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BEYOND COST: PRODUCT COMPLEXITY AND THE GLOBAL PRODUCT DEVELOPMENT LOCATION ADVANTAGE

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ABSTRACT:

Discussions of location advantages in global product development are largely based on self-reported surveys, and often agnostic to product characteristics. We build on this previous work by investigating location advantages and the influence of product complexity using negative binomial models. We find that the likelihood of developing products in a country increases as its market size, number of engineering graduates and national capability increases. However, it neither varies with labor cost nor market growth rate. We also find that complex products are more likely to be developed in countries with high national capability, and national capability is directly related to firm capability.

Keywords: global product development, location advantage, complexity, capability, market size, engineering workforce, labor cost and market growth rate.

1 INTRODUCTION

Many firms involved in global product development cite several reasons for choosing to develop products specified countries. For instance, General Electric cites “strong market growth, dynamic innovation and highly qualified people”[1; p. 20], and Schneider Electric cites “reducing product expenses”[2; p. 13]. As stated by the companies, the list of these location advantages is long. Since research in global product development has been growing, we can now investigate some of the cited location advantages. Current investigations have largely relied on opinion surveys while others have generalized from related streams of research such as international research and development, and multinational enterprises research. In this paper, we focus specifically on global product development and empirically investigate three themes that contribute to a holistic understanding of location advantages in global product development. We first investigate location advantages using generalized linear models. Such models have not been employed in this stream of research before. Secondly, we investigate the moderating role of product complexity, and thirdly, we investigate the relationship between firm capability and national capability as instigated by investigation of product complexity and location advantages.

Besides contributing to an academic understanding of global product development, our work enables executives to see through the fog and make informed location advantage decisions. Bringing product characteristics such as complexity into the decision processes improves decisions beyond what the literature has covered so far. Moreover, we observed firms making such location decisions on a one-off basis; hence a systematic understanding will help improve global product development.

The rest of this paper is structured such that Section 2 reviews related literature. Since global product development literature is nascent, we use international research and development, and multinational enterprise research as starting points. Section 3 describes our research method which is divided into two phases. The first phase enables us to down select reviewed location advantages to those applicable to global product development while the second phase describes our methods for investigating the resultant location advantage hypotheses. Section 4 describes the negative binomial model analysis which we use to test the hypotheses and Section 5 covers the hypotheses tests results in detail. While Section 6 summarizes the results and Section 7 highlights our contributions, Section 8 discusses the results and their implications for making decisions in global product development.

2 REVIEW OF THE LITERATURE

Global Product Development (GPD) is defined as a “single, coordinated, product development operation that includes distributed teams in more than one country utilizing a fully digital and connected collaborative product development process”[3, p. 23]. In choosing the countries to develop product modules or phases of product development, firms consider advantages associated with each country i.e. location advantages. Since literature specific to GPD is scant, we use international research and development (international R&D), and multinational enterprise (MNE) research as launching pads for literature on these location advantages. However, the three are slightly different. While GPD is primarily concerned with product development, international R&D is “primarily concerned with expanding scientific knowledge and assessing its feasibility”[4; p. 71], and MNE research is more holistic encompassing different aspects of the enterprise such as strategy [5-7], human resources [8, 9], leadership styles [10, 11], and marketing [12, 13]. Thus we will review location advantages from these research streams and use the first phase of our research to down select location advantages relevant to global product development.

2.1 Labor Cost

Doz, Santos, and Williamson [7] argue that cheap labor is a common location advantage. Their findings are grounded in extensive qualitative case studies of thirty six companies from North America, Asia and Europe. Dias and Galina [14], Eppinger and Chitkara [3], and von Zedtwitz and Gassman [15] come to the same conclusion as Doz et al. [7] though they study different industries. Dias and Galina [14] study the Brazilian automobile and telecommunications industries, Eppinger and Chitkara [3] study the manufacturing industry, and von Zedtwitz and Gossman[15] study a wide breadth of industries.

