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Abstract: Policy makers seek to identify an institutional framework that facilitates the commercialization of publicly funded R&D. In the space industry, the formation of such a framework is complicated by certain non-economic factors, such as national security considerations and the fact that numerous sovereign nations are often included in the commercialization process. In this paper, a model is outlined, that incorporates both economic and non-economic factors. The paper then demonstrates the importance of co-ordination in national technology policy to achieve an optimal result. The benefits of co-ordination are illustrated through a case study of the design of a major European public-private partnership (PPP) in the space industry, referred to as Galileo.

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I. INTRODUCTION

The recent rise of public-private research partnerships in OECD nations has underscored the importance of the need for an institutional framework that facilitates the commercialization of publicly funded R&D. This paper describes an unconventional program that attempts to achieve this objective: the Galileo space based navigation system. Though there is a lengthy literature on research partnerships in general and PPPs in particular (see Hagedoorn et al, 2000; Vonortas, 1997), a unique aspect of the paper is that we model negative security spillovers of 'unilateral' space projects such as Galileo, or space based anti-ballistic missile defense, on the public sector of the other region (U.S. vs. EU).

Galileo is a proposed European non-military, space-based, radio-navigation program that relies on ground-controlled satellites to provide users with accurate positioning information. This project is expected to have broad commercial applications, such as radio-navigation based automatic landing systems and navigation and positioning systems in autos. Galileo is a classic example of a public-private partnership (PPP), as its development (the "D" of R&D) was publicly funded, while its deployment and implementation will be largely financed and managed by firms, who will assume equity in the enterprise. Policymakers hypothesize that this PPP will result in the further development and commercialization of high accuracy, space-based navigation assets (see Link, 1998). The projected cost of developing and implementing Galileo is approximately € 3.3 billion (see Table 1).

This program is quite unusual because it constitutes the first time the European Commission (EC) and the European Space Agency (ESA) have agreed to share equity/ownership with European space firms, service providers, and financial institutions. The unprecedented nature of this joint venture, coupled with the large risks associated with large-scale investment in the space industry, raise concerns about the nature of the social returns to this project. These concerns are heightened by the fact that the revenue resulting from Galileo will result from its value-added products, which utilize the precision signal, since its basic, less accurate navigation signal will be un-coded and provided free of charge[1]. This is the same approach used in the American Global Positioning System (henceforth, GPS) and the Russian Glonass. Several consulting firms project a high return to Galileo (see EC, 2002). They also predict a substantial increase in space-based navigation services worldwide. However, the time horizon for the realization of these returns is quite long. Private funds will not be required until its deployment stage, which is expected to run from 2006 to 2007. The EC expects no to provide further public subsidies after 2007, when the operational phase begins. It is important to note that there are substantial risks associated with this endeavor, including delays and dramatic changes in market conditions.[2] Furthermore, firms may be reluctant to do what is necessary to successfully implement the project, once substantial public funds have been incurred. This is especially likely to occur when indirect public subsidies end in 2007.

Security concerns regarding Galileo have risen substantially in the aftermath of the September 11th terrorist attack. To deal with such cases, the provisions of the Galileo proposal provides for an independent management team, under European political control, that is authorized to assume stricter security measures in the event of another terrorist attack. U.S. involvement in Galileo has not yet been finalized at either institutional, or industry level, although it is possible that there will be participation at the sub-contracting level. Note that Galileo is quite different from the well-known U.S. GPS, which is owned and controlled by the U.S. Department of Defense (DOD). In contrast to GPS, Galileo will be managed by a commercial entity, and a potential concern among the military establishment in several

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[1] For example, value added services include the incorporation of positioning functions for emergency services in mobile telephones, high-precision navigation support for aircraft and in-vehicle navigation services to drivers, EC (2002).

[2] For example, the status of the U.S. GPS can change, or problems with global security can arise, due to the non-maturing of sustained commercial applications of high-accuracy navigation. The bankruptcy of the space-based

nations (especially after September 11th) is that profitability might take precedence over security.

These areas of concern, which have traditionally being treated separately, are shown to be interrelated in our analysis. Specifically, we outline a model that accounts for the structure of the European-U.S. industries and public sectors, market conditions and industrial/procurement policies. This allows the examination of an alternative scenario where the U.S. and European public sectors promote trans-Atlantic industrial links in undertaking such projects.

Our findings imply that trans-Atlantic co-ordination in technology policy is required to allow the respective space industries (in the U.S. and E.U.) to exploit the benefits of cross-border strategic research partnerships (SRPs). This coordination not only reduces the costs of the respective programs, but also addresses security concerns.

