The Concept of Primordial Markets

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***Abstract*—The majority of governmental agencies, NASA, and Department of Defense acquisition programs are technologically advanced complex systems that are unique, costly, and have a long development and design lifecycle. The supply and demand for such unique, complex engineered systems and the stakeholder interactions often do not fit the traditional consumer market concepts, where millions of technological artifacts are developed and sold as a result of a single development cycle. There is a need to define and characterize these unique markets that govern large-scale governmental engineered systems. In this paper, the authors describe these markets as "Primordial Markets" in which government stakeholders and major defense/aerospace companies interact through acquisition processes to create one-of-a-kind engineered systems. Primordial Markets are differentiated from consumer markets by six attributes: 1) only a small number of institutions such as government agencies (including but not limited to various divisions of the U.S. government, Department of Defense and NASA) and aerospace/technological companies are the stakeholders; 2) the development lifecycle duration of Primordial Market projects majorly exceed those of consumer products; 3) only one or a few of complex engineered system are produced as a result of each development; 4) the monetary value resulting of such unique complex systems is often difficult to quantify (e.g., defense projects, scientific projects); 5) the resulting complex systems and their uniquely acquired technologies have at least one degree of separation and removal from consumer markets, (e.g. no easy and direct technology transfer occurs between Primordial Market and mainstream market); 6) the knowledge and science on novel technologies and systems developed within the Primordial Markets are often protected with limited public access due to various security levels. In this paper, the authors define and discuss the unique characteristics and dynamics of Primordial Markets and its differentiating dimensions from the consumer market. The paper continues with discussions on illustrative examples, including dissemination of GPS and the Lunar economy to explain the differentiating aspects of Primordial Markets and their perceivable effects and impacts. The paper concludes with suggestions for directions for research for further study of these markets.**

I. Introduction

Markets are diverse and can be described as omnipresent. Nobel laureate Oliver E. Williamson, in the 1975 book "Markets and Hierarchies," describes the assumption that "in the beginning there were markets" [1], which some describe as the foundation of New Institutional Economics (NIE) [2]. The aerospace industry, the Department of Defense, and multiple other government agencies are often in a unique environment that positions them to influence consumer markets indirectly by investing in unique and technologically advanced projects and complex systems acquisitions. Over the past few decades, the stakeholders in various government agencies have funded the development of numerous technologies and large-scale complex systems that have enabled many scientific and technological discoveries. There are numerous examples of such unique complex systems including the Hubble Space Telescope, James Webb Space Telescope, GPS, Galileo Satellite Navigation, Voyager spacecraft 1 and 2, and many more. Several technologies developed in these unique environments have eventually been declassified or approved for use in the public domain years to decades after these technologies were first developed. For example, DARPA has funded various advanced scientific and defense projects that enabled the development of the internet and GPS use in the public domain. The aerospace and defense agencies interact in a unique and secure environment, or a type of "market," in which the stakeholders and players are limited to the government agencies, various aerospace/defense/scientific companies, and defense/government contractors through a mechanism of the acquisition process that defines and regulates these interactions. We define this particular type of market as a "Primordial Market" since this market has the potential

to seed commercial use and advance state-of-the-art technological and scientific discoveries by acting as the precursor of emergent new technologies in commercial markets. A subset of the technologies developed in Primordial Markets have the potential to be gradually declassified and disseminated into mainstream commercial markets. This market, therefore, behaves as a conceptual primordial soup of protected and secure innovations and unique complex systems that, after maturation, have the potential to be introduced as unclassified research and cutting-edge technologies into mainstream society.

The Primordial Markets have unique characteristics that differentiates them from the mainstream markets which are as follows: 1) Limited number of players/agents in the market (government agencies, contractors/companies), 2) Projects duration and systems lifecycle often spans years/decades, 3) Limited number of technologically advanced systems such as satellites, aircrafts, submarines, ships, etc. are produced that often require very large upfront amount of investment, 4) The benefits or return on investment on these projects are often measured in non-monetary values such as technological superiority, scientific discoveries, defense capabilities and responsiveness to critical scenarios, 5) The resulting technologies developed are often at least one degree removed from mainstream market consumer and initially not readily accessible, 6) The resulting complex developed system is not directly used in commercial market and is often protected by various security levels of information dissemination according to the appropriate restrictions or security clearances.