Kumar [16] finds that “the relative cost of qualified R&D personnel, holding supply constant, does seem to affect the global pattern of location of overseas R&D especially for the Japanese [vs. US] MNEs” (p 168). Though the tone of his statement is nuanced, the statistical analysis does not yield a statistically significant labor cost advantage for US multinational enterprises. The analysis is based on wage data for equally qualified engineers in different countries provided by the Union Bank of Switzerland. Hakanson [17] also finds that inexpensive labor is not a significant location advantage for Swedish multinational firms. Likewise, Mansfield, Teece, and Romeo [18] find that the cost advantage evaporates with the depreciation of the US dollar from an analysis of the 1970s wave of globalization.

2.2 Capability

Firms are characterized as exploiting or enhancing their capabilities. In exploiting their capabilities, firms apply capabilities they already have in a foreign country, and in enhancing capabilities, firms augment their capabilities using capabilities from their host countries [5, 19]. Thus some researchers argue that national capability is *not* a location advantage i.e. firms largely exploit their capability abroad [20, 21], while others argue that national capability is a location advantage i.e. firms enhance their capabilities through globalization [22-26]. Cantwell [27] sheds some light on the argument and argues that internal globalization (when firms captive offshore i.e. do own product development in a foreign country) largely exploits internal capabilities while external globalization (global partnership or outsourcing i.e. when firm develop products through external partners or suppliers in a foreign country) largely enhances capabilities. Moreover, Cantwell and Janne [28] add that if the home base capability is strong, firms’ foreign R&D will complement that capability, and if the home base capability is weak, foreign activities will tend to be in the same area.

With respect to the *specific* capability being acquired through globalization, researchers often agree that distributing research and development efforts provides access to different *technological* capabilities. The argument is that regions around the world have different technology clusters; hence having presence in a cluster increases a firm’s access to the technology [7, 29, 30]. Kogut and Zander [31] add know-how to this technological capability. They argue that ability to transfer or exploit technological capability is a unique capability in its own right.

2.3 Market Size

Hakanson [17] and Zejan [32] survey the top 20 Swedish firms and find that large market size attracts more research and development. This finding is further supported by von Zedtwitz and Gassman [15] using a broader data set; Mansfield et al. [18], Odagiri and Yasuda [33] using an analysis of R&D expenditure; and Papanastassiou and Pearce [34] using an analysis of production share (i.e. ratio of products produced in a market to products sold in that market). Beyond enabling the firm to sell products in chosen markets, accessing the market allows firms to better sense the market [7], get access to lead users who can influence trends around the world [35], and support sales and manufacturing activities [36].

2.4 Engineering workforce

Studying Japanese firms and using the number of researchers per million as a measure of the available engineering workforce, Ito and Wakasugi [26] find that firms are attracted to regions with large human capital. Kumar [16] finds the same while studying Japanese and American firms, Hemmert [37] while studying German and Japanese firms, and Florida [24] while studying American firms. However, other researchers argue that the quality of the engineers is more important than the quantity [38]. In this paper, the quality of engineers is related to capability; hence by engineering workforce we mean the number of engineers in a country.

2.5 Political benefits

Locating product development in the country where products are sold boosts the company's public relations profile, and entitles the company to local tax and other political benefits [14, 33]. Moreover, the ability to appropriate political benefits is being enhanced by global regulatory frameworks [39]. However, Davis and Meyer [40] argue that government support increases the incidence of subsidiary R&D but not necessarily the level of R&D.

2.6 Other location advantages

Other documented location advantages include stronger enforcement of intellectual property protection [26], the necessity of manufacturing support [22], historical reasons tied to mergers and acquisitions [41], and cheap resources [7]. There is also an emerging debate on the role of national culture in global product development [42, 43]. Nonetheless, we believe the factors discussed above are likely to play key roles in global product development.

Lastly, location advantages reviewed above are largely pull factors. The same factors can be viewed as push factors as well. For instance, multinational enterprises from small countries such as Netherlands (Phillips), Sweden (Ericsson), and Switzerland (ABB) are among the most globalized firms as they seek large markets outside their home markets [39].