The remainder of the paper is organized as follows. The next section presents background information on the Galileo project. Section III describes the nature of space markets, with an emphasis on the characteristics of industry structure and firm conduct. We outline the model in Section IV and then present our findings, based on calibrated values of the parameters of this model, in the following section. The final section consists of conclusions and suggestions for additional research.

II. BACKGROUND INFORMATION ON GALILEO

As noted earlier, the two existing global satellite-based positioning and navigation systems are the Russian Glonass and the U.S. Global Positioning System (GPS). These systems were designed during the Cold War era. Thus, they were developed primarily for military operations, such as navigation and targeting on a global scale.[3] For instance, the U.S. military uses GPS for navigation and targeting. It was used quite effectively during the Gulf War to guide tanks through the desert in Iraq and Saudi Arabia. Although both systems are operational, GPS is much more widely known, due to its widespread commercialization. It is managed by the U.S. Department of Defense (DOD), which provides a non-military-coded, signal (based on GPS) that can be used by commercial enterprises free of charge. By design, for national security reasons, the commercial signal is less accurate than the signal used for military purposes. Over time, however, DOD has allowed a much more accurate signal to be used in the commercial domain (down to a few meters by 2000, Dana, 1999). The purpose of this change is to enhance the social return to public investment in R&D, as the signal has broad commercial applications and can significantly increase productivity in downstream sectors. In fact, the commercial potential of GPS is probably the greatest of any space-based, military spin-off since the Internet. Uses of these systems range from auto-navigation to GPS-based automated aircraft landing systems (EC, 2001).

Thus, the decision of E.U. ministers to launch a new, fully commercial positioning and navigation system in early 2002 is a landmark one. It is significant for two reasons: it represents a strong commitment to <u>full</u> commercialization of space-based navigation and positioning services and it constitutes the first public-private partnership involving numerous countries in the space sector.

Table 1 presents a schedule for the implementation of Galileo, which involves three stages. The first stage, which is expected to run through 2005, involves development and in-orbit testing of the system (satellites and ground stations). This phase is expected to cost approximately € 1.1 billion, shared equally by the two partners, the European Space Agency (ESA) and the EC. Next is the deployment stage, which is expected to transpire from 2006 to

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[3] [illegible]

2007. This stage involves the assembly and launch of the satellites constellation (30 satellites required) as well as the completion of the satellite signal receivers. The second stage is expected to cost about € 2.1 billion, out of which just € 0.6 billion is expected to be publicly funded. The third and final stage is the operational phase, starting at 2008, when no public subsidies are expected and the annual costs of running the system are estimated at € 0.2 billion annually, borne fully by the public-private partnership that will manage Galileo (EC 2000).

In essence, the system will be built with European public funds, facilitated through a <u>public-public</u> partnership between ESA and EC. The second (lower risk) stage will be financed with private funds, which will enlarge accordingly the partnership into a <u>public-private</u> partnership. This organizational structure is novel and the resulting joint venture is a public-private partnership, where not only the ‘private' part of the partnership is comprised of more than one entity, but also the ‘public' part.

Firms have two concerns when they embarking on such a partnership: standard concerns about profitability, technology and market risk, and concerns regarding undue interference from the public sector, since public institutions are subsidizing the endeavor and will be regulating the firm. On the other hand, Galileo's key prime contractors will be European space firm(s) which is likely to hold equity in the resulting enterprise.

The development and operation of the system would have benefit greatly from avoidance of duplication and the technical expertise of the U.S. and Russian space industries, which have a long established experience in radio-navigation. Although there are some ongoing technical discussions taking place between European and Russian space officials, there has been limited contact with the U.S. This is partly due to the lingering effects of Cold War animosity, which seem to be slowly drifting away, but also due to concerns about additional competition and industrial policies in the U.S. and Europe that prohibit certain would also have much to benefit from collaboration, primarily with the U.S. (see Audretsch et al, 1996), and finally collaboration would result in reduced pressure for further costly commercialization of the U.S. GPS. There are clear benefits for both the U.S. and European public sectors from such collaboration at industry level, as well as for the space industries involved. However, there are also greater complications associated with such collaborations, as compared to the European-Russian endeavor. This is due to the fact that a U.S.-European collaboration would not simply exist on a technical level, but would also require the formation of partnerships for developing the system, managing it, and marketing the resulting commercial services in the U.S.

