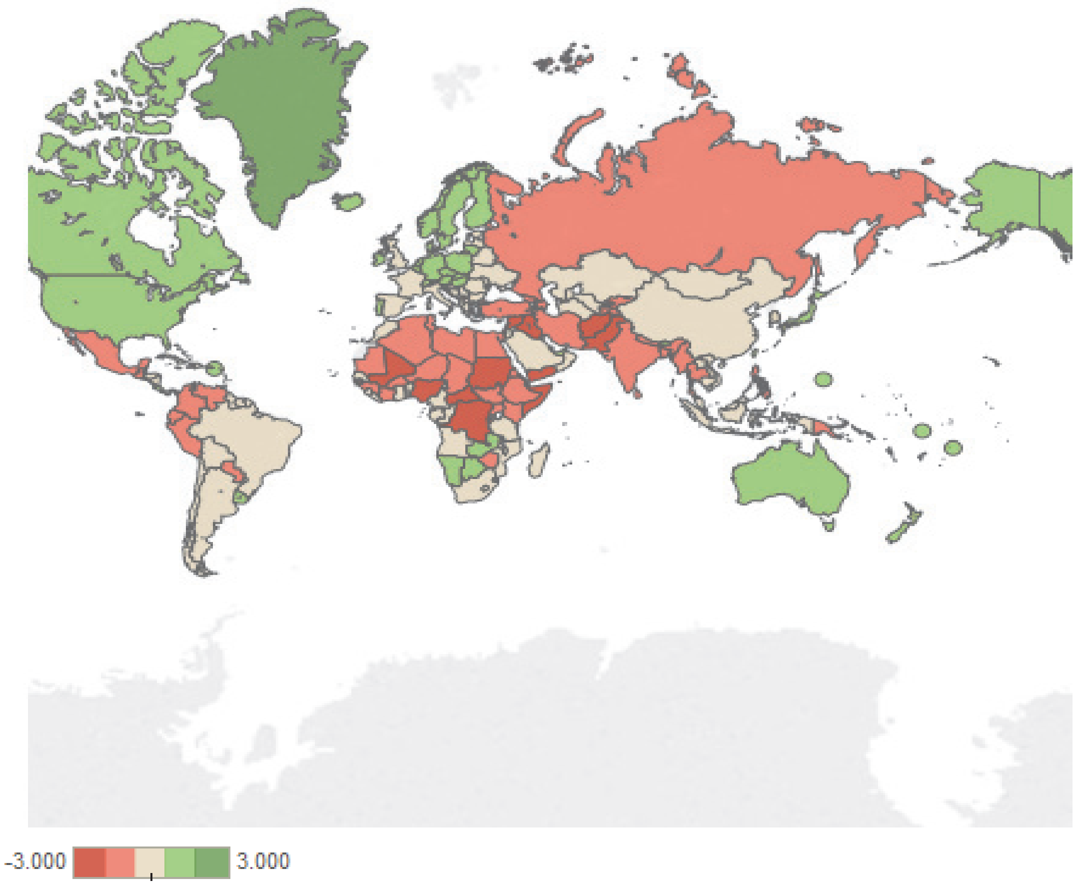
Regional stability and market transparency are two correlated and critical factors that affect the outcome of EODIs.

First, to ensure the safety of costly infrastructure, equipment, and human resources, investors will evaluate the stability of the investing country when looking for long-term, multi-phase oil extraction projects. Meanwhile, stability factor will also affect the sales policies of EODIs. As the result of this analysis show, in Africa, most U.S. EODIs choose to sell their crude oil products to global traders, producing much lower profit margins than selling directly to domestic markets. However, if regional stability is increased, i.e. if the safety environment, transportation facilities, labor force skill levels etc. are all improving, the foreign investors will be more inclined to sell crude oil products in the hosting countries or even expand high-value downstream efforts in the region.

Market transparency, another factor usually correlated with regional/country stability, also directly affects the production capacity, lifting costs, and profit margins of EODIs. Transparent markets predict low lifting cost, high (realistic) production capacity expectation, and thus higher profit margins.

The following Figure 5.12 maps the stability and market transparency scores of all the countries in the six regions. An interesting pattern can be observed. Compared to other countries in the regions, most oil-rich hosting countries in the FSU (Russia), the Middle East, Sub-Sahara Africa and Other Western Hemisphere (Venezuela and Columbia) exhibit both lower levels of transparency and stability. While this study doesn't have further evidences to prove that oil richness is a contributing factor to regional instability or intransparency, several studies such as Arezki and Brückner (2009)[79] already identified their correlation through empirical evidence. If true, then increasing EODIs from both the U.S. and Chinese oil companies in the above mentioned regions will exacerbate the regional instability and intransparency, and in return further reduce their profit margins, increases lifting costs and investment risks.

Figure 5.12 Stability and Transparency by Region, 2012



Data Source: World Governance Indicator, 2013[80]

5.3.5 Impact of Critical New Technologies: Recent Development in Hydraulic Fracking

Technology innovation, as an important discussed impacts of investment in technology exploration on the EODIs outcomes. Section 5.3.3 already discusses the choices of investment in gradual processes. However, this analysis only considers gradual technology exploration activities, but doesn't apply to the scenario of critical technology transition, such as recent development in hydraulic fracking, particularly as horizontal drilling technology matures. This technological breakthrough is reported since 2010. The direct effect of such critical new technologies is that the proven energy reserves have soared. The latest EIA data survey (EIA, 2013[81]) revised proven U.S. Oil & Gas reserve data as of 2011. After reaching its lowest point since 1979 in 2008(20.6 billion barrels), the proven reserves of crude oil increases to 22.3 in 2009, 25.2 billion barrels in 2010 and 29.0 billion barrels in 2011—the highest level since 1986. The revolutionary effect of these technologies on gas reserves is more phenomenal than in crude oil, even though gas is not the primary focus of this modeling. Specifically, the estimated natural gas reserve reached 350 trillion cubic feet in 2011, close 1.7 times of its peak historical reserve of 208 trillion cubic feet in 1979. According to another estimate conducted by EIA[82], Chinese Oil Reserves also sharply increased from 16 billion barrels in 2009 to 20.35 billion barrels in 2010, and then to 25.5 billion barrels in 2013.

Such changes in proven energy reserves may increase the uncertainty of U.S. and Chinese EODIs estimate through several major mechanisms, constraints, and parameters.

- The first effect on the model is Chinese strategic objective: China might be aware of the fact there is more oil reserves domestically. Therefore, China might not place a high weight on capturing risky foreign oil investments. Thus, the objective functions for China will be revised.
- Second, discovering more oil reserves domestically may change the location choices of the energy production and investments in the long term.
- Third, the proven oil reserves will affect confidence in oil prices and thus affect the sales and production decisions of the U.S. and Chinese companies. For example, the Chinese companies may not distinguish its sale to foreign markets and its sale to China directly, and

the U.S. markets may invest less overseas given the availability of easily extractible oil reserves in the U.S.

- Last but not least, because this critical technology brings about natural gas booming in the U.S., there might be changes in the demand side as well. For example, electric cars (use electricity produced from natural gas) might replace traditional automobiles. And thus the demand for oil will decrease accordingly.

5.3.6 Limitations of the Analytical model and Outcomes

During the period of this dissertation research (2010-2014), unprecedented technology breakthroughs in critical oil and gas extraction technologies occurred in the U.S. In response, this analysis discussed the potential impacts of these major breakthroughs on the analysis outcomes (Section 5.3.5). However, the analytical model, making assumptions based on observations of historical data (1977-2011), exhibits limitations in understanding the scales of impacts regarding the redistribution of EODIs, shift of objectives, sales and productions of EODIs.

Another limitation of the model arises from the fact that the model is lack of falsification and validity tests. While the model design is based on rigorous examination of evidences of mechanisms, actors and interactions, future falsification and validity tests will help improve validity of the model design and thus help improve the generalizability of this model to EODI analysis for other country-pair comparison. One possible validity test could re-run the model for the time period between 2002 and 2011, and then compares the model calculation results with historical data.

6 Conclusions

This study aims at understanding the current status the future prospects of U.S. and Chinese EODI behaviors. To that end, this analysis draws upon their EODI data drawn from multiple data sources, detailing their EODI investment amount, year, location, corporate yields and operation outcomes can be found in the Appendix Table 1-5. The major findings of this analysis are summarized as follows.

- *The differences in objectives between companies from the two countries are minor, and will have negligible effects on their respective production, sales, and storage decisions, as well as their profit payoffs in the short, medium, and long term.*

This, may be due to the fact that the two largest components of both Chinese and US foreign investments are in Africa and Canada, where investments are quite diversified in terms of investment size and portfolios. These regions are relatively open to competition, in which resource dominance strategies will not necessarily help in making better investment decisions for either of them. More importantly, the resource dominance strategies of the Chinese NOCs, as witnessed in existing cases, were not thought of highly by outside experts, and they will be even less so in the future. As their global investments further expand, Chinese NOCs must emulate the strategies of other IOCs, in order to gain a more competitive and flexible market position.