2.7 Opportunities for contribution

As discussed above, market size, capability, number of engineers, labor cost, culture, and political benefits are factors important for international R&D and MNE leaders to consider as location advantages. Whether these factors apply to product development as well is not clear. Product development tends to be closer to the customer than R&D, requires more coordination than research and development, and more often than not, ends in a physical product. Given these differences, we firstly intend to investigate whether these international R&D and MNE location advantages are important in global product development as well. Secondly, we intend to go beyond the relevance of the factors and investigate the relationship between product complexity and the location advantages. Thirdly, we intend to examine the relationship between national capability and firm capability from a different angle than reviewed above.

3 RESEARCH METHODS

Our research method consists of two major phases. The first phase allows us to down select from R&D and MNE location advantages above to GPD location advantages. These serve as our hypotheses [see 44, 45]. The second phase focuses on testing hypotheses from the first phase.

3.1 Phase I: Exploratory Research: Hypotheses Generation

Phase I Case Selection Process

The interview population consists of product development leaders working for American firms who recently developed complex electromechanical systems globally. Thus we are controlling for firm size [see 46], parent-firm country of origin [e.g. 16], and type of product [24] influencing the location decision by focusing on large American firms developing electromechanical systems.

We first interviewed executives at a large Fortune 10 company, where the lead author spent 500 hours as a global product development engineer. In the spirit of quota sampling, the rest of the interviewees are chief technology officers, directors and vice presidents of engineering from 17 other American firms involved in developing electromechanical systems globally. These 17 firms were chosen to test the replicability of findings from the first firm. All in all, we interviewed 80 product development executives over 15 months. The executives are mostly located in the US. A few are located in Europe and Asia though they all work for American companies.

Phase I: Data Collection Process

Using the grounded theory research approach, the data collection process began with open-ended interviews on location advantages. Each interview was done and recorded in person, and lasted from 30 minutes to 3 hours depending on the seniority of the interviewee and stage in the research process. The average interview lasted for an hour. The interviews tended to be longer during the early phases of the research and as the responses converged, we used semi-structured interviews which tended to be shorter. The interview data is supplemented by observation data gathered when the lead author worked on a globally distributed product development project for 500 hours.

Phase I: Findings - Hypotheses

Findings from coding the interviews serve as our hypotheses. For instance, we code as “national capability” statements that reference the capability of a country or the region within a country in developing a product: “At the very beginning, we take advantage of the *ecosystem*. When it [product] matures we move it to *low cost regions*” is coded as referencing national capability and labor cost.” Similarly, “we go to India because they have a talented *engineering workforce*,” and “we are growing capability in Guangzhou because they will be an important *market*” are coded as referencing the engineering workforce and market size respectively. A tally of such coded statements yields: National Capability (33), Cost (24), Market Size (21), Engineering Workforce (11), IP Protection (4), History (4) and Market Growth Rate (2) where the number in brackets is the number of times the location advantage is mentioned as important in making location decisions.

From these results, we derive the first four hypotheses using location advantages mentioned as important more than 10 times. The directionality of each hypothesis is dictated by the literature reviewed above as well as the interviewee responses.

1. H1: As the average national capability increases, the likelihood of product development in that particular country increases
2. H2: As the labor cost decreases, the likelihood of product development in that particular country increases
3. H3: As the market size increases, the likelihood of product development in that particular country increases
4. H4: As the engineering workforce increases, the likelihood of product development in that country increases

In an attempt to better understand the relationship between the market and global development, we formulated the following hypothesis despite the low frequency associated with market growth rate.

5. H5: As the market growth rate increases, the likelihood of product development in that particular country increases

As formulated above, the hypotheses are agnostic to product characteristics. Given the complexity of electromechanical system, we take into account product complexity and hypothesize the following:

6. H6: There is significant tendency to develop complex products in countries with higher national capability

The seventh and final hypothesis emerges from a discussion of the relationship between national capability and firm capability. Do firms engage the foreign entity for the firm capability or for the national capability?

7. H7: National capability is directly related to firm capability

3.2 Phase II: Hypotheses Testing

Phase II: Case Selection Process

There are two populations during this phase of the research: the country and the module populations. The country population is the list of all countries in the world. Similar to Pisano [47], our country sample consists of the top 50 countries that trade with the US in electromechanical systems. We obtained this list from United Nations Commodity Trade Database [48]. Using the Harmonized System 2002 codes 85 and 87, we chose the top 50 (by value) countries that export modules of electromechanical systems to the US. The modules population consists of relatively complex electromechanical modules developed by (or for) large American firms outside the program home-country. Once again, we use quota sampling strategy for the modules. Beyond the first case study, we limited each company to at most 12 modules.