This paper is organized into the following sections: First, an initial review of existing relevant literature is briefly discussed. Then, the concept of Primordial Markets is discussed in more detail. The concept follows GPS and the lunar economy as examples of a primordial market. The last section provides an overview of the paper, focusing on the potential future direction of research, needed tools, and modeling techniques.

II. Literature Review

When looking at the concept of markets throughout history and across various scientific fields, we often face the challenge of identifying a universal definition of a market and its dynamics. While some scholars, such as Nobel laureate Oliver E. Williamson state that "in the beginning there were markets" [1], others describe a more fragmented view [2] and partially disagree [3]. Markets in the modern sense can today be defined as organized commodity exchanges that "help to structure, organize, and legitimize [...] transactions" as well as prices [4]. In their publication, Depeyre and Dumez [5] stated that there is no universal understanding of what markets are and that, in addition, the nature of markets is defined by the concepts and activities in them alike. This publication brings us to the second part of the literature review, which addresses the defense and government's state of the art and trends in acquisition processes. In Defense Acquisition programs, Etemadi and Kamp [6] discuss factors in the Department of Defense acquisition environment regarding developments over time. Specifically, Etemadi and Kamp looked at innovation activity and cycle time in connection to the contract types. Furthermore, their work discusses the conditions created by these dynamics and analyzes how they affect outcomes and different types of interactions. In another report, Day [7] describes the defense sector's acquisition limits. Day points out the issues with pricing in monopsonies, which are markets with a single buyer. He argues that the dynamics of a monopsony can have significant effects on pricing; for instance, the absence of civilian application can make pricing difficult and, in some cases, also work against the acquiring party. In addition, the dynamics at play in these environments can exceed the limits of efficiencies in regular markets, according to him, and therefore, the power dynamics normally at play in a monopsony can get lost, which can be a significant disadvantage for the purchasing party. FitzGerald et al. [8] outline a more diverse view of the acquisition market and divide the projects into four groups. With these groups, FitzGerald et al. argue that the different competition segments require different approaches, which supports the purpose of the concepts and ideas presented in this paper.

III. The Concept of Primordial Markets

Primordial Markets are unique types of markets in which government agencies and a limited set of companies interact under specific rules and various layers of security and information protection to procure and acquire, design, manufacture, operate, and eventually retire sophisticated and unique complex engineering designs. These complex systems are essential in providing unique technological advancement and superiority in the domain of defense as well as scientific discoveries and innovations. These complex systems in such markets often have the following characteristics:

- Each complex system has one or more unique technological advances that provide major scientific/defense advantages.
- The acquisition, design, and manufacturing process of these complex systems takes years to decades to complete before the system is fielded.
- There are often a single or a few such complex systems that are created and operational.
- The lifecycle cost of such complex systems is often extremely high, so these systems can rarely be

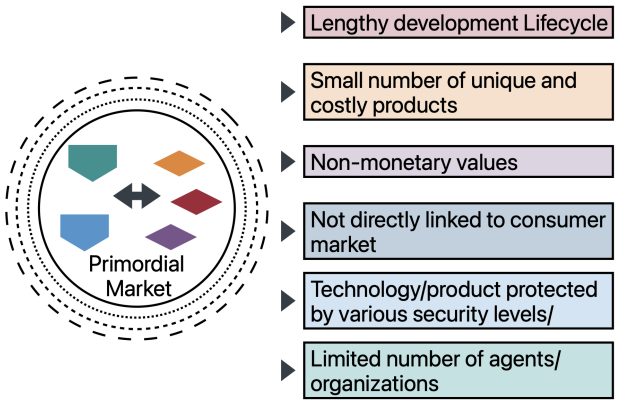

Fig. 1. Characteristics of Primordial Markets

supported financially by the mainstream market to be built.

- These unique complex systems often experience various programmatic risks in their lifecycle and face cost and schedule overruns due to the project's unique nature. These systems often face large amounts of risks in their lifecycle. "It is not possible to know exactly how a particular design will perform until it is built. But the product cannot be built until the design is selected. Thus, design is always a matter of decision making under conditions of uncertainty and risk" [9], [10].