- *Africa and Other Eastern Hemisphere countries are the two markets of common interest to companies from both countries* in the future.

With relatively open access to the investment markets, U.S. and Chinese competition for investments will become fiercer in the two regions. The effects of fierce competition, as observed in this analysis, will increase the profitability, productivity, and exploration capacity of companies from both countries.

- *In the Middle East & the FSU, where rich oil resources have been found, the investment potential for both Chinese and US companies is very limited due to market access barriers.*

Undoubtedly, with the help national policy guidance from their respective countries, companies from both the U.S. and China have secured some large investment deals in these regions. However, such successes are not generalizable to all the investment initiatives in the two regions. Rather, the more advantageous strategies for Chinese and U.S. companies would be cooperation with each other: the U.S. and Chinese oil companies will both be better off with a joint commitment to promoting free foreign investment and trade environment.

- *Chinese and U.S. companies have differing sales destination priorities: Chinese prefer to sell more production to domestic markets, whereas the U.S. companies sell their production equally in the domestic and global markets.*

The analyses show that in the future, Chinese oil companies will sell almost all their oil to domestic markets, whereas the U.S. oil companies will only sell about half of theirs to domestic markets and the other half to global markets. This is because the lifting cost of oil from EODI is much lower than oil purchased from international markets and is also much lower than the cost of oil produced domestically. But for U.S. companies, the costs of oil produced from EODI are not necessarily lower than the domestic prices, and thus might not be as competitive as domestic oil. The outcome of this competition, in this case, will be ambiguous, because it is contingent on how open the U.S. domestic market will be in the future. In one scenario, if the U.S. were to open its energy investment markets, at least the upstream market, the Chinese oil companies would also join the market competition for the U.S. domestic oil wells, given their cost advantages. And increased competition would also result in even lower prices for oil in the U.S. Vice versa, if the U.S. market remains close to Chinese investors, this increased competition would not exist.

- *The analysis should be interpreted with multiple caveats in the context of the complicated uncertainties connected with technology breakthroughs in hydraulic fracturing and horizontal drilling, as well as other uncertainties relating to the OPEC countries.*

Given the breakthroughs in these critical technologies since 2010, the conclusions of this study should be viewed with special caution because natural gas and oil production and reserves can drastically change decisions relating to EODIs' objectives, scale, location, and yields. Notwithstanding these caveats, the unique data and analysis presented in the study should be of interest and value to the policy communities in both the US and Chinese governments and in the oil companies for comparison with the actual EODIs that emerge in ensuing years, and that reflect the effects of advancing technology as well as changing external circumstances

Appendices

The following Appendix Tables 1-5 summarize the study's unique time-series data on the major oil companies' EODI scale, location, production, and proven reserves, focussed on the 2002-2011 period, along with partial coverage of earlier decades.

Appendix Table 1-5: U.S.-China EODIs time series Data

Appendix Table 1. Major Chinese EODI (upstream Oil) investments: 2002-2011

Year	Investor(s)	Quantity in Millions $ (current year)	Quantity in Million (2009 $)	Country	Region
2002	CNPC	$262	$312	Indonesia	OEH
2002	CNOOC	$585	$696	Indonesia	OEH
2003	Sinochem	$105	$123	UAE	Middle East
2004	Sinopec	$153	$174	Kazakhstan	FSU
2004	CNPC	$2,000	$2,280	Angola	OEH
2005	CNPC	$290	$319	Syria	Middle East
2005	CNPC and Sinopec	$1,420	$1,562	Ecuador	OWH
2005	CNPC	$4,200	$4,620	Kazakhstan	FSU
2006	Sinopec	$430	$456	Colombia	OWH
2006	Sinopec	$730	$774	Angola	OEH
2006	Sinopec	$2,800	$2,968	Iran	Middle East
2007	CNPC	$200	$206	Chad	Africa
2007	Sinopec	$2,000	$2,060	Iran	Middle East
2008	Sinochem	$470	$470	Yemen	Middle East
2008	CNPC	$490	$490	Chad	Africa
2008	Sinopec	$560	$560	Australia	OEH
2008	Sinopec	$1,990	$1,990	Syria	Middle East

2008	CNOOC	$2,490	$2,490	Norway	Europe
2008	CNPC	$3,010	$3,010	Iraq	Middle East
2008	CNPC	$3,290	$3,290	United Arab Emirates	Middle East
2008	CNPC	$4,990	$4,990	Niger	Africa
2009	CNPC	$240	$240	Iraq	Middle East
2009	CIC	$300	$300	Russia	FSU
2009	CNOOC and Sinopec	$320	$320	Trinidad-Tobago	OWH
2009	Sinochem	$880	$880	Britain	Europe
2009	CNPC	$1,020	$1,020	Singapore	OEH
2009	CNPC	$1,160	$1,160	Singapore	OEH
2009	CNPC	$1,240	$1,240	Myanmar	OEH
2009	CIC	$1,580	$1,580	USA	North America
2009	CNPC	$1,740	$1,740	Canada	North America
2009	CNPC	$1,760	$1,760	Iran	Middle East
2009	CNPC	$1,900	$1,900	Canada	North America
2009	CNPC	$2,250	$2,250	Iran	Middle East
2009	Sinopec	$7,200	$7,200	Nigeria/Cameroon/North Sea	Africa
2010	Three Gorges	$170	$167	Russia	FSU
2010	CNPC and Sinopec	$610	$598	Ecuador	OWH
2010	CNPC	$900	$882	Venezuela	OWH
2010	CIC	$1,220	$1,196	Canada	North America
2010	CNPC	$1,480	$1,450	Syria	Middle East
2010	Rongsheng Holding and Sinochem	$1,990	$1,950	Egypt	Africa
2010	CNOOC	$2,370	$2,323	USA	North America

2010	Sinopec	$2,470	$2,421	Argentina	OWH
2010	Sinochem	$3,070	$3,009	Brazil	OWH
2010	Sinopec	$4,650	$4,557	Canada	North America
2010	CNPC	$5,990	$5,870	Cuba	OWH
2010	Sinopec	$7,100	$6,958	Brazil	OWH
2010	China State Construction Engineering	$8,000	$7,840	Nigeria	Africa
2011	China Petroleum and Engineering	$170	$162	Iraq	Middle East
2011	CNOOC	$330	$314	Argentina	OWH
2011	CNPC	$400	$380	Afghanistan	Middle East
2011	Sinopec	$540	$513	Cameroon	Africa
2011	Sinopec	$850	$808	Kazakhstan	FSU
2011	CNOOC	$1,450	$1,378	Uganda	Africa
2011	CNOOC	$2,040	$1,938	Canada	North America
2011	Sinopec	$2,100	$1,995	Canada	Canada
2011	Zhejiang Hengyi and Sinopec	$2,500	$2,375	Brunei	OEH
2011	Sinopec	$3,750	$3,563	Saudi Arabia	Middle East

Sources: Heritage Foundation China Global Investment Tracker, IEA 2011, Media coverage.
Note: (unit transaction value > 100 million USD)

Appendix Table 2. U.S. EODI (upstream Oil Well investments): 1977-2009

Unit: in 2009 million $

Region / Year	Africa	Canada	Europe	FSU	Middle East	OEH	OWH
1977	$1,996	$4,404	$7,350	-	$511	$822	$1,032
1978	$2,229	$4,227	$7,178	-	$736	$1,026	$1,532
1979	$2,107	$5,800	$7,461	-	$461	$1,158	$1,884
1980	$3,111	$7,029	$9,795	-	$463	$1,820	$2,286
1981	$4,436	$3,830	$10,579	-	$687	$3,928	$2,656
1982	$4,216	$3,673	$12,486	-	$883	$4,688	$2,219
1983	$3,165	$3,105	$8,105	-	$922	$3,899	$1,153
1984	$6,221	$9,866	$10,025	-	$856	$3,724	$996
1985	$2,824	$3,367	$6,621	-	$1,540	$2,372	$1,233
1986	$1,853	$1,961	$5,518	-	$592	$2,066	$1,118
1987	$1,277	$3,167	$5,050	-	$652	$4,681	$778
1988	$1,374	$8,838	$7,067	-	$615	$2,240	$1,203
1989	$1,614	$9,880	$5,580	-	$641	$3,601	$960
1990	$2,163	$2,760	$10,044	-	$907	$3,694	$1,017
1991	$2,236	$2,538	$10,022	-	$720	$3,500	$1,078
1992	$1,995	$1,584	$9,733	-	$799	$3,451	$926
1993	$2,062	$2,185	$7,682	$368	$960	$3,459	$863
1994	$1,910	$2,518	$6,092	$408	$611	$3,785	$1,020
1995	$2,746	$2,553	$6,996	$482	$485	$3,267	$1,176
1996	$3,685	$2,064	$7,344	$608	$610	$5,451	$2,159
1997	$3,860	$2,590	$9,142	$814	$834	$3,868	$2,136
1998	$4,018	$6,161	$11,006	$1,625	$1,208	$5,063	$4,754
1999	$3,909	$2,598	$5,226	$765	$496	$4,348	$4,788