Phase II: Data Collection Processes

With the list of countries in hand, we gathered characteristics of each country using several databases. Though we used the best data available to any researcher, there are weaknesses associated with using databases not specifically constructed for a research project at hand. In our case, definitions varied slightly across countries. For example, the definition of an engineer in India includes an IT specialist while it does not in the US. These differences extend into the US as well. For instance, computer science is in the engineering department at MIT, but in the science department at Duke University.

In addition to these slightly different definitions, some data is politically sensitive hence countries might report misleading numbers [49]. Countries are also subject to different levels of constraints and different areas of constraints e.g. different levels of financing vs. red tape in getting the data. To mitigate these weaknesses, we correlated three data sources for each data point as shown in Table 1. For instance, we used the GDP as a surrogate for the market size, and we obtained GDP data from the World Bank, IMF and UNCTAD. Since the correlation among the three is high as shown in Table 1, we use the IMF data in the negative binomial model. We also use the number of engineering graduates as a surrogate for engineering workforce, and the national capability is a product of the country's revealed comparative advantage [50, 51] and its value chain presence [52-54] obtained from the Global Competitiveness Report.

For module level data, we documented where the module was developed, and measured the module complexity using a data template where the columns represented module characteristics. We first took each interviewee through one row of the data template in order to make sure that they understood needed data, and then gave them a reference document and a week to complete the rest of the template. Most responses came back within three days. Finally we measure complexity as a combination of module technological novelty, amount of interactions and number of parts [42, 55]. All in all, we collected 156 modules developed in 25 countries from 18 companies. From the 156 modules, 38 were missing data hence we could only use 118.

Table 1: Country Data Sources

Sources of Data for Triangulation	Data used
Market Size and Growth Rate –World Bank (WB) –International Monetary Fund (IMF) –United Nations Conference on Trade and Development (UNCTAD)	Correlations >0.90 Used IMF data ($r^2 = 1$, randomly chose one)
Exchange Rates –Federal Reserve Bank –International Monetary Fund –World Bank	Correlations >0.90 Used IMF data as well
Number of Engineering Graduates –National Science Foundation (NSF) –United Nations Educational, Scientific and Cultural Organization –Organization for Economic Cooperation and Development (OECD)	Correlations >0.90 Used NSF data (most specific, larger N)
Labor Cost –International Labor Organization (ILO) –Bureau of Labor Statistics (BLS) –Organization for Economic Cooperation and Development (OECD)	Correlations >0.90 Used ILO manufacturing (larger N, and $r^2 = 0.93$ with engineering)
National Capability –United Nations Commodity and Trade Statistics –World Competitiveness Report	Used both

4 NEGATIVE BINOMIAL MODEL ANALYSIS

Our study is cross-sectional. From the interviews, one director mentioned “We try to look out five years.” Another commented that the development of their systems takes 4 years. Given the mix of complex products in the study, it is fair to assume that the earliest decisions were made in 2003, and the most recent decisions were around 2005. As a result, independent variable values discussed in this paper are average of values from 2003, 2004 and 2005. For instance, each market size data point used in the analysis is an average of three market size (GDP) values corresponding to the years 2003, 2004 and 2005. Since we triangulated each data source, nine values are used to come up with each value used in the analysis.

4.1 Model Specification

The hypotheses are summarized in (1) below.

$$\# \text{ of modules} = \beta_1(\text{National Capability}) - \beta_2(\text{Labor Cost}) + \beta_3(\text{Mkt Size}) + \beta_4(\# \text{ of Eng. Grads}) + \beta_5(\text{Mkt Growth Rate}) \quad (1)$$

The unit of analysis is the country, and the dependent variable is the number of modules developed in the country i.e. the likelihood of product development in the country. The independent variables are the location advantages measured as summarized in Table 1. Among the 50 countries, we dropped 5 countries because they were missing some data points, and plotted the number of modules developed in each of the 45 countries. Based on deviance values, the plot of the dependent variable most closely matches a negative binomial distribution; hence we specify the dependent variable as a negative binomial distribution. The independent variables exhibit heteroskedasticity, hence we specify the link function as negative binomial as well because the dispersion parameter in the negative binomial model reduces heteroskedasticity.