Table I shows a selective set of examples of the United States DoD programs, their total cost, the type of complex system (Aircraft, artillery, avionic systems, communication systems, ships, space systems, etc.), primary contractor, cost and schedule overruns and Technology Readiness Level (TRL). It can be noted that due to the complexity and cost of the project, these projects often experience cost and schedule overruns. The Primordial Markets are defined by the following characteristics that differentiate them from commercial markets:

1) A limited number of government agencies and aerospace/defense-related companies form such Primordial Markets (Government agencies, contractors/companies).
2) Lengthy project duration and systems lifecycle development often span years/decades.
3) A limited number of technologically advanced systems, such as satellites and spacecrafts, aircraft, submarines, ships, etc., are produced.
4) The benefits/values generated by these complex systems are often measured in non-monetary values such as technological superiority, scientific discoveries, defense capabilities, responsiveness to critical scenarios, etc.
5) The resulting unique technologies or systems developed are often at least one degree removed from mainstream market consumers and initially not readily accessible to the mainstream consumer market.
6) The resulting complex system is not directly used in the commercial market. It is often protected by various security levels of information dissemination according to the appropriate restriction or security clearance.

Figure 1 shows a conceptual representation of the characteristics of Primordial Markets.

Primordial Markets often have the potential to seed and permeate the commercial market under special circumstances when a specific complex system or technologies developed within this market are released (often with a delay, e.g., a few years) and declassified for use in commercial markets. The following illustrative cases are examples of innovations that are developed in primordial markets and, years/decades later, filtered into commercial/mainstream markets.

A. Example 1: Commercialization of GPS constellation

The concept of GPS took shape when American physicists at Johns Hopkins University's Applied Physics Laboratory utilized the Doppler effect to track Sputnik 1's orbit in 1957 [12]. This discovery laid the groundwork for the TRANSIT system, the first satellite navigation system, tested successfully in 1960 [13]. In the 1960s, recognizing the potential for an advanced navigation system, technologies from projects were integrated. This led to significant advancements by Harold L Jury and his team, who from 1970 to 1973 employed real-time data assimilation techniques to improve navigational accuracy [14].

A pivotal meeting in 1973 at the Pentagon led to the creation of the Defense Navigation Satellite System (DNSS), later known as Navstar, which synthesized these technologies into a cohesive system [13]. Following the

Program Name	Total Program Cost (M$)	Type of System	Primary Contractor	% Cost Overru	% Schedule Slip	Type of Acquisitic
C-130	$6,204	Aircraft	Boeing	252	0	High TRL
E2-D Advanced Hawkeye	$17,747	Aircraft	Northrup Gruman	20.3	43.2	Medium TRL
F-35	$326,535	Aircraft	Lockheed Martin	78.2	N/A	Low TRL
FAB-T	$4,688	Aircraft	Boeing	29.1	35	Medium TRL
Global Hawk	$12,812	Aircraft	Northrup Gruman	172.2	127.3	Low TRL
Grey Eagle	$5,159	Aircraft	General Atomics	-18	N/A	High TRL
HC-130	$13,091	Aircraft	Lockheed Martin	-5.1	N/A	High TRL
MQ-4C UAV	$13,052	Aircraft	Northrup Gruman	1.6	0	High TRL
P-8A Poseidon	$32,969	Aircraft	Boeing	0.1	0	High TRL
Reaper UAV	$11,919	Aircraft	General Atomics	18.9	19	Medium TRL
Excalibur Guided Artillery	$1,781	Artillery	Raytheon	282.4	27.2	Medium TRL
IDECOM	$821	Avionic System	ITT Electronics	-0.5	-8.5	High TRL
Joint Precision-Apparoach and Landing System	$26,575	Avionic System	Raytheon	-2.9	2.7	High TRL
Airbrone and Tactical Radio System	$8,160	Communication System	Lockheed Martin	0.1	13.8	Medium TRL
Joint Tactical Radio System Handheld	$8,358	Communication System	General Dynamics	1	22.4	Medium TRL
Mobile User Objective System	$6,978	Communication System	Lockheed Martin	3.8	28.9	Medium TRL
Navy Multi-band Terminal	$1,214	Communication System	Raytheon	-11.2	0	High TRL
Warfighter Information Network Tactical	$6,052	Communication System	General Dynamics	8.6	42	Medium TRL
Apache block IIIA	$10,737	Helicopter	Boeing	39.7	3.8	High TRL
CH-53	$22,439	Helicopter	Sikorsky	5.7	32	High TRL
AGM 88E	$1,902	Missile	ATK Missile Systems	10.9	22.4	High TRL
Army Integrated Air and Missile Defense	$5,529	Missile	Northrup Gruman	9.9	1.3	High TRL
Joint Land Attack Cruise Missile Defense	$7,858	Missile	Raytheon	18	6.2	Medium TRL
Standard Missile RAM	$6,297	Missile	Raytheon	10.5	25.3	Medium TRL
CVN 78	$33,994	Ship	Huntington Ingalls	-4.4	13.1	High TRL
DDG 1000	$20,985	Ship	BAE Systems	543	73	Low TRL
Joint Highspeed Vessel	$3,674	Ship	Austral USA	1	4.2	High TRL
LHA Replacement Assault Ship	$10,096	Ship	Huntington Ingalls	5.8	13	High TRL
LCS	$32,867	Ship	Lockheed Martin	76	183	Low TRL
GPS III	$4,210	Space System	Lockheed Martin	6.8	N/A	Medium TRL
Space-Based IR System (SBIRS)	$18,266	Space System	Lockheed Martin	231.2	N/A	Low TRL