2000	$3,362	$6,035	$9,299	$1,104	$680	$8,392	$6,736
2001	$6,707	$18,530	$6,497	$1,065	$893	$6,035	$3,735
2002	$6,058	$7,957	$11,654	$1,515	$921	$7,372	$1,854
2003	$10,701	$5,711	$6,675	$2,470	$1,137	$4,847	$1,317
2004	$7,820	$6,008	$4,993	$2,313	$1,440	$4,260	$1,852
2005	$11,738	$9,948	$6,672	$6,862	$1,592	$13,166	$1,825
2006	$13,644	$17,999	$9,554	$2,563	$3,339	$7,047	$8,671
2007	$12,919	$5,976	$8,372	$3,022	$3,260	$7,041	$3,476
2008	-	$6,469	$8,494	-	$4,503	$9,657	-
2009	$13,861	$8,594	$8,340	$3,025	$2,147	$8,808	$2,880

Source: Aggregated Data from EIA FRS Form 28 Survey, Table 17- Exploration and Development Expenditures by Region.

Appendix Table 3. Yield of EODI (upstream) of Major U.S. Oil Companies: 2002-2011

Unit: RoR on Capital Employed (%)

Company / Year	ExxonMobil	Chevron
2002	23.7	15.4
2003	31	17.2
2004	31.5	27.8
2005	45.6	26.6
2006	47.9	28.3
2007	43.7	25.6
2008	56.7	31.4
2009	24.8	15.7
2010	29	22.4
2011	39.2	27.9

Source: Corporate Annual Reports. Chinese data is not available.

Appendix Table 4. Proven Reserves and Production of U.S. EODI (crude oil): 2000-2009

Year	Production (million barrels						
	Canada	OECD-Europe	FSU	Africa	Middle East	OEH	OWH
2000	203.9	614.1	-	359.3	117.9	320.2	108.7
2001	234.7	588.6	-	370.9	116.8	316.7	119.2
2002	217.9	567.2	-	409.2	112.4	295.9	111.0
2003	203.3	558.8	-	468.1	102.2	298.8	111.9
2004	189.0	548.0	-	500.4	96.6	284.1	101.7
2005	164.1	440.6	86.2	594.6	147.2	258.8	84.2
2006	151.4	406.3	121.8	563.7	147.6	242.7	66.0
2007	152.7	382.9	92.1	547.5	150.4	226.5	66.9
2008	191.6	372.7	60.5	593.8	150.3	239.9	66.2
2009	203.9	614.1	-	359.3	117.9	320.2	108.7
Year	Proven Reserve (million barrels)						
	Canada	OECD-Europe	FSU	Africa	Middle East	OEH	OWH
2000	2012	5040	-	4335	849	1889	1754
2001	2046	5242	-	5015	818	1865	1614
2002	2584	5397	-	5258	857	3049	1600
2003	2182	5134	-	5738	786	2674	1435
2004	2259	5614	-	6128	796	2546	1269
2005	1327	5313	-	5663	669	2241	1162
2006	1590	3182	1602	5736	652	1960	1077
2007	1771	2818	1556	5526	1390	1910	995
2008	1780	2613	1369	5041	1595	1718	575
2009	4101	2308	1906	5065	2030	1911	486

Source: Table 21-Exploration and Development Expenditure, Reserves, and Production by Region, EIA-28

Appendix Table 5. Proven Reserves and Production of major Chinese EODIs: 2002-2011

Company / Year	CNOOC		CNPC		Sinopec	
	Production (million barrels)	Proven Reserve at year end(million barrels)	Production (million barrels)	Proven Reserve at year end(million barrels)	Production (million barrels)	Proven Reserve at year end(million barrels)
2002	13.5	138.7	*	*	*	*
2003	14.8	103.4	*	*	*	*
2004	10.9	101.9	*	*	*	*
2005	8.6	99.1	*	*	*	*
2006	8.8	145.3	205.8	6,478	*	*
2007	9.4	156.7	219.3	8,159	*	*
2008	8.7	178.7	223.6	7,769	*	*
2009	23.6	172.3	251.6	*	*	*
2010	33.0	217.5	264.1	*	134.6	2,888
2011	30.7	384.6	305.9	*	188.2	2,848

Sources: CNOOC Annual Reports & 10-K Form, CNPC Annual Report, Sinopec annual reports.

Note: For cells marked in *, domestic and overseas operations data (production/reserve) was not separated in financial reporting segments. CIC(equity production & reserve) and Sino-chemical productions and reserves are not listed. The total is projected based on the total three companies' investment as a ratio of total investment.

Appendix pages 138-141 summarize the partial equilibrium model specifications and simulations for US and Chinese companies' EODIs, as discussed in Chapters 5 and 6. Appendix pages 142-162 illustrate the coding used in programming the simulations.

P.E. Model Systems

1. U.S. Model

Max $\pi = \sum_{i=1}^{n} \sum_{2010}^{2025} (EG_{ij} + EI_{ij} - I_{ij} - OM_{ij} - SC_{ij})$; i.e.

$$\underset{\{s_{ij}^G, s_{ij}^D, e_{ij}^{US}, p_{ij}\}}{Max\, \pi} = \sum_{i=1}^{n} \sum_{2010}^{2025} ((\alpha \times P_{ij} \times s_{ij}^G + P_j^s \times s_{ij}^D) - e_{ij}^{US} - UOM \times p_{ij} - USC \times S_{i,j})$$

$$\begin{cases} I_{ij} = e_{ij}^{US} \leq E_{ij}^{US} = \varphi(A_{ij}) = \varphi\left(k(\sum_{j}^{J-1} (e_{ij}^{CN} + e_{ij}^{US}))^{\frac{\log(\emptyset)}{\log(2)}} \right) \\ s_{ij}^D + s_{ij}^G = S_{i,j-1} + p_{i,j} - S_{i,j} \\ \min(s_{ij-history}^D) < s_{ij}^D \\ \min(s_{ij}^G - history) < s_{ij}^G \\ p_{i,j} \leq PC_{ij} = f\left(\sum_{k}^{j-1} p_{ik}, \sum_{k}^{j-1} e_{ik} \right) \\ P_{ij} = g(D_{ij}, S_{ij}, SPR_j) = g(D_{ij}, s_{ij}^{CN} + s_{ij}^{US}, SPR_j) \end{cases}$$

Explicit Functions and Parameter Estimates:

$$\varphi\left(k(\textstyle\sum_j^{J-1}(e_{ij}^{CN}+e_{ij}^{US}))^{\frac{\log(\emptyset)}{\log(2)}}\right)=\frac{(\sum_j^{J-1}(e_{ij}^{CN}+e_{ij}^{US}))^{\frac{\log(\emptyset)}{\log(2)}}}{J-1}$$

$$f\left(\sum_k^{j-1}p_{ik},\ \sum_k^{j-1}e_{ik},UOM\times\ p_{ij}\right)=\frac{\sum_k^{J-1}p_{ik}}{J-1}+\lambda*\sum_{k=T}^{j-1}e_{ik}$$

$$T=j-1,j-3,j-5;$$

$$P_{ij}=g(D_{ij},S_{ij},SPR_j)=g(D_{ij},s_{ij}^{CN}+s_{ij}^{US},SPR_j)=(0.6\times P_{i,j-1}+0.3\times P_{i,j-2}+0.1\times P_{i,j-3})+\Delta\pi$$

The expected values of $\emptyset,\lambda,\Delta\pi$ are maximum likelihood estimates based on historical data (1977-2009) calculation.