Modules in the sample are either captive offshored i.e. self-developed in a foreign country, globally outsourced i.e. supplier-developed in a foreign country or developed through global partnerships. It is plausible that the significance of each location advantage might be influenced by the mode of global product development. Thus we test (Brown-Forsythe test) whether each location advantage varies across countries grouped by their predominant mode of global product development. The predominant mode is the majority of the three modes in that particular country, and we dropped countries with no predominant mode of GPD for this test. The test shows that the location advantages do not vary as driven by the GPD mode hence we pooled all the modules together for the analysis.

5 NEGATIVE BINOMIAL MODEL HYPOTHESES TESTS RESULTS

5.1 Location Advantage Results

Table 3 summarizes the hypotheses tests results. Model 1 includes all variables corresponding to hypotheses 1 through 5 i.e. national capability, labor cost, market size, engineering workforce, and market growth rate. Because of the high correlation between the engineering workforce and the market growth rate we dropped the market growth rate from the analysis. The market growth is the non-significant of the two, and it did not emerge as a key location advantage from the first phase of the research. Thus the data does not support hypotheses five (H5) i.e. the likelihood of product development in a country increases with an increase in the market growth rate.

Model 2 is our complete model. The coefficients support the hypotheses that *ceteris paribus*, as each of national capability (H1), market size (H3), and engineering workforce (H4) increases, the likelihood of product development in that country increases. However, hypothesis two (H2) i.e. as labor cost decreases, the likelihood of product development increases, is not supported by the data.

Model 3 tests the robustness of the results with respect to company A which was overrepresented in the sample because the lead author obtained extended access at the company. From the 118 modules in the analysis, we dropped 40 modules from company A. As model 3 shows, results are robust to removing company A from the analysis.

We also tested the robustness of the results with respect to time by running the same analysis with data from 2005 only. As shown with model 4 in Table 3, the results are statistically the same; hence our findings are robust to specific time within the stated time period.

5.2 Moderating Effect of Complexity Results

We use the Brown-Forsythe to test the moderating effect of complexity on location advantages. Thus we test whether the corresponding average module complexity increases as the independent variable increases.

H_0 : Average module complexity is the same across all values of the independent variable

H_A : Average module complexity is not the same across all values of the independent variable

From the significance values in Table 2, we reject the null hypothesis for national capability, but can not reject the null hypotheses for all other independent variables. Thus the sixth hypothesis (H6) is statistically supported: i.e. there is a statistically significant tendency to develop more complex modules in countries with higher national capability.

Table 2: Robust complexity test equality of means

Brown-Forsythe Robust Tests of Module Complexity Equality of Means	
	Significance
Market	0.13
National capability	0.01
Engineering workforce	0.13
Labor Cost	0.14

Table 3: Location advantage hypotheses tests results

Negative Binomial Model : Dependent Variable is the Number of Modules Developed in a Country					
Independent Variable	Estimated Coefficients	Model 1 (all data)	Model 2 (all data)	Model 3 (Without Co. A)	Model 4 (2005 only)
Market Size	β_1	2.75E-05*** (9.45)	2.50E-05*** (9.18)	3.99E-05*** (13.02)	2.78E-05*** (9.43)
National Capability	β_2	1.70E-02 (1.66)	3.00E-02*** (9.56)	3.7E-02** (3.88)	3.10E-02*** (10.30)
Number of Engineers	β_3	2.11E-06*** (7.56)	1.26E-06*** (11.50)	1.57E-06*** (10.03)	1.32E-06*** (10.42)
Labor Cost	β_4	3.28E-06 (0.00)	5.26E-05 (0.95)	3.47E-05 (0.21)	5.57E-05 (1.02)
Market Growth Rate	β_5	-6.70E-02 (1.96)			
Model likelihood Chi-Square Significance		0.00	0.00	0.00	0.00
Likelihood Ratio		28.06	26.28	23.3	25.43
Number of countries with development		25 of 40	25 of 40	24 of 40	22 of 40
Number of modules		118	118	88	110
		*p < 0.1	**p < 0.05	***p < 0.01	

