ECONOMICS AND EXPLORATION: A BIT OF HISTORICAL PERSPECTIVE ON OUR NEW AGE OF EXPLORATION. D. T. Britt, Dept. of Physics, University of Central Florida, Orlando FL 32816 and the Center for Lunar and Asteroid Surface Science (dbritt@ucf.edu).

Introduction: It has been 50 years since Apollo 11 landed on the Moon and most of the optimistic (and fictional) predictions about rapid progress to Moon bases and Mars exploration have not become reality. An analogy may be found in the age of western exploration. Why did 115 years elapse between Columbus' discovery of the Americas and the establishment of Jamestown to begin the settlement of North America? It turns out that there were substantial economic reasons for this hiatus along with many underappreciated "features" of exploration. The 16th century age exploration has several interesting analogues and lessons for our current situation that can provide insight into a range of exploration issues including planetary protection, the development of In-Situ Resource Utilization, and the growth of new launch providers.

Economic Framework: In my previous life I trained as an economist and was interested in the Economic History, which was the use of economic theory to analyze historical actions and trends [1]. There are several basic economic principles that we apply to the economics of exploration:

- *Risk-Return Matrix:* Investors assess expected return and discount return by associated risks.
- *Investment/Entry Costs:* Are there barriers (legal, physical, social, technological, etc.) to entry and/or high initial investments?
- *Opportunity Cost:* What is the next best alternative to your proposed investment?
- *Externalities:* What are the unintended costs of the investment and who bears the costs?

Using this framework, we can systematically analyze the events of the 16th and 17th century great European age of exploration.

Columbus and Spanish America: The Columbus expedition was the result of multiple failed proposals to the Portuguese and Spanish Governments based on bad science and a transparently erroneous reading of distances. But the potential rewards outweighed the risks [2].

Risk-Return: The proposal was highly speculative, reviewed very poorly, but with the potential of high return.

Investment/Entry Costs: The funding agency appears to have substantially cut the grant relative to proposed costs. The crown dumped a lot of the supply costs onto coastal cities and the ships used were small and old. However, shipping technology, even with old/small ships, was more than robust enough to traverse the Atlantic.

Opportunity Cost: With the conclusion of the Moorish War unemployment was high and there was a funding "peace dividend" which resulted in low crewing and ship rental costs.

Externalities: Unknown and largely unexpected.

Once the Americas were discovered Europe realized that this new area was well within the one-way range of current shipping technology.

Investment/Entry Costs: ISRU 1500's style: A serious problem for all the early expeditions was basic support i.e. food, ship repair, crew replacement. This is essentially of our "gear-ratio" problem. You cannot carry enough food and supplies from Europe to support extended stays and exploration in the new territories. All the European exploring countries quickly established advanced bases to support their exploration goals. Havana was developed as a central supply and refit hub for the Spanish Caribbean. Manila served that role in the far east. Same story for other European exploring countries New England served that role for the English possessions, Goa in India for Portugal and Cape Town and Java for the Dutch. In all cases advanced bases were a critical feature of exploration.

Risk/Return: The Treasure of the Americas: HUGE return from a trivial investment. The Spanish encountered organized and very wealthy civilizations, which they systematically looted. Silver from the Americas accounted for one-fifth of the Spanish Empire's budget for the next 200 years and enabled a completely crazy and over-extended foreign policy. Gold and silver from the Americas roughly tripled the world's stock of precious metals [3]. These kinds of returns set off a frenzy of investment and settlement. In the 16th century about 500,000 Spaniards emigrated to the Americas (note that this is about 5% of Spain's population). It also encouraged competition. The Age of Exploration was also the Age of Piracy. Lots of high-value cargos going thru sparsely populated areas with no effective rule of law. For example, the Anglo-Saxon world calls Francis Drake a great man, but the Hispanic world loathes him as the worst sort of pirate, thug, and bandit. He was just one example of a huge collection of freebooters that existed because shipping technology outran the reach of institutional control.