III. SPACE MARKETS AND INDUSTRY STRUCTURE

From an economic standpoint, space systems, industries and public sectors are interdependent. That is, there are strategic interactions between space industries and public sectors in Europe and the U.S. The decision by Europe to build such a system has implications for the competitiveness of the commercial markets of European and U.S. space firms, their size and performance, as well as the strategies of the U.S. public sector.

Both industries have undergone substantial consolidation, assisted by respective public policies. This has left just one major space integrator in Europe, the European Aerospace and Defence Systems (EADS), and two in the U.S., Lockheed Martin and Boeing. The two industries virtually control the commercial market for expendable launch services and telecommunications satellites, the two major commercial space markets. This is achieved by the fact that the substantial Russian and Ukranian launching services, which carry a high level of reliability and low cost are marketed by Arianespace (directly controlled by EADS) and the respective US firms (Zervos, 2000). In major projects in the US, both space integrators are expected to participate, since, if there is a consistent single ‘winner’ of projects, this inevitably leads the other firm to exit the market (see for example, the united space alliance, a 50-50 joint venture maintaining the Space Shuttle.

European and American firms encounter almost no domestic competition in their respective domestic space industries. However, they do encounter competition in commercial space markets, such as launching services, telecommunication satellites, and remote sensing products. As a result, each firm is assumed to behave as a monopolist in the domestic public space market it is faced with, and as a duopolist, in competition with the other firm in the commercial space market (Zervos, 1998 and Zervos, 2001).

This setting, though quite simple, adequately describes the preferential treatment the domestic space industries of the U.S. and Europe enjoy in their respective public sectors. Policymakers in the U.S. and Europe and the US also use procurement and industrial policies (although the Americans would never refer to this as an industrial policy!) to enhance the competitiveness of their domestic space industries in commercial markets. Some of the actions they take to achieve these goals include:

- Promoting consolidation, which has resulted in a domestic monopoly or duopoly
- Raising entry barriers for foreign firms (e.g., the 'Buy American Act' in the U.S. and 'juste retour' in Europe).
- Inhibiting free trade in commercial space products and controlling the supply and pricing policies of the Russians and the Chinese. Such restrictions are diminishing as U.S. and European firms utilize the capabilities of the countries of the former USSR.

In sum, public agencies in the U.S. and Europe demonstrate a clear preference in the procurement of space products for domestic manufacturers. When possible, national governments also implement policies to enhance the competitive position of their domestic space industries in commercial markets. In light of these facts, the European space industry is producing two space goods[4], one for the commercial marketplace, and another for the European public sector, i.e., ESA or the Western European Union (WEU). Equivalently, the U.S. space industry is assumed to be producing a commercial space good and a public sector space good, where the relevant U.S. agencies are the National Aeronautics and Space Administration (NASA) and the Department of Defense (DoD).

This paper models the structure and conduct of space firms and analyses the impact of collaboration and competition in public space markets (e.g. European Galileo, US reusable launch system- RLV) on firm performance, costs incurred by public agencies, and the resulting market price and size of commercial markets.

IV. MODEL

The model assumes two space firms, representing the U.S. and European space industries. There are three markets: two U.S. and European public space markets that are closed to foreign competition and a third international commercial market where the two industries compete as duopolists (see Zervos, 2001).

The inverse demand functions of the respective space integrators in public space markets are a function of quantity, but also 'endogenous security' concerns. This is reflected in the fact that the price is also a function of the public space good supplied by the other areas' integrator. The inclusion of this additional argument is justified on two grounds:

- First, the power of the space industry lobby on the domestic public choice. This results in the incorporation of 'reaction factors' in the demand for national space products. A reaction factor would result in increases in demand for national space products, in response to increases in the rival's demand for public space goods, which,

[4] There is an extensive literature analyzing the impact of monopoly markets on competition in a single product case (Brander and Krugman, 1983; Cooper and Hartley, 1970), as well as the examining a numerical example of a similar

if left un-answered can result in the rival obtaining a competitive advantage in commercial space markets.

-Second, in particular, for radio-navigation systems extreme reliance on the other area's capabilities result in loss of control of strategic assets. The reaction to such loss of control for Europe, for example, has contributed much in its decision to build its own system (Galileo). The investment of Europe into Galileo is expected to result in the US further developing GPS (more than if Galileo was not built) to maintain its leadership in space.