5.3 National Capability vs. Firm Capability Results

We operationalized national capability as the product of the revealed comparative advantage [50, 51] and the value chain presence [52-54]. Firm capability is measured using an above average, average and below average score. Since the unit of analysis is the country, we compare the national capability to the average firm capability in that nation using the Pearson Chi-Squared test of independence.

H_0 : There is an association between national capability and firm capability

H_A : There is no association between national capability and firm capability

The chi-squared test yields Pearson Chi-square value of 1.51, which is equivalent to a significance of 0.22. Thus we can not reject H_0 , and we conclude that there is an association between national capability and firm capability. Thus national capability is directly related to firm capability and hypotheses 7 (H_7) is supported by the data.

6 SUMMARY

We set out to investigate location advantages and product complexity in global product development. We found that the likelihood of product development in a country statistically increases as its market size, engineering workforce and national capability increases. Thus the three are significant location advantages. Of the three, the market size is generally the most important location advantage, followed by the engineering workforce and then national capability. However, the likelihood of product development is neither related to labor cost nor the market growth rate. We also found that complex products are more likely to be developed in countries with higher national capability. Finally, we found that national capability and firm capability are statistically related i.e. we are more likely to find highly capable firms in countries with high national capability.

7 CONTRIBUTIONS

- We discovered the influence of product complexity on location advantages. Prior contributions had been agnostic to product complexity. We found that complex products are more likely to be developed in countries with high national capability. Thus as product complexity increases, national capability increases in importance as a location advantage
- Using a negative binomial linear model accomplished two goals: Firstly, models of its type had not been used in investigating location advantage before (researchers have largely used self-assessment surveys), and secondly it allowed us to gauge the weight of each location advantage in the model which has not been done with surveys.
- Combined with the statistical model, we focused on global product development instead of research and development or holistic multinational enterprise, and we were able to boil down the several location advantages in the literature into market size, national capability and engineering workforce.
- Finally, we explicitly discussed the relationship between national capability and firm capability in global product development which had not been done before. We found that the two are directly related.

8 DISCUSSION AND IMPLICATIONS

We find that firms are drawn to countries with high market size, large pools of engineers and high national capability. From the standardized coefficients, the market size is the most important location advantage. This finding supports our conjecture that global product development is closer to the end-user than research and development; hence the market would play a critical role.

It is surprising to find that the market growth rate is not statistically significant as a location advantage. However, the product of market size and market growth rate is highly correlated with the market size, hence we statistically can not differentiate between the two i.e. market size, and the product of market size and market growth rate unless we use findings from the qualitative interviews. These findings show that the market size is the more significant of the two.

The engineering workforce is the second most important location advantage, while the national capability is the third. Since firms do build host firm capability *if* they deem it necessary, this ranking is in line. However, product complexity only increases as national capability increases hence firms are more likely to develop complex products in capable countries than train suppliers to develop complex products.

We also find that labor cost is not a statistically significant location advantage in the context of global product development. Based on the qualitative interviews, this might be explained by the increase in labor costs as driven by inflation differentials, and increased competition for *skilled* labor among firms in a particular region. However, global product development might help firms reduce other product development costs if the costs are shared among members of a partnership. This form of cost reduction is common where the sunk costs associated with a development project are high.

In the case of China and India, the two countries are producing a significant number of engineers, but those engineers are not as qualified as the engineers produced in the US according to Wadhwa et al [49]. Farrell et al. [38] of the McKinsey Global Institute argue that only 13% of the engineers from China and India would be suitable to do the high level engineering work in the US. However, they do not discuss the fraction of engineering graduates in the US who are capable of doing high level engineering work.

Finally, national capability is directly related to firm capability. In practice, this implies that chances of finding firms highly capable in designing a system in a less capable nation are much less than chances of finding a highly capable firm in a highly capable nation.

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