TABLE I
AN ILLUSTRATIVE SET OF DOD PROGRAMS AND PRIMARY CONTRACTORS [11]

downing of Korean Air Lines Flight 007 due to navigational errors in 1983, President Ronald Reagan mandated the civilian use of GPS to enhance global navigational safety, a policy fully implemented with the completion of the satellite constellation in 1994 [13], [15]. This marked the transition of GPS from a military asset to a vital global utility accessible to civilians worldwide.

Originally developed for military purposes, GPS transcended its initial scope to become a dual-use technology with profound civilian applications, significantly influencing commerce, science, tracking, and surveillance. The precise timing capabilities of GPS are foundational to varied activities, including banking transactions, mobile phone operations, and the synchronization of power grids. This technology, leveraging its three fundamental components—absolute location, relative movement, and time transfer—supports a wide array of applications: from synchronization in amateur radio and atmospheric studies to enhancing emergency services and automating vehicles.

In the realm of daily life and industry, civilian uses of GPS extend to cartography, disaster response, and geofencing, where it underpins real-time fleet tracking, enables geotagging of digital objects, and supports detailed surveying crucial for construction and environmental research. Furthermore, the integration of GPS into smartphones has exponentially broadened its utility, supporting diverse applications such as navigation, recre-

ation, and mental health monitoring, thereby embedding GPS deeply into the fabric of modern society.

The economic impact of GPS is equally substantial, driving significant growth across sectors like telecommunications, logistics, and transportation. These technological advances have not only increased efficiency but also opened new avenues for commerce and everyday convenience, demonstrating the expansive influence of GPS across global economic and social landscapes.

B. Lunar Economy

One example of an emerging primordial market is the anticipated lunar economy. Over the next decade, NASA's Artemis program is planning to land the first woman and first person of color on the Moon, then establish systems and infrastructure that enable sustained lunar missions and develop capabilities for Mars. The build-up of capabilities planned for Artemis includes an unpressurized Lunar Terrain Vehicle (LTV), a pressurized rover, a surface habitat, a fission surface power element, and an in-situ resource utilization (ISRU) pilot plant. In orbit is the Gateway, which is an aggregation and logistics location where Orion can dock and transfer crew to the landers, as well as a unique deep space science platform. Later, the Gateway becomes the location to aggregate Mars mission elements and perform dress rehearsals for Mars. Lunar economic activity can play an expanding role in future deep space missions. The commercial delivery of water, could become a highly competitive industry sector. A government customer can create an initial stable economic framework by purchasing water for its own exploration programs. By demonstrating to private investors the technological and economic feasibility of in-space refuelling, a water economy could develop with a diversity of suppliers and customers. The primary resources, or utilities, required by a developing lunar exploration campaign include power, communications, mobility, propellants, and crew consumables. Of all the lunar-producible resources, water remains the first and foremost commodity of choice for two primary reasons: no other resource is as ubiquitous in the inner solar system while having as many productive and life-sustaining uses, while also providing the highest performance chemical propellants from a single compound that is relatively easy to extract, refine, transport, transfer, and store. Additionally, water is an excellent source of hydrogen for NTP systems, which provide significant propellant efficiency advantages for the crewed exploration of Mars, while preserving high thrust for planetary orbit injection maneuvers and aborts. Architectures based around water products offer the best long-term sustainability because water products can be generated entirely in-situ from lunar resources. The term water products includes water and any useful resources