Note that this scenario does not constitute a 'space race' model, where adversaries are engaged in efforts to create public assets of strategic significance with the purpose of having an advantage in case of war (see Sandler and Hartley, 1995 and Zervos, 1999a). However, it is a form of 'space competition' based on security and commercial considerations (Zervos, 2001: 142). As such, increases in an areas' public space funding to its domestic space industry are met by respective increases by the other areas' public sector. This means that the inverse demand of the public space market is not characterized as a pure monopoly, since it incorporates security considerations and a 'competing public sector reaction' element.

If European and U.S. space integrators encounter overseas competition in public markets, it is likely that U.S. integrators will be major participants/contractors in Galileo, or that European integrators will be major contractors on the U.S. RLV, or the U.S. space-based missile defense system (an updated version of the Cold War "Star Wars"). This could result in a U.S.-European (and even Russian) space industrial base, with major restructuring at firm-level leading to multinational space integrators. For the case of radio-navigation service providers, the incorporation of US space firms as major contractors in Galileo, followed by European firms becoming contractors of US civil space systems (RLV) would result in the phasing out of the 'public sector reaction' factor of the demand for public space systems. A

There are however, reforms under way in the US in the direction of allowing the US industry to participate in programs with allied partners who have the respective technological capabilities (see Commission, 2002). In addition, the high concentration of the European space industry and the public-private partnership nature of the project would make easier the monitoring of technological 'leaks' to third parties.

To compare the two scenarios of open and closed foreign competition in public space projects, we outline and calibrate a model under two scenarios: **Scenario 1** is the case of closed public markets, while **Scenario 2** represents open public space markets. The results are compared in terms of prices in commercial and public space markets (costs faced by ESA-Galileo partnership, or NASA for RLV), profitability of the space industries and the respective quantities supplied. The key assumptions of the modeling of markets and costs under scenarios 1 and 2 are summarized in Table 2.

From Table 2, for Scenarios 1 and 2, the inverse demand function of the commercial markets is assumed to be of the following form:

$$p = a-b(q_1+q_2), \quad (1)$$

where p = price of the commercial space good
q_1 =the quantity of the commercial space good supplied by the U.S. firm
q_2 = the respective quantity supplied by the European firm.
a = the vertical intercept
b = the slope of the demand line
(a and b are assumed greater than zero).

In Scenario 1 the inverse demand functions for the US and European firms are assumed to be of the following form:

$$p_{di} = c-d(q_{di}) + s(q_{dj}) \quad \text{for 'i, j'=} {}_{US,\ EU}, \quad (2)$$

where p_{di} = the price of the domestic public space good in the US and the European markets, respectively;
q_{dj} = the quantity of the government purchased space good by the US and the European public sectors, and $c, d > 0$.
s = the reaction coefficient, whose value depends on the perceived 'threat' by

space industry, as well as the lobby power of the domestic space industry. Both of these factors are positively related to s.

While in Scenario 2, there is a joint US/European duopoly market, as the respective public sectors are open to overseas competition and there are multinational space integrators. This results in the value of 's' diminishing (normalized to zero), as domestic industries have control over the other area's space projects:

$$p_d = e - f(q_{di} + q_{dj}) \qquad \text{for 'i, j'} = {}_{US}, {}_{EU}, \tag{3}$$

where $e, f > 0$

The total cost (TC) function used to represent the total costs of the US and the European space manufacturer is assumed to be symmetric for the two industries. [5] It must also exhibit the cost characteristics of a multi-product space firm (i.e. economies of scale and economies of scope) for the relevant output range[6]. There are also certain desired theoretical properties for such a cost function: a TC function must be non-negative, non-decreasing, concave and linearly homogenous in input prices (Baumol et al, 1982). In addition, the TC function should be meaningful in the case of the production of a subset of the products set and should "not in itself prejudge the presence or absence of any of the cost properties that play an important role in the analysis of the industry" (Baumol et al, 1982: pp 449).

The cost function employed is presumed to be a function only of output quantities and not input prices. This method of formulating cost functions makes the analysis less complicated, without much loss in generality when the main concern is to examine the impact

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[5] Several reports on the European space industry (see Zervos, 2001: 281) indicate that there is no substantial cost differences between the US and European space industries, this result seems plausible for the commercial products, given the commercial orientation of the European space industry. For the military space products however, due to their generic and custom made nature, this is hard to establish. This lack of substantial cost differences can also be attributed to the subsidization of the EU space industry by the EU public sector, in the form of contributions to ESA and subsidization of publicly owned or controlled aerospace firms.