- i: host country/region; j: year;
  - $EG_{i,j}$: earnings from global market sales from host country i in year j;
  - $EI_{i,j}$: earnings from sales from host country i to the domestic market in year j;
  - $I_{i,j}$: EODI exploration investments in host country I in year j;
  - $OM_{i,j}$: operation and maintenance costs in host country i in year j;
  - $SC_{i,j}$: storage costs in host country I in year j;
  - s_{ij}^D: sales from host country i to domestic markets in year j;
  - s_{ij}^G: sales from host country i to global markets in year j;
  - $S_{i,j-1}$: Inventory in host country i by the end of previous year j-1;
  - $S_{i,j}$: Inventory in host country i by the end of current year j;
  - $p_{i,j}$: Production in host country i, year j;
  - $e_{i,j}$: Exploration investments in host country i, year j;
  - $s_{j_{historical}low}^G$: lowest amount sold to global markets;
  - PC_{ij}: Production capacity in host country i, year j;

2. China Model

Max $U = \sum_{i=1}^{n}\sum_{2010}^{2025}(EG_{ij} + EI_{ij} - I_{ij} - OM_{ij} - SC_{ij}) + \gamma\sum_{i=1}^{n}\sum_{2010}^{2025} I_{ij}$ i.e.

$$\underset{\{s_{ij}^{G}, s_{ij}^{D}, e_{ij}^{CN}, p_{ij}\}}{Max\ U} = \sum_{i=1}^{n}\sum_{2010}^{2025}(\alpha \times (P_{ij} \times s_{ij}^{G} + P_{j}^{s} \times s_{ij}^{D}) - e_{ij}^{CN} - UOM \times p_{ij} - USC \times S_{i,j}) + \gamma\sum_{i=1}^{n}\sum_{2010}^{2025} e_{ij}^{CN}$$

$$= \sum_{i=1}^{n}\sum_{2010}^{2025}(\alpha \times (P_{ij} \times s_{ij}^{G} + P_{j}^{s} \times s_{ij}^{D}) - UOM \times p_{ij} - USC \times S_{i,j}) + (\gamma - 1)\sum_{i=1}^{n}\sum_{2010}^{2025} e_{ij}^{CN}$$

$$\begin{cases} I_{ij} = e_{ij}^{US} \leq E_{ij}^{US} = \varphi(A_{ij}) = \varphi\left(k(\sum_{j}^{J-1}(e_{ij}^{CN} + e_{ij}^{US}))^{\frac{\log(\emptyset)}{\log(2)}}\right) \\ s_{ij}^{D} + s_{ij}^{G} = S_{i,j-1} + p_{i,j} - S_{i,j} \\ \min(s_{ij-history}^{D})\ s_{ij}^{D} \\ \min(s_{ij-history}^{G}) < s_{ij}^{G} \\ p_{i,j} \leq PC_{ij} = f\left(\sum_{k}^{j-1} p_{ik}, \sum_{k}^{j-1} e_{ik}\right) \\ P_{ij} = g(D_{ij}, S_{ij}, SPR_{j}) = g(D_{ij}, s_{ij}^{CN} + s_{ij}^{US}, SPR_{j}) \end{cases}$$

Explicit Functions:

$$\varphi\left(k(\sum_j^{J-1}(e_{ij}^{CN}+e_{ij}^{US}))^{\frac{\log(\emptyset)}{\log(2)}}\right)=\frac{\sum_j^{J-1}(e_{ij}^{US}))^{\frac{\log(\emptyset)}{\log(2)}}}{\text{J}-1};$$

$$f\left(\sum_k^{j-1}p_{ik},\ \sum_k^{j-1}e_{ik}\right)=\frac{\sum_j^{J-1}p_{ij}}{\text{J}-1}+\lambda*\sum_{k=T}^{J-1}e_{ik};$$

$$T=j-1,j-3,j-5;$$

$P_{ij}=g(D_{ij},S_{ij},SPR_j)=g(D_{ij},s_{ij}^{CN}+s_{ij}^{US},SPR_j)$=$(0.6\times P_{i,j-1}+0.3\times P_{i,j-2}+0.1\times P_{i,j-3})+\Delta\pi$

λ , π is a coefficient decided based on the observation of historical data.

The expected values of $\emptyset, \lambda, \Delta\pi$ are maximum likelihood estimates based on historical data (1977-2009) calculation.

- γ, γ' weight of resource domination for Chinese NOC decision-makers;
- i: host country/region; j: year;
- $EG_{i,j}$: earnings from global market sales from host country i in year j;
- $EI_{i,j}$: earnings from sales from host country i to the domestic market in year j;
- $I_{i,j}$: EODI exploration investments in host country I in year j;
- $OM_{i,j}$: operation and maintenance costs in host country i in year j;
- $SC_{i,j}$: storage costs in host country I in year j;
- s_{ij}^D: sales from host country i to domestic markets in year j;
- s_{ij}^G: sales from host country i to global markets in year j;
- $S_{i,j-1}$: Inventory in host country i by the end of previous year j-1;
- $S_{i,j}$: Inventory in host country i by the end of current year j;
- $p_{i,j}$: Production in host country i, year j;
- $e_{i,j}$: Exploration investments in host country i, year j;
- $s_{j_{historical}low}^G$: lowest amount sold to global markets;
- PC_{iJ}: Production capacity in host country i, year j;

Selected Programming Codes

The following appendices exhibit the annotated program codes for three scenarios of this P.E./Sensitivity Analysis: (1) P.E. Simulation for U.S.-Chinese EODIs for the Short-term (2011-2015); (2) Sensitivity Analysis of P.E. outcomes when choosing 3-year payback investment for the Mid-term (2011-2010); and (3) Sensitivity analysis of P.E. outcome of U.S.-China collaboration in EODIs for the long-term Scenario(2011-2025). For further inquiry of program codes, please contact via email: chaoling.feng@gmail.com

(Others are the same: here below are the sorted constraint conditions and iterations: AX<=b.
Note differences in array of location of k in A matrix**)**