Risk/Return: Unknown Unknowns: Columbus set off on 3 August 1492 and returned 15 March 1493. People who live along the Gulf and Atlantic call this date range "Hurricane Season". Columbus was very lucky during his voyages to miss hurricanes. During the age of sail, an encounter with a hurricane was generally fatal. Once they learned about hurricanes, the commercial and military fleets evacuated the tropics during hurricane season.

Externalities: The Columbian Exchange: In 1491 the population of the Americas was probably around 100-120 million, about 20% of world population at the time. By 1600 it had collapsed to around 5 million because of a range of diseases common in Europe but unknown in the Americas (flu, measles, smallpox, plague, malaria, yellow fever, to name a few). The population of central Mexico was around 25-30 million before Cortes, it dropped to 800,000 by 1600. It was not until the 20th century that the population of Mexico recovered.

North America during the 1500s: It is not that English and others were ignoring the Americas**.** John Cabot was hired by English merchants to explore North America and made two voyages in 1497 and 1498**.** He just did not find much except lumber and fishing grounds

Risk/Return: The shores of North America were thickly settled by with warlike and well-organized natives. Getting a foothold was very tough.

Investment-Entry: The Spanish claimed everything and were known to discourage other explorers. The shipping technology used was the same as the Spanish.

Opportunity Cost: Wages and shipping costs were high (northern Europe was still recovering from the Black Death).

This does not mean that North America was ignored. Activities included Grand Banks fishing, lumbering on offshore islands, and fir trading. It is just that the economic factors need to change to allow continued exploration and development. That change came in the form of a technological breakthrough in shipping.

Investment-Entry: The Dutch Fluyt: Designed to facilitate transoceanic delivery with maximum of space for cargo and with labor-saving technology to maximize crew efficiency (the Falcon of its time). Was cheaper to build, carried twice the cargo per ton as a galleon, and could be handled by a much smaller crew. The fluyt design used block and tackle (new technology in the 1500's) extensively to facilitate ship operations. Minimized or eliminated armaments to maximize available cargo space. These factors combined to sharply lower transportation costs.

Jamestown 1607:

Risk-Return: By this time the natives were dying off from new diseases and the Spanish were too busy to interfere with new settlement. Return came from the production of staples (rice, lumber) and drugs (1612 Tobacco cultivation was introduced at Jamestown. By 1627 exports were 500,000 pounds/yr.)

Investment-Entry: Transportation costs have dropped by a factor of ~3 over the last 100 years due to the technology of the Dutch Fluyt. Land was increasingly expensive in Europe, but very cheap in America.

Opportunity Cost: Population had recovered from the Black Death. Real wages have been falling for 80 years. Effective wages for laborers in Virginia were more than double that in England. The major European export was people.

Plymouth 1620:

Risk-Return: With the revolution in transportation costs you could make money shipping people to New England and raw lumber or salted fish back to Europe. One attraction for immigrants was local political power (particularly religious fringe groups like the Puritans. From 1630 through 1640 approximately 20,000 Puritans came to New England).

Investment-Entry: Land was cheap, the Spanish were less of the threat, the natives were mostly dead

Opportunity Cost: Wages and transport costs were low. The major European export was people

What developed from low transport costs and abundant land was an integrated Atlantic economy based on the production of bulk agricultural staples in the Americas**.** Low transport costs, cheap land, few barriers to entry or investment, good legal protection made this possible [1,4].

Conclusions:

- Institutional and legal frameworks are very important. But, watch out for lax enforcement. The Age of Exploration was also the Age of Piracy.
- Development of local resources (ISRU) are huge! All the exploring countries depended on local resources and advanced bases (Havana, Goa, Boston)
- Transportation costs are key. They were key in the 1500's, they are key now. The revolution in shipping technology made a wide range of exploration and development possible.
- Unintended consequences are the RULE, NOT THE EXCEPTION in exploration and new settlement.

References:

[1] North D. (1973) The Rise of the Western World: A New Economic History. [2] Mann C. (2005) 1491: New Revelations of the Americas Before Columbus. [3] Mann C. (2011) 1493: Uncovering the New World Columbus Created. [4] Morris I. (2010) Why the West Rules-For Now.