[6] It would be reasonable to expect that beyond some production level, the production of any good would be subject to

of output changes (Baumol et al, 1982: pp 453). Based on the above, the TC function is of the following form [7]:

$$C_i = F + M(q_i + q_{di}) + a_i (q_i^2 + q_{di}^2) + a_{ii} (q_i q_{di}) \quad (4)$$

where $i = 1, 2$ (US and European industries respectively);
F = fixed costs (including R&D)
a_{ii} = coefficient denoting economies of scope
a_i =coefficient denoting economies of scale.

None of the coefficients needs to be constrained to be non-negative, provided that for the output range considered, a negative coefficient will not result in a decreasing cost function, or negative average or marginal costs.

The calibration of the two scenarios faces a major quantitative challenge as no quantification of the cost characteristics of multi-product space firms has been undertaken. A main reason for a lack of empirical evidence demonstrating economies of scope and scale in this industry is that most space firms are divisions of multi-product aerospace firms. Many of them have a military and commercial range of aerospace and space products, some of which are produced in production lines, while others are developed as prototypes. On the other hand, cost data on certain top-secret military space and aerospace projects cannot be obtained. Such differences in the information of the production of space goods makes the quantification of a general cost function very complicated and with doubtful validity for output range outside the current production levels.

As a result, the calibration of the cost function was done for illustration purposes, with the only requirement being that for the relevant output range the cost function is well behaved and exhibits economies of joint production and economies of scale. The values for F, M, a_{ij} and a_i were thus chosen arbitrarily in terms of their absolute magnitudes, but in order to support the assumptions of the presence of economies of scale and scope between public and commercial space goods and are presented in Table 3.

As Table 3 indicates, the assumption of symmetry in cost characteristics is also employed in the case of public space markets in the US and the Europe. Given the substantial size differences between these two markets, this is not a realistic assumption; it is employed however, since it simplifies this analysis, without having an impact on its results.

V. RESULTS

Having outlined the characteristics of the cost functions of space firms, their market structure, and the nature of their conduct, it is necessary to determine the behavior of the firms with respective to their objectives.

Following the convention in this literature, we assume that these firms are attempting to maximize profit and that the industry is characterized by Cournot quantity-based competition (see Bulow et al (1985), Klepper (1990, 1994) and Neven and Seabright (1995)). Thus, firms make an output choice, assuming that their rivals will produce exactly what they made in the previous period. Given the complicated nature of the theoretical solution to this model, the equilibrium solutions to the two calibrations for Scenarios 1 and 2 are examined and compared in Table 4.

As Table 4 indicates, the most economically efficient structure in terms of low prices and high output is under Scenario 2. The profits of the two firms are lower under Scenario 2, as they have to compete in domestic and international markets and they loose their domestic monopoly status. This means that for a project such as Galileo, there would exist competitive pressures for the private space firms/manufactures diminishing the possibility of 'lock-in'. Benefits from collaboration at firm level in programs such as Galileo and RLV, or space based missile defence, will also lead to avoidance of duplication at R&D level and

This is expected to lead to reductions in fixed costs (F in equation 1), which incorporates R&D. The only quantitative implication of such reductions for the equilibrium results of this model is that for each Euro saving in fixed costs there is a one Euro increase in profits. Thus, for the two space firms profits will be higher under Scenario 2 by the savings accrued due to absence of duplication at R&D level.

This model illustrates how the introduction of non-protective market-considerations in European and U.S. public policies can reduce uncertainties and costs of space programs, such as Galileo. Specifically, the model illustrates how the introduction of the U.S. technical expertise, industrial capabilities and facilitation of market access (primarily to the U.S. public radio-navigation market) will benefit the Galileo project in terms of size of markets (public and commercial) and costs of the system.

The losses at the political level from Scenario 2 refer mostly to shared control of strategic radio-navigation and other assets which must be weighted against economic losses. The political issues that need to be addressed refer to political, security and military issues. For example, the introduction of U.S. firms into the Galileo partnership, coupled by corresponding partnerships between the U.S. and European industry on U.S. projects, would result in economic benefits in the form of know-how and risk sharing, but such know-how would be subject to export restrictions of the U.S., which could prove complicated, given that GPS is a DOD project.

This highlights the requirement of improved co-ordination and formation of links at industry and public office levels between Europe and the US to improve economic efficiency, lower costs of space projects and facilitate in the expansion of space-based commercial markets.

