Quantitative Analysis of the Civilian Bilateral Cooperation in Front-End of the Nuclear Fuel Cycle

Viet Phuong Nguyen, Man-Sung Yim*
Nuclear Energy Environment and Nuclear Security Laboratory, Department of Nuclear and Quantum Engineering
Korea Advanced Institute of Science and Technology, 291 Daehak-ro, Yuseong, Daejeon 305-701, Korea
* Corresponding author: msyim@kaist.ac.kr

1. Introduction

As part of the academic endeavour in analysing the proliferation risks of nuclear power, bilateral civilian nuclear cooperation has been studied through both qualitative and quantitative analysis in order to establish the implications of such cooperation on nuclear proliferation. A substantial part of such cooperation is related to the front-end of the nuclear fuel cycle, which encompasses the processes that help manufacturing nuclear fuel, including mining and milling of natural uranium, refining and chemical conversion, enrichment (in case of fuels for Pressurized Water Reactor – PWR), and fuel fabrication. Traditionally, the supply of natural uranium was dominated by Canada and Australia, whereas enrichment services have been mostly provided by companies from Western states or Russia, which are also the main customers of such services [1]. However, Kazakhstan and African countries like Niger, Namibia, and Malawi have emerged as important suppliers in the international uranium market [2] and recent forecasts show that China will soon become a major player in the front-end market as both consumer and service provider. In this paper, the correlation between bilateral civil nuclear cooperation in front-end of the nuclear fuel cycle and the political and economic relationship among countries was examined through a dataset of bilateral nuclear cooperation in the post-Cold War era, from 1990 to 2011. This period was selected based on the observation that the geo-political landscape, as well as the conditions for civilian nuclear cooperation, have changed drastically after the end of the Cold War.

2. Methods and Results

In this section, the development of the dependent and independent variables in the bilateral nuclear cooperation dataset is presented. The correlations between those attributes are examined using linear regression analysis and the findings are discussed with respect to their implications to nuclear nonproliferation and export control regimes.

2.1 Dependent variable

A dichotomy variable named *nuccop* was selected to represent the civilian nuclear cooperation between two countries. This variable has value "1" if, since 1990, there have existed exporting activities related to front-end from an exporter to an importer, including material export of natural or enriched uranium, export of front-end services like conversion or enrichment, or financial export in form or partnership or ownership in front-end projects. The variable was coded "0" otherwise. To get a comprehensive view of the front-end bilateral cooperation worldwide, 100 states were chosen in this study due to their existing or potential involvement in front-end activities, of which 65 were solely "importer" whereas the other 35 were considered as both "exporter" and "importer" taking into account their front-end capabilities and potentials. As such, 3465 *dyads* (pair of countries) were formed with one *nuccop* value assigned to each dyad based upon the literature review of academic papers and other information sources such as the International Atomic Energy Agency (IAEA), the World Nuclear Association (WNA), or the Nuclear Threat Initiative (NTI).

2.2 Independent variables

The independent variables were selected to reflect the bilateral relationship between countries in both political and economic aspects. These variables were developed based on the publicly available databases of: the International Monetary Fund (IMF); the World Trade Organisation (WTO); the Nuclear Energy Agency (NEA); the United Nations Conference on Trade and Development (UNCTAD); the Stockholm International Peace Research Institute (SIPRI); and the projects Correlates of War (COW), Polity IV, and Rivalry dataset [3]. Since the existence of a nuclear cooperation agreement (NCA) is often the prerequisite condition for civilian nuclear trade [4] and the geographical proximity would likely facilitate such transaction, these two were considered as control variables of this analysis. Brief description of these variables is presented in Table 1.

Table 1: Description of the independent variables utilized to describe the relationship between two states

No	Variable and description	Reference
Variables related to political aspect		
01	*polidiff*: Similarity in term of democracy level, reflected through the Polity IV score	Polity IV Project
02	*affinity*: Similarity in the voting results at the United Nations General Assembly	COW

03	*alliance*: Existence of a military alliance between two country since 1990	COW
04	*midbdiff*: Similarity in term of level of involvement in militarized interstate dispute	COW
05	*rival1990*: Existence of rivalry between two countries since 1990	Rivalry dataset
06	*igo*: Similarity in term of participation in international governmental organizations	COW
07	*ce1990*: Existence of common enemy between two countries since 1990	Rivalry dataset
Variables related to economic aspect		
01	*bitrade*: Bilateral trade between two countries	IMF
02	*fdi*: Foreign direct investment from the nuclear exporter to its importer	UNCTAD
03	*armtrade*: Existence of conventional weapon transactions from the nuclear exporter to its importer	SIPRI
04	*GDP1/GDP2*: Ratio of GDP between the nuclear exporter and its importer	WTO
05	*cinc*: Similarity in term of industrial capabilities of two countries, reflected through the Composite Index of National Capability (CINC)	COW
06	*u_diff*: Difference in term of annual net uranium production capabilities (annual production minus requirement) between two countries	NEA
Control variables		
01	*proximity*: Geographical proximity between countries	COW
02	*nca1990*: Existence of a nuclear cooperation agreement between two countries since 1990	NCA dataset