1. P.E. Simulation for Short-Term Scenario

```
for i_region=1:1:7 %%  Region Setup
%% 1=Canada,2= OECD Europe 1, 3=FSU&E,Europe2, 4=Africa, 5=Middle East, 6=Other Eastern Hemisphere, 7=other western Hemisphere
%%%%%%%%%%%%%%%Parameter Setup: REGION 1%%%%%%%%%%%%%%%
if i_region==1
eus05=1331; %% E&D investment in 2005 in region 1
eus06=1201; %% E&D investment in 2006 in region 1
eus07=931; %% E&D investment in 2007   in region 1
eus08=1096; %% E&D investment in 2008 in region 1
eus09=1169; %% E&D investment in 2009 in region 1
PCus05=189012; %% Production capacity in 2005 in region 1
PCus06=164100; % Production capacity in 2006 in region 1
PCus07=151356; % Production capacity in 2007 in region 1
PCus08=152658; % Production capacity in 2008 in region 1
PCus09=191577; % Production capacity in 2009 in region 1
sGus_min=132538*0.2; %% minimum sale to global market from region 1.(US)
S_US_09=5472997;     %% total inventory by the end of 2009 in region 1.(US)
P_G_US07=52.76;      %% sale price in region 1-07
P_G_US08=83.3;       %% sale price in region 1 -08
P_G_US09=52.74;      %% sale prices in region 1-09
k_Gprice=2.66;       %% Delta_Pi_1
end
```

```
%%%%%%%%%%%%%%%%%%REGION 2-7 %%%%%%%%%%%%%%
   Similar as Region 1.

 %%%%%%%%% Parameter Setup: US domestic %%%%%%%%%%%%

P_D_US07=65.78;   %% U.S. domestic crude oil price-07
P_D_US08=98.44;   %% U.S. domestic crude oil price-07
P_D_US09=63.83;   %% U.S. domestic crude oil price-07
k_Dprice=3.134;   %% Delta_pi_0
k=31.97;  %% lambda

%%%%%%%%% Parameter Setup: China setup%%%%%%%%%%
r=0.5; %% when r=0.5;  PC_cn_0=1/2* PC_us_0;  E_cn_0=0.5*E_us_0
r_cn=2;  %%  weight on resource domination=historic Prof/E&D ratio_cn
r_e=1.02; %% Phi=2^1.02=2.023-> r_e=log(Phi)/log(2)
USC=10;
UOM=15.5;
ecn05=eus05*r;
ecn06=eus06*r;
ecn07=eus07*r;
ecn08=eus08*r;
ecn09=eus09*r;
PCcn05=PCus05*r;
PCcn06=PCus06*r;
PCcn07=PCus07*r;
PCcn08=PCus08*r;
PCcn09=PCus09*r;
sGus_max=1000000000;
sDus_min=1056751*0.2/7; %% US-domestic minimum sale
sDus_max=1000000000;
sGcn_min=sGus_min*r; %% CN-global sale minimum
sGcn_max=sGus_max*r;
sDcn_min=sDus_min*r;
sDcn_max=sDus_max*r;
S_CN_09=S_US_09*r;
```

```
%%%%%%%Parameter estimate: moving average to calculate future prices%%%%%%%%%%
  for i=1:1:5
    if i==1
      P_G_US(i)=k_Gprice+(0.1*P_G_US07+0.3*P_G_US08+0.6*P_G_US09);
    end
    if i==2
      P_G_US(i)=k_Gprice+(0.1*P_G_US08+0.3*P_G_US09+0.6*P_G_US(1));
    end
    if i==3
      P_G_US(i)=k_Gprice+(0.1*P_G_US09+0.3*P_G_US(1)+0.6*P_G_US(2));
    end
    if i>=4
      P_G_US(i)=k_Gprice+(0.1*P_G_US(i-3)+0.3*P_G_US(i-2)+0.6*P_G_US(i-1));
    end

   if i==1
      P_D_US(i)=k_Dprice+(0.1*P_D_US07+0.3*P_D_US08+0.6*P_D_US09);
    end
    if i==2
      P_D_US(i)=k_Dprice+(0.1*P_D_US08+0.3*P_D_US09+0.6*P_D_US(1));
    end
    if i==3
      P_D_US(i)=k_Dprice+(0.1*P_D_US09+0.3*P_D_US(1)+0.6*P_D_US(2));
    end
    if i>=4
      P_D_US(i)=k_Dprice+(0.1*P_D_US(i-3)+0.3*P_D_US(i-2)+0.6*P_D_US(i-1));
    end
  end
  for i=1:1:15
  P_G_CN(i)=P_G_US(i).*1.0;   %% China global sales prices
  P_D_CN(i)=P_D_US(i).*1.0575;  %% China sale prices to domestic market
  End
```

```
afus_C=5*USC*S_US_09;
afcn_C=5*USC*S_CN_09;

%%%%%%Sorting Constant vector (b_us) of the constraints (AX<=b) %%%%%%%
b1_us=(eus05+eus06+eus07+eus08+eus09).*(1+r).*r_e;
b2_us=(eus06+eus07+eus08+eus09).*(1+r).*r_e;
b3_us=(eus07+eus08+eus09).*(1+r).*r_e;
b4_us=(eus08+eus09).*(1+r).*r_e;
b5_us=eus09.*(1+r).*r_e;
b6_us=PCus05+PCus06+PCus07+PCus08+PCus09+eus09.*k;
b7_us=PCus06+PCus07+PCus08+PCus09;
b8_us=PCus07+PCus08+PCus09;
b9_us=PCus08+PCus09;
b10_us=PCus09;

%%%%%%%%%%% Sorting Constant vector (b_cn) of the constraints (AX<=b) %%%%%%
b1_cn=(ecn05+ecn06+ecn07+ecn08+ecn09).*(1+1./r).*r_e;
b2_cn=(ecn06+ecn07+ecn08+ecn09).*(1+1./r).*r_e;
b3_cn=(ecn07+ecn08+ecn09).*(1+1./r).*r_e;
b4_cn=(ecn08+ecn09).*(1+1./r).*r_e;
b5_cn=ecn09.*(1+1./r).*r_e;
b6_cn=PCcn05+PCcn06+PCcn07+PCcn08+PCcn09+ecn09.*k;
b7_cn=PCcn06+PCcn07+PCcn08+PCcn09;
b8_cn=PCcn07+PCcn08+PCcn09;
b9_cn=PCcn08+PCcn09;
b10_cn=PCcn09;

%%%%%%%%%% Sorting utility function parameter vector (f_us) %%%%%%%%%

for i_temp=1:1:5
afus1(i_temp)=-(P_G_US(i_temp)+(5-i_temp+1)*USC);
afus2(i_temp)=-(P_D_US(i_temp)+(5-i_temp+1)*USC);
afus3(i_temp)=1;
afus4(i_temp)=UOM+(5-i_temp+1)*USC;
end
f_us=[afus1(1);afus1(2);afus1(3);afus1(4);afus1(5);afus2(1);afus2(2);afus2(3);afus2(4);afus2
(5);afus3(1);afus3(2);afus3(3);afus3(4);afus3(5);afus4(1);afus4(2);afus4(3);afus4(4);afus4(5)];
```

```
%%%%%%%%% Sorting constraint parameter matrix A(A_us) %%%%%%%%

    A=[0 0 0 0 0 0 0 0 0 0 5 0 0 0 0 0 0 0 0 0;
      0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e 5 0 0 0 0 0 0 0 0;
      0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e 5 0 0 0 0 0 0 0;
      0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e 5 0 0 0 0 0 0;
      0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e 5 0 0 0 0 0;
      0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 5 0 0 0 0;
      0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 -1 5 0 0 0;
      0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 -1 -1 5 0 0;
      0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 -1 -1 -1 5 0;
      0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 -1 -1 -1 -1 5;
      1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 -1 0 0 0 0;
      1 1 0 0 0 1 1 0 0 0 0 0 0 0 0 -1 -1 0 0 0;
      1 1 1 0 0 1 1 1 0 0 0 0 0 0 0 -1 -1 -1 0 0;
      1 1 1 1 0 1 1 1 1 0 0 0 0 0 0 -1 -1 -1 -1 0;
      1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 -1 -1 -1 -1 -1];
    b=[b1_us;b2_us;b3_us;b4_us;b5_us;b6_us;b7_us;b8_us;b9_us;b10_us;S_US_09;S_US_09;S
_US_09;S_US_09;S_US_09];
    Aeq=[];
    beq=[];

    %%%%%%%%%%%% First iteration value setup%%%%%%%%%%%%%%%
    VLB=[sGus_min;sGus_min;sGus_min;sGus_min;sGus_min;sDus_min;sDus_min;sDus_min
;sDus_min;sDus_min;0;0;0;0;0;0;0;0;0;0];
    VUB=[];

    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
     Main function--utility function_us; f_us: objective function parameter matrix; A: sorted
constraint variable parameter matrix; b, VLB, VUB: constraint parameters;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

    [x,fval]=linprog(f_us,A,b,Aeq,beq,VLB,VUB);
    VLB_cn=[sGcn_min;sGcn_min;sGcn_min;sGcn_min;sGcn_min;sDcn_min;sDcn_min;sDcn
_min;sDcn_min;sDcn_min;0;0;0;0;0;0;0;0;0;0];
    VUB_cn=[];
    %% CN_paramter-matrix
    for i_temp=1:1:5
    afcn1(i_temp)=-(P_G_CN(i_temp)+(5-i_temp+1).*USC);
```

```
afcn2(i_temp)=-(P_D_CN(i_temp)+(5-i_temp+1).*USC);
afcn3(i_temp)=1-r_cn;
afcn4(i_temp)=UOM+(5-i_temp+1).*USC;
end
f_cn=[afcn1(1);afcn1(2);afcn1(3);afcn1(4);afcn1(5);afcn2(1);afcn2(2);afcn2(3);afcn2(4);afcn
2(5);afcn3(1);afcn3(2);afcn3(3);afcn3(4);afcn3(5);afcn4(1);afcn4(2);afcn4(3);afcn4(4);afcn4(5)];
A_cn=[0 0 0 0 0 0 0 0 0 0 5 0 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 -r_e 5 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 -r_e -r_e 5 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e 5 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e -r_e 5 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 5 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 -1*k 0 0 0 0 -1 5 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 -1*k 0 0 0 -1 -1 5 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 -1*k 0 0 -1 -1 -1 5 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 -1*k 0 -1 -1 -1 -1 5;
  1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 -1 0 0 0 0;
  1 1 0 0 0 1 1 0 0 0 0 0 0 0 0 -1 -1 0 0 0;
  1 1 1 0 0 1 1 1 0 0 0 0 0 0 0 -1 -1 -1 0 0;
  1 1 1 1 0 1 1 1 1 0 0 0 0 0 0 -1 -1 -1 -1 0;
  1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 -1 -1 -1 -1 -1];
b_cn=[b1_cn;b2_cn+x(11).*r_e;b3_cn+(x(11)+x(12)).*r_e;b4_cn+(x(11)+x(12)+x(13)).*r_e
;b5_cn+(x(11)+x(12)+x(13)+x(14)).*r_e;b6_cn;b7_cn;b8_cn;b9_cn;b10_cn;S_CN_09;S_CN_09
;S_CN_09;S_CN_09;S_CN_09];
[y,fval_cn]=linprog(f_cn,A_cn,b_cn,Aeq,beq,VLB_cn,VUB_cn);
 %% main function--utility function_cn; f_cn: objective function parameter matrix;A: sorted
constraint variable parameter matrix; b, VLB, VUB: constraint paramters;
 %% y--CN variables Y[5];
```

```
A_us=[0 0 0 0 0 0 0 0 0 0 5 0 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 -r_e 5 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 -r_e -r_e 5 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e 5 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e -r_e 5 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 5 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 -1*k 0 0 0 0 -1 5 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 -1*k 0 0 0 -1 -1 5 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 -1*k 0 0 -1 -1 -1 5 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 -1*k 0 -1 -1 -1 -1 5;
  1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 -1 0 0 0 0;
  1 1 0 0 0 1 1 0 0 0 0 0 0 0 0 -1 -1 0 0 0;
  1 1 1 0 0 1 1 1 0 0 0 0 0 0 0 -1 -1 -1 0 0;
  1 1 1 1 0 1 1 1 1 0 0 0 0 0 0 -1 -1 -1 -1 0;
  1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 -1 -1 -1 -1 -1];
b_us=[b1_us;b2_us+y(11).*r_e;b3_us+(y(11)+y(12)).*r_e;b4_us+(y(11)+y(12)+y(13)).*r_e;
b5_us+(y(11)+y(12)+y(13)+y(14)).*r_e;b6_us;b7_us;b8_us;b9_us;b10_us;S_US_09;S_US_09;S
_US_09;S_US_09;S_US_09];
[x,fval_us]=linprog(f_us,A_us,b_us,Aeq,beq,VLB,VUB);
i=0;
F0=1000000000; %% default starting value
F1=10; %% default starting value
while(abs(F0-F1)>100)
   F0=fval_us;
b_cn=[b1_cn;b2_cn+x(11).*r_e;b3_cn+(x(11)+x(12)).*r_e;b4_cn+(x(11)+x(12)+x(13)).*r_e;b5
_cn+(x(11)+x(12)+x(13)+x(14)).*r_e;b6_cn;b7_cn;b8_cn;b9_cn;b10_cn;S_CN_09;S_CN_09;S_
CN_09;S_CN_09;S_CN_09];
[y,fval_cn]=linprog(f_cn,A_cn,b_cn,Aeq,beq,VLB_cn,VUB_cn);
%% US exploration affects China (exploration capacity) constraint
b_us=[b1_us;b2_us+y(11).*r_e;b3_us+(y(11)+y(12)).*r_e;b4_us+(y(11)+y(12)+y(13)).*r_e;
b5_us+(y(11)+y(12)+y(13)+y(14)).*r_e;b6_us;b7_us;b8_us;b9_us;b10_us;S_US_09;S_US_09;S
_US_09;S_US_09;S_US_09];
[x,fval_us]=linprog(f_us,A_us,b_us,Aeq,beq,VLB,VUB);
%% CN exploration affects US(exploration capacity) constraint
   F1=fval_us;
 i=i+1; %% iteration and re-write new variable values.
end
-fval_cn-afcn_C
-fval_us-afus_C
```