VI. CONCLUSIONS

In this paper, we examined the design of Galileo, a proposed European radio-navigation space project. We attempted to illustrate the impact that U.S.-European policy collaboration on publicly-funded R&D can have on the cost, market size and prices of space programs. Galileo faces the problem of high risk, given the absence of European experience at integrators level on space-based radio-navigation, which could result in duplication of technologies developed in Russia (Glonass) and the U.S. (GPS) which increase cost. In addition, Galileo faces the problem of the possibility of further upgrades and commercialization of the U.S. GPS, as well as, security concerns by the US regarding potential misuse of Galileo's commercial services by terrorists and other enemies of the free world. These areas of concern, which have traditionally being treated as separate issues, were shown to be interrelated in our analysis.

The paper models two scenarios for the European and the US space industries, that take into consideration economic factors (such as fixed costs- R&D) and policy factors (procurement policies and national security considerations). The first scenario is based on the assumption that all markets are closed to foreign competition, reflecting the current procurement policies of the respective areas. This, results in the exclusion of the U.S. space industry from being a major competitor/contractor and also the European space integrators being excluded from U.S. public space markets. The second Scenario is based on the assumption that there is open competition in public space markets in Europe and the U.S. In the case of Galileo, this would result in the formation of trans-Atlantic collaboration at industry level which could well extend into US programs (see Zervos, 1999b).

The comparison demonstrates the importance of trans-Atlantic cooperation at the public policy level to achieve an optimal result in space projects like Galileo. We show this by public procurement and commercial application services, as well as an increase in the respective production levels. In addition, co-ordination in national technology and procurement policies under Scenario 2 enables the respective industries to exploit the benefits of cross-border strategic research partnerships (SRPs), reducing duplication and maintaining profit levels for the respective industries. Such policy coordination might also yield benefits for other public goods.

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Table 1

Implementation Plan for the Galileo Project

	Phase	Period	Funding € (2000) billions/ *amount of subsidy*	Galileo Partnership
Stage 1	Development	2001-2005	*1.1*	Joint Undertaking Between ESA and EC, private funding and partners possible, but not necessary
Stage 2	Deployment	2006-2007	2.1 *(0.6)*	Operating company Equity provided by EC, ESA (controlled by a single public management scheme) and private shareholders. There are debt providers. Public regulation with regards to security issues
Stage 3	Operations	2008 onwards	0.2	

Sources: EC (2000), EC (2002), PriceWaterHouseCoopers (2001)

Table 2

Key Assumptions Regarding the Type of Markets for Alternative Scenarios

Type of Market	Scenario 1	Scenario 2
US PUBLIC MARKET (mainly NASA, DoD)	Monopoly facing the US space industry because of: Exclusion of non-US major integrators from public procurement (‘Buy American Act’-FAR, 2002) and consolidation-encouraging policies result in nationally confined concentrated integrators.	Both public markets ‘merge’ into a duopoly transatlantic public space market. This results in a wide spectrum of space programs/projects facing the US and European space corporate entities multinational integrators/joint ventures). This allows the formation of trans-Atlantic public- private commercial partnerships in space (Galileo).
EU PUBLIC MARKET (ESA, European national space agencies)	Monopoly facing the EU space industry because of: Preferential treatment in public procurement (‘juste retour’) of European national space firms and consolidation-encouraging policies at EU level result in Europe-confined multinational Integrators.	
COMMERCIAL MARKETS	Duopoly in the manufacturing of space projects/ programs by major space integrators between the US and European space industries. Russian and Ukranian space industries, though technically highly competent, are best seen as partnering subcontractors/ major suppliers to US and European space firms.	

Table 3
Calibrated Values of the Parameters of Equations (1) – (4) Under Alternative Scenarios

Parameter	**Scenario 1**	**Scenario 2**
a	100	100
b	2	2
c	50	-
d	4	-
e	-	50
f	-	2
s	0.5	-
F[8]	50	50
M	15	15
a_i	0.6	0.6
a_{ij}	-0.6	-0.6

[8] As ‘F’ captures R&D costs for the development of projects, such as Galileo, its value in Scenario 2 is expected to be lower compared to Scenario 1. This is because under Scenario 2 it is expected that there is scope for [illegible]

Table 4
Equilibrium Outcomes Under Alternative Scenarios

Scenarios	Variable	Firm 1 (US)	Firm 2 (EU)
Scenario 1	q_i	12.21	12.21
	p	51.15	
	q_{di}	4.86	4.86
	p_{dj}	32.97	32.97
	Profits	410.91	410.91
Scenario 2	q_i	12.30	12.30
	p	50.81	
	q_{di}	5.88	5.88
	p_{dj}	26.45	26.45
	Profits	389.74	389.74

Notes: The data of p, p_{dj} variables is in monetary units.