2.3 Regression results

Possible correlations between the dependent variable *nuccop* and the above-mentioned independent attributes were investigated through simple linear regression analysis using the method proposed by Nelson and Sprecher (2010) [5]. The regression results show that there is a statistically significant correlation between the existence of bilateral cooperation in front-end of the nuclear fuel cycle and all the independent variables except for the politics-related variables *polidiff*, *midbdiff*, *igo*, and *ce1990*. Among those statistically significant attributes, the economics-related factors have more important influence on the dependent variable *nuccop*, of which the difference in term of net uranium production capabilities *u_diff* has the strongest effect, followed by the bilateral trade *bitrade*, and the foreign direct investment *fdi*. As predicted, the control variables *proximity* and *nca1990* also strongly correlate with the dependent variable *nuccop*. The resulted coefficients of the statistically significant variables from the regression analysis are presented in Figure 1.

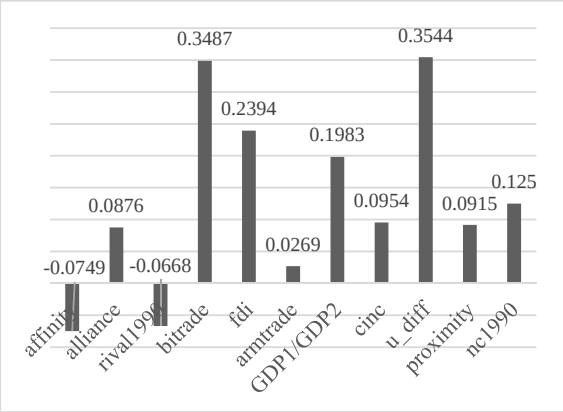

Fig. 1. Correlation coefficients of the statistically significant independent variables with the dependent variable *nuccop* resulted from the regression analysis.

2.4 Discussions

From the regression results, it can be observed that the commercial factors have significant contribution to the existence of bilateral cooperation related to front-end of the nuclear fuel cycle. This quantitative finding complements the traditional view on civilian nuclear cooperation, in which strategic and geo-political factors are more important in enabling nuclear assistance [4][6], and is in accordance with a recent qualitative assessment by Lantis (2014) regarding this aspect [7]. As uranium and front-end capabilities like enrichment are essential to both nuclear power development and possible proliferation intent, the research on forecasting and preventing nuclear proliferation should take into account such implication of the economics-related factors.

Using the above-mentioned coefficents to calculate the potential of the exporting countries in creating new tie with the importing countries, it was found that China and Kazakhstan have significant potential in expanding their front-end exportation. Given this situation, the export regimes, especially the Nuclear Suppliers Group (NSG), needs to be reviewed and strengthened, since China and Kazakhstan are relatively new NSG members with lesser experiences in nuclear export control.

3. Conclusions

To study the socio-economic nature of the bilateral cooperation related to front-end of the nuclear fuel cycle, a new dataset was developed including both political and economic aspects of such cooperation. Using linear regression analysis, a strong correlation between the existence of bilateral front-end cooperation and the

commercial attributes was observed. Such finding has implication on not only the nonproliferation research but also the necessary reinforcement of export control regimes like such as the Nuclear Suppliers Group. Further improvement of this dataset and the regression method are also needed in order to increase the robustness of the findings as well as to cover the whole scope of the nuclear fuel cycle, including both front-end and back-end activities.

REFERENCES

[1] G. Rothwell, Market Power in Uranium Enrichment, Science & Global Security: The Technical Basis for Arms Control, Disarmament, and Nonproliferation Initiatives, 17:2-3, 132-154, 2009.
[2] OECD/NEA & IAEA, Uranium 2014: Resources, Production and Demand, Organisation for Economic Co-Operation and Development, 2014.
[3] J. P. Klein & G. Goertz, The New Rivalry Dataset: Procedures and Patterns, Journal of Peace Research, Vol. 43, No. 3, 2006.
[4] M. Fuhrmann, Taking a Walk on the Supply Side: The Determinants of Civilian Nuclear Cooperation, Journal of Conflict Resolution, Vol. 53, No. 2, 2009.
[5] P. Nelson & C. M. Sprecher, Are sensitive technologies enablers of civil nuclear power? An empirical study, Atoms for Peace – An International Journal, Vol. 3, No. 2, 2010.
[6] M. Kroenig, Exporting the Bomb: Why States Provide Sensitive Nuclear Assistance, American Political Science Review, Vol. 103, No. 1, 2009.
[7] J. Lantis, Economic Competition and Nuclear Cooperation, The Nonproliferation Review, Vol. 21, No. 1, 2014.