2. **Sensitivity Analysis: EODIs in 3-year payback Outcome in Mid-term Scenario**

```
%%%%%%%%%%%%%%%%b_us vector%%%%%%%%%%%%%%%%
b1_us=(eus05+eus06+eus07+eus08+eus09).*(1+r).*r_e;%%
b2_us=(eus06+eus07+eus08+eus09).*(1+r).*r_e;
b3_us=(eus07+eus08+eus09).*(1+r).*r_e;
b4_us=(eus08+eus09).*(1+r).*r_e;
b5_us=eus09.*(1+r).*r_e;

b6_us=PCus05+PCus06+PCus07+PCus08+PCus09+eus07.*k;
b7_us=PCus06+PCus07+PCus08+PCus09+eus08.*k;
b8_us=PCus07+PCus08+PCus09+eus09.*k;
b9_us=PCus08+PCus09;
b10_us=PCus09;

%%%%%%%%%%%%%%%%b_cn vector %%%%%%%%%%%%%%%%
b1_cn=(ecn05+ecn06+ecn07+ecn08+ecn09).*(1+1./r).*r_e;
b2_cn=(ecn06+ecn07+ecn08+ecn09).*(1+1./r).*r_e;
b3_cn=(ecn07+ecn08+ecn09).*(1+1./r).*r_e;
b4_cn=(ecn08+ecn09).*(1+1./r).*r_e;
b5_cn=ecn09.*(1+1./r).*r_e;

b6_cn=PCcn05+PCcn06+PCcn07+PCcn08+PCcn09+ecn07.*k;
b7_cn=PCcn06+PCcn07+PCcn08+PCcn09+ecn08.*k;
b8_cn=PCcn07+PCcn08+PCcn09+ecn09.*k;
b9_cn=PCcn08+PCcn09;
b10_cn=PCcn09;

for i_temp=1:1:10
afus1(i_temp)=-(P_G_US(i_temp)+(10-i_temp+1)*USC);
afus2(i_temp)=-(P_D_US(i_temp)+(10-i_temp+1)*USC);
afus3(i_temp)=1;
afus4(i_temp)=UOM+(10-i_temp+1)*USC;
end
```

```
f_us=[afus1(1);afus1(2);afus1(3);afus1(4);afus1(5);afus1(6);afus1(7);afus1(8);afus1(9);afus1
(10);afus2(1);afus2(2);afus2(3);afus2(4);afus2(5);afus2(6);afus2(7);afus2(8);afus2(9);afus2(1
0);afus3(1);afus3(2);afus3(3);afus3(4);afus3(5);afus3(6);afus3(7);afus3(8);afus3(9);afus3(10)
;afus4(1);afus4(2);afus4(3);afus4(4);afus4(5);afus4(6);afus4(7);afus4(8);afus4(9);afus4(10)];
```

```
A=[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e 5 0 0 0 0 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e 5 0 0 0 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e 5 0 0 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 5 0 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 5 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 5 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 0 0 -1 -1 -1 5 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 0 -1 -1 -1 -1 5 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5;
  1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 0 0 0 0 0 0 0 0 0;
  1 1 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 0 0 0 0 0 0 0 0;
  1 1 1 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 0 0 0 0 0 0 0;
  1 1 1 1 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 0 0 0 0 0 0;
  1 1 1 1 1 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 0 0 0 0 0;
  1 1 1 1 1 1 0 0 0 0 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 0 0 0 0;
  1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 0 0 0;
  1 1 1 1 1 1 1 1 0 0 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 0 0;
  1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 0;
  1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1];
```

```
b=[b1_us;b2_us;b3_us;b4_us;b5_us;0;0;0;0;0;b6_us;b7_us;b8_us;b9_us;b10_us;0;0;0;0;0;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09];
    Aeq=[];
    beq=[];
    VLB=[sGus_min;sGus_min;sGus_min;sGus_min;sGus_min;sGus_min;sGus_min;sGus_min;sGus_min;sGus_min;sDus_min;sDus_min;sDus_min;sDus_min;sDus_min;sDus_min;sDus_min;sDus_min;sDus_min;sDus_min;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0];
    VUB=[];

    [x,fval]=linprog(f_us,A,b,Aeq,beq,VLB,VUB);
     %%

    VLB_cn=[sGcn_min;sGcn_min;sGcn_min;sGcn_min;sGcn_min;sGcn_min;sGcn_min;sGcn_min;sGcn_min;sGcn_min;sDcn_min;sDcn_min;sDcn_min;sDcn_min;sDcn_min;sDcn_min;sDcn_min;sDcn_min;sDcn_min;sDcn_min;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0];
    VUB_cn=[];

    %%afcn 0~20:
    for i_temp=1:1:10

    afcn1(i_temp)=-(P_G_CN(i_temp)+(10-i_temp+1).*USC);
    afcn2(i_temp)=-(P_D_CN(i_temp)+(10-i_temp+1).*USC);
    afcn3(i_temp)=1-r_cn;
    afcn4(i_temp)=UOM+(10-i_temp+1).*USC;
    end
    f_cn=[afcn1(1);afcn1(2);afcn1(3);afcn1(4);afcn1(5);afcn1(6);afcn1(7);afcn1(8);afcn1(9);afcn1(10);afcn2(1);afcn2(2);afcn2(3);afcn2(4);afcn2(5);afcn2(6);afcn2(7);afcn2(8);afcn2(9);afcn2(10);afcn3(1);afcn3(2);afcn3(3);afcn3(4);afcn3(5);afcn3(6);afcn3(7);afcn3(8);afcn3(9);afcn3(10);afcn4(1);afcn4(2);afcn4(3);afcn4(4);afcn4(5);afcn4(6);afcn4(7);afcn4(8);afcn4(9);afcn4(10)];
```

```
A_cn=[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0;
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0;
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0 0;
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 5 0 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 5 0 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 5 0 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 0 0 -1 -1 -1 5 0 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 0 -1 -1 -1 -1 5 0 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0;
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5;
  1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 0 0 0 0 0 0 0 0 0;
  1 1 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 0 0 0 0 0 0 0 0;
  1 1 1 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 0 0 0 0 0 0 0;
  1 1 1 1 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 0 0 0 0 0 0;
  1 1 1 1 1 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 0 0 0 0 0;
  1 1 1 1 1 1 0 0 0 0 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 0 0 0 0;
  1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 0 0 0;
  1 1 1 1 1 1 1 1 0 0 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 0 0;
  1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 0;
  1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1];

b_cn=[b1_cn;b2_cn+x(21).*r_e;b3_cn+(x(21)+x(22)).*r_e;b4_cn+(x(21)+x(22)+x(23)).*r_e;b5_cn+(x(21)+x(22)+x(23)+x(24)).*r_e;(x(21)+x(22)+x(23)+x(24)+x(25)).*r_e;(x(22)+x(23)+x(24)+x(25)+x(26)).*r_e;(x(23)+x(24)+x(25)+x(26)+x(27)).*r_e;(x(24)+x(25)+x(26)+x(27)+x(28)).*r_e;(x(25)+x(26)+x(27)+x(28)+x(29)).*r_e;b6_cn;b7_cn;b8_cn;b9_cn;b10_cn;0;0;0;0;0;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09];

[y,fval_cn]=linprog(f_cn,A_cn,b_cn,Aeq,beq,VLB_cn,VUB_cn);
```

```
%%
A_us=A_cn;
b_us=[b1_us;b2_us+y(21).*r_e;b3_us+(y(21)+y(22)).*r_e;b4_us+(y(21)+y(22)+y(23)).*
r_e;b5_us+(y(21)+y(22)+y(23)+y(24)).*r_e;(y(21)+y(22)+y(23)+y(24)+y(25)).*r_e;(y(22)+y
(23)+y(24)+y(25)+y(26)).*r_e;(y(23)+y(24)+y(25)+y(26)+y(27)).*r_e;(y(24)+y(25)+y(26)+
y(27)+y(28)).*r_e;(y(25)+y(26)+y(27)+y(28)+y(29)).*r_e;b6_us;b7_us;b8_us;b9_us;b10_us;
0;0;0;0;0;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S
_US_09;S_US_09];
[x,fval_us]=linprog(f_us,A_us,b_us,Aeq,beq,VLB,VUB);

i=0;
F0=1000000000;
F1=10;

while(abs(F0-F1)>100)
   F0=fval_us;

b_cn=[b1_cn;b2_cn+x(21).*r_e;b3_cn+(x(21)+x(22)).*r_e;b4_cn+(x(21)+x(22)+x(23)).*
r_e;b5_cn+(x(21)+x(22)+x(23)+x(24)).*r_e;(x(21)+x(22)+x(23)+x(24)+x(25)).*r_e;(x(22)+
x(23)+x(24)+x(25)+x(26)).*r_e;(x(23)+x(24)+x(25)+x(26)+x(27)).*r_e;(x(24)+x(25)+x(26)
+x(27)+x(28)).*r_e;(x(25)+x(26)+x(27)+x(28)+x(29)).*r_e;b6_cn;b7_cn;b8_cn;b9_cn;b10_c
n;0;0;0;0;0;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_
09;S_CN_09;S_CN_09];
[y,fval_cn]=linprog(f_cn,A_cn,b_cn,Aeq,beq,VLB_cn,VUB_cn);


b_us=[b1_us;b2_us+y(21).*r_e;b3_us+(y(21)+y(22)).*r_e;b4_us+(y(21)+y(22)+y(23)).*r_e;
b5_us+(y(21)+y(22)+y(23)+y(24)).*r_e;(y(21)+y(22)+y(23)+y(24)+y(25)).*r_e;(y(22)+y(23
)+y(24)+y(25)+y(26)).*r_e;(y(23)+y(24)+y(25)+y(26)+y(27)).*r_e;(y(24)+y(25)+y(26)+y(2
7)+y(28)).*r_e;(y(25)+y(26)+y(27)+y(28)+y(29)).*r_e;b6_us;b7_us;b8_us;b9_us;b10_us;0;0
;0;0;0;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_U
S_09;S_US_09];
[x,fval_us]=linprog(f_us,A_us,b_us,Aeq,beq,VLB,VUB);
   F1=fval_us;
 i=i+1;
end
-fval_cn-afcn_C
-fval_us-afus_C
```