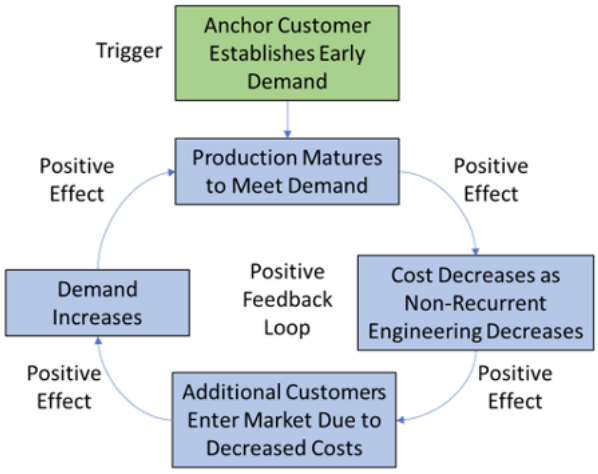

Fig. 2. Primordial Market Forms with Early Demand, then Spirals into a Commercial Market [16].

made from water, including: freshly mined but contaminated water, which can be used for radiation shielding or thermal storage; pure water, which can be used for drinking, environmental control, hygiene, agriculture, radiation shielding, flow batteries, and many other uses; gaseous oxygen and hydrogen, which can be used for crew habitation, life support, and regenerative fuel cells; and liquid oxygen (LOX) and liquid hydrogen (LH2), two powerful chemical rocket propellants, and the propellants of choice for a fully sustainable commercial cislunar and interplanetary transportation ecosystem. Of any commodity, the interoperability of water's many uses gives it the best industrial ecology, defined as the conservation and reuse of material and energy flow within a system. A water-based economy generates less waste and preserves as much value within the ecosystem as possible.

Figure 2 illustrates how this primordial market could transition into a commercial market. In its dissemination stage, an anchor customer could provide the early demand that can trigger economic activity on the Moon. Economically, water holds great promise for catalyzing this early cislunar commerce. Achieving true sustainability depends not only on good industrial ecology, where value is preserved within a space exploration ecosystem, but also on commercial viability, where that value is multiplied, and this growth is leveraged to create further value. The guarantee by an early customer to purchase a large quantity of water by the gallon represents the first concrete step toward establishing such an economy. This first transaction—likely a national space agency using public funds for a state endeavor like space exploration—may not qualify as truly commercial; however, in doing so, such an anchor customer establishes a stable framework to foster further investment and

development by private actors. The purchase and use of large quantities of LOX/LH2 propellants is useful from a scientific and operational perspective. However, from a commercial perspective, the real advantage of such a purchase is that it necessarily flows that investment back up through the value chain to an entire ecosystem of exploration, mining, production, storage, transfer, mobility, power, and communication providers, with commercial transactions at every step. Although the first transaction by an anchor customer will likely employ public funds, eventually, the purchase of a highly developed resource like LH2 will be made by a private customer investing its own profit in pursuit of private commercial objectives. At this point, this segment of the market can transition from primordial and be considered truly commercial.

IV. Summary and Conclusion

Primordial Markets provide unique opportunities for advancement in science and technology. They do have the potential to disseminate a fraction of the technologies and discoveries that become unrestricted/unclassified into the mainstream market. However, their dynamics, interaction between stakeholders, governing rules of interactions, and potential dissemination of science and technology from these markets are severely understudied. The authors of this paper define the characteristics of primordial markets and highlight some of their dynamics and potentials. The future work in this domain will include but not limited to: identifying modeling and simulation techniques for establishing the optimal acquisition processes, better approaches to modeling and managing risks in technical and programmatic domain of primordial markets, identifying the technologies with dissemination potential into commercial market, studies on the effect of agents and stakeholders interactions in Primordial Markets and their relationship to cost and schedule overruns in such major endeavors.

Acknowledgment

The views expressed herein are those of the authors and do not reflect the position of the Department of the Army or the Department of Defense.

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