3. Sensitivity Analysis: U.S. –China EODIs collaboration under the long-term Scenario

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
b1_us=(eus05+eus06+eus07+eus08+eus09).*(1+r).*r_e;%%
b2_us=(eus06+eus07+eus08+eus09).*(1+r).*r_e;
b3_us=(eus07+eus08+eus09).*(1+r).*r_e;
b4_us=(eus08+eus09).*(1+r).*r_e;
b5_us=eus09.*(1+r).*r_e;
b6_us=PCus05+PCus06+PCus07+PCus08+PCus09+eus09.*(1+r).*k;
b7_us=PCus06+PCus07+PCus08+PCus09;
b8_us=PCus07+PCus08+PCus09;
b9_us=PCus08+PCus09;
b10_us=PCus09;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
b1_cn=(ecn05+ecn06+ecn07+ecn08+ecn09).*(1+1./r).*r_e;
b2_cn=(ecn06+ecn07+ecn08+ecn09).*(1+1./r).*r_e;
b3_cn=(ecn07+ecn08+ecn09).*(1+1./r).*r_e;
b4_cn=(ecn08+ecn09).*(1+1./r).*r_e;
b5_cn=ecn09.*(1+1./r).*r_e;
b6_cn=PCcn05+PCcn06+PCcn07+PCcn08+PCcn09+ecn09.*(1+r).*k;
b7_cn=PCcn06+PCcn07+PCcn08+PCcn09;
b8_cn=PCcn07+PCcn08+PCcn09;
b9_cn=PCcn08+PCcn09;
b10_cn=PCcn09;
for i_temp=1:1:15
afus1(i_temp)=-(P_G_US(i_temp)+(15-i_temp+1)*USC);
afus2(i_temp)=-(P_D_US(i_temp)+(15-i_temp+1)*USC);
afus3(i_temp)=1;
afus4(i_temp)=UOM+(15-i_temp+1)*USC;
end
f_us=[afus1(1);afus1(2);afus1(3);afus1(4);afus1(5);afus1(6);afus1(7);afus1(8);afus1(9);afus1(10)
;afus1(11);afus1(12);afus1(13);afus1(14);afus1(15);afus2(1);afus2(2);afus2(3);afus2(4);afus2(5);
afus2(6);afus2(7);afus2(8);afus2(9);afus2(10);afus2(11);afus2(12);afus2(13);afus2(14);afus2(15)
;afus3(1);afus3(2);afus3(3);afus3(4);afus3(5);afus3(6);afus3(7);afus3(8);afus3(9);afus3(10);afus
3(11);afus3(12);afus3(13);afus3(14);afus3(15);afus4(1);afus4(2);afus4(3);afus4(4);afus4(5);afus
4(6);afus4(7);afus4(8);afus4(9);afus4(10);afus4(11);afus4(12);afus4(13);afus4(14);afus4(15)];
```

```
A=[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e 5 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e 5 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e 5 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e 5 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e 5 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e 5 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e 5 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e 5
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e
5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -(1+r).*r_e -
(1+r).*r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
```

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*k 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 5 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*k 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 5 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*k 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 5 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*k 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 5 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*k 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*k 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*k 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*k 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*k 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*k 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*k 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*k 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*k 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -(1+r).*k 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5;
1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 0 0 0 0 0 0 0 0 0 0 0 0 0;
1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 0 0 0 0 0 0 0 0 0 0 0 0;
1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 0 0 0 0 0 0 0 0 0 0 0;
1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 0 0 0 0 0 0 0 0 0 0;
1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 0 0 0 0 0 0 0 0 0;
1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 0 0 0 0 0 0 0 0;
1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 0 0 0 0 0 0 0;
1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 0 0 0 0 0;
1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 0 0 0 0;
1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 0 0 0;
1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 0 0;
1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 0;

1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0;
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1];

```
b=[b1_us;b2_us;b3_us;b4_us;b5_us;0;0;0;0;0;0;0;0;0;0;b6_us;b7_us;b8_us;b9_us;b10_us;0;
0;0;0;0;0;0;0;0;0;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_
09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09];

%% collaboration scenario A matrix difference (K location)
Aeq=[];
beq=[];
VLB=[sGus_min;sGus_min;sGus_min;sGus_min;sGus_min;sGus_min;sGus_min;sGus_min
;sGus_min;sGus_min;sGus_min;sGus_min;sGus_min;sGus_min;sGus_min;sDus_min;sDus_mi
n;sDus_min;sDus_min;sDus_min;sDus_min;sDus_min;sDus_min;sDus_min;sDus_min;sDus_m
in;sDus_min;sDus_min;sDus_min;sDus_min;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;
0;0;0;0];
VUB=[];

[x,fval]=linprog(f_us,A,b,Aeq,beq,VLB,VUB);
VLB_cn=[sGcn_min;sGcn_min;sGcn_min;sGcn_min;sGcn_min;sGcn_min;sGcn_min;sGcn
_min;sGcn_min;sGcn_min;sGcn_min;sGcn_min;sGcn_min;sGcn_min;sGcn_min;sDcn_min;sDc
n_min;sDcn_min;sDcn_min;sDcn_min;sDcn_min;sDcn_min;sDcn_min;sDcn_min;sDcn_min;s
Dcn_min;sDcn_min;sDcn_min;sDcn_min;sDcn_min;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;
0;0;0;0;0;0;0;0];
VUB_cn=[];
for i_temp=1:1:15
afcn1(i_temp)=-(P_G_CN(i_temp)+(15-i_temp+1).*USC);
afcn2(i_temp)=-(P_D_CN(i_temp)+(15-i_temp+1).*USC);
afcn3(i_temp)=1-r_cn;
afcn4(i_temp)=UOM+(15-i_temp+1).*USC;
end
f_cn=[afcn1(1);afcn1(2);afcn1(3);afcn1(4);afcn1(5);afcn1(6);afcn1(7);afcn1(8);afcn1(9);afcn
1(10);afcn1(11);afcn1(12);afcn1(13);afcn1(14);afcn1(15);afcn2(1);afcn2(2);afcn2(3);afcn2(4);af
cn2(5);afcn2(6);afcn2(7);afcn2(8);afcn2(9);afcn2(10);afcn2(11);afcn2(12);afcn2(13);afcn2(14);a
fcn2(15);afcn3(1);afcn3(2);afcn3(3);afcn3(4);afcn3(5);afcn3(6);afcn3(7);afcn3(8);afcn3(9);afcn3
(10);afcn3(11);afcn3(12);afcn3(13);afcn3(14);afcn3(15);afcn4(1);afcn4(2);afcn4(3);afcn4(4);afc
n4(5);afcn4(6);afcn4(7);afcn4(8);afcn4(9);afcn4(10);afcn4(11);afcn4(12);afcn4(13);afcn4(14);af
cn4(15)];
```

```
A_cn=[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -r_e -r_e -r_e -r_e -r_e 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 5 0 0 0 0 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 5 0 0 0 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 5 0 0 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 5 0 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0 0;
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5 0;
        0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -k 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 5;
        1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
        1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 0 0 0 0 0 0 0 0 0 0 0 0 0;
        1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 0 0 0 0 0 0 0 0 0 0 0 0;
```

1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 0 0 0 0 0 0 0 0 0 0 0;
1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 0 0 0 0 0 0 0 0 0 0;
1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 0 0 0 0 0 0 0 0 0;
1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 0 0 0 0 0 0 0 0;
1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 0 0 0 0 0 0 0;
1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 0 0 0 0 0;
1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 0 0 0 0;
1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 0 0 0;
1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 0 0;
1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 0;
1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0;
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 1];

```
b_cn=[b1_cn;b2_cn+x(31).*r_e;b3_cn+(x(31)+x(32)).*r_e;b4_cn+(x(31)+x(32)+x(33)).*r_e
;b5_cn+(x(31)+x(32)+x(33)+x(34)).*r_e;(x(31)+x(32)+x(33)+x(34)+x(35)).*r_e;(x(32)+x(33)+x
(34)+x(35)+x(36)).*r_e;(x(33)+x(34)+x(35)+x(36)+x(37)).*r_e;(x(34)+x(35)+x(36)+x(37)+x(38
)).*r_e;(x(35)+x(36)+x(37)+x(38)+x(39)).*r_e;(x(36)+x(37)+x(38)+x(39)+x(40)).*r_e;(x(37)+x(
38)+x(39)+x(40)+x(41)).*r_e;(x(38)+x(39)+x(40)+x(41)+x(42)).*r_e;(x(39)+x(40)+x(41)+x(42)
+x(43)).*r_e;(x(40)+x(41)+x(42)+x(43)+x(44)).*r_e;b6_cn;b7_cn+x(31).*k;b8_cn+x(32).*k;b9
_cn+x(33).*k;b10_cn+x(34).*k;+x(35).*k;+x(36).*k;+x(37).*k;+x(38).*k;+x(39).*k;+x(40).*k;
+x(41).*k;+x(42).*k;+x(43).*k;+x(44).*k;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S
_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_
CN_09];
 %% collaboration scenario A matrix difference (K location)
[y,fval_cn]=linprog(f_cn,A_cn,b_cn,Aeq,beq,VLB_cn,VUB_cn);
A_us=A_cn;
b_us=[b1_us;b2_cn+y(31).*r_e;b3_us+(y(31)+y(32)).*r_e;b4_us+(y(31)+y(32)+y(33)).*r_e;
b5_us+(y(31)+y(32)+y(33)+y(34)).*r_e;(y(31)+y(32)+y(33)+y(34)+y(35)).*r_e;(y(32)+y(33)+y(
34)+y(35)+y(36)).*r_e;(y(33)+y(34)+y(35)+y(36)+y(37)).*r_e;(y(34)+y(35)+y(36)+y(37)+y(38)
).*r_e;(y(35)+y(36)+y(37)+y(38)+y(39)).*r_e;(y(36)+y(37)+y(38)+y(39)+y(40)).*r_e;(y(37)+y(
38)+y(39)+y(40)+y(41)).*r_e;(y(38)+y(39)+y(40)+y(41)+y(42)).*r_e;(y(39)+y(40)+y(41)+y(42)
+y(43)).*r_e;(y(40)+y(41)+y(42)+y(43)+y(44)).*r_e;b6_us;b7_us+y(31).*k;b8_us+y(32).*k;b9_
us+y(34).*k;b10_us+y(34).*k;+y(35).*k;+y(36).*k;+y(37).*k;+y(38).*k;+y(39).*k;+y(40).*k;+y
(41).*k;+y(42).*k;+y(43).*k;+y(44).*k;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US
_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09]
;
[x,fval_us]=linprog(f_us,A_us,b_us,Aeq,beq,VLB,VUB);
i=0;
F0=1000000000;
F1=10;
while(abs(F0-F1)>100)
  F0=fval_us;
b_cn=[b1_cn;b2_cn+x(31).*r_e;b3_cn+(x(31)+x(32)).*r_e;b4_cn+(x(31)+x(32)+x(33)).*r_e
;b5_cn+(x(31)+x(32)+x(33)+x(34)).*r_e;(x(31)+x(32)+x(33)+x(34)+x(35)).*r_e;(x(32)+x(33)+x
(34)+x(35)+x(36)).*r_e;(x(33)+x(34)+x(35)+x(36)+x(37)).*r_e;(x(34)+x(35)+x(36)+x(37)+x(38
)).*r_e;(x(35)+x(36)+x(37)+x(38)+x(39)).*r_e;(x(36)+x(37)+x(38)+x(39)+x(40)).*r_e;(x(37)+x(
38)+x(39)+x(40)+x(41)).*r_e;(x(38)+x(39)+x(40)+x(41)+x(42)).*r_e;(x(39)+x(40)+x(41)+x(42)
+x(43)).*r_e;(x(40)+x(41)+x(42)+x(43)+x(44)).*r_e;b6_cn;b7_cn+x(31).*k;b8_cn+x(32).*k;b9
_cn+x(33).*k;b10_cn+x(34).*k;+x(35).*k;+x(36).*k;+x(37).*k;+x(38).*k;+x(39).*k;+x(40).*k;
+x(41).*k;+x(42).*k;+x(43).*k;+x(44).*k;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S
```

```
_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_CN_09;S_
CN_09];
    [y,fval_cn]=linprog(f_cn,A_cn,b_cn,Aeq,beq,VLB_cn,VUB_cn);
            %% constants;k factor--> CN-production capacity constrained is increased to include
contributions of exploration efforts from the US(k*x(.))
    b_us=[b1_us;b2_cn+y(31).*r_e;b3_us+(y(31)+y(32)).*r_e;b4_us+(y(31)+y(32)+y(33)).*r_e;
b5_us+(y(31)+y(32)+y(33)+y(34)).*r_e;(y(31)+y(32)+y(33)+y(34)+y(35)).*r_e;(y(32)+y(33)+y(
34)+y(35)+y(36)).*r_e;(y(33)+y(34)+y(35)+y(36)+y(37)).*r_e;(y(34)+y(35)+y(36)+y(37)+y(38)
).*r_e;(y(35)+y(36)+y(37)+y(38)+y(39)).*r_e;(y(36)+y(37)+y(38)+y(39)+y(40)).*r_e;(y(37)+y(
38)+y(39)+y(40)+y(41)).*r_e;(y(38)+y(39)+y(40)+y(41)+y(42)).*r_e;(y(39)+y(40)+y(41)+y(42)
+y(43)).*r_e;(y(40)+y(41)+y(42)+y(43)+y(44)).*r_e;b6_us;b7_us+y(31).*k;b8_us+y(32).*k;b9_
us+y(34).*k;b10_us+y(34).*k;+y(35).*k;+y(36).*k;+y(37).*k;+y(38).*k;+y(39).*k;+y(40).*k;+y
(41).*k;+y(42).*k;+y(43).*k;+y(44).*k;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US
_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09;S_US_09]
;
     [x,fval_us]=linprog(f_us,A_us,b_us,Aeq,beq,VLB,VUB);
             %% constants;k factor--> US-production capacity constrained is increased to include
contributions of exploration efforts from the CN(k*y(.))
       F1=fval_us;
      i=i+1;
    end
    -fval_cn-afcn_C
    -fval_us-afus_C
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