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A BASIS OF SETTLEMENT: ECONOMIC FOUNDATIONS OF PERMANENT PIONEER COMMUNITIES

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High transport costs will dominate the course of lunar development. During the earliest phases, when lunar facilities consist of a research and resource development complex with staff serving tours of a few months, transport costs will encourage local production of fuel, food, and building materials. Once these capabilities are in place and the number of personnel grows to a few hundred, staff rotation might well dominate transport budgets. At that point it would make economic sense to encourage some members of staff to become permanent residents. By analogy with early British settlement in Australia, a vigorous private sector economy could emerge if the lunar organization provided quasi-export earnings through its role as the community's major employer and as the major buyer of locally produced goods. By providing such a market for goods and services, the lunar organization would not only provide a means whereby permanent residents could support themselves, but could also accelerate the process of replacing imported goods with local manufactures, thereby reducing the cost of operations. By analogy with recent Alaskan experience, if the resource development activity started making money from sales to orbital customers, export taxes and/or royalty payments could also provide means by which a lunar community could support itself.

INTRODUCTION

In the half century before Sputnik, many space enthusiasts believed that space travel would eventually lead to settlement; that permanent residents of extraterrestrial communities would someday raise children and make livings from mining, manufacturing, tourism, farming, and a hundred other occupations, as had countless terrestrial settlers before them (e.g., *Clarke*, 1950). The settlement goal has remained in the background since Sputnik; the space powers have concentrated on transportation technologies and space science. However, posterity may well remember these efforts as preliminaries to settlement. In some sense, for the last quarter century human and robot explorers have been doing basic reconnaissance, and while there is a good deal of exploring still left to do, the time for space pioneering may be only a few decades in the future. Implementation of the goal of "expanding the human presence beyond Earth into the solar system," adopted recently by the Reagan Administration, could lead, step-by-step, from an Antarctic-style science base to permanent settlement.

Setting a goal is, of course, a different matter from actually accomplishing the deed. In the last few years we have made great progress in sketching the essential features of the science bases and resource development facilities that will be important precursors to permanent settlements (*Mendell*, 1985). With those sketches in hand, we can now give thought to ways in which economically viable extraterrestrial communities might plausibly emerge in the context of an affordable space program.

Although pioneering settlements, particularly in novel environments, are often established for political, ideological, historical, or social reasons, their long-term viability and growth almost always depend on economic factors. Living standards and the potential for economic growth depend, in part, on the development of local production capacity. However, any small community—pioneering

or otherwise—can produce only some of the needed goods and services. The rest have to be bought from outside suppliers. Support of an import capacity comes from sales to customers outside the community. Export opportunities available to early-stage lunar or martian communities will be limited; the emergence of permanent communities will require dependence on public sector employment and on public sector markets to a degree uncommon in American frontier experience, in particular, and in terrestrial frontier experience in general.

THE CLASSIC AMERICAN PATTERN

Because of our particular national experience, Americans are generally used to thinking about the frontier in terms of small-scale, private settlement ventures. The vast majority of American settlers were family farmers, farm workers, trappers, miners, or town-based craftsmen and professionals, almost all of whom were either self-employed or worked for others in small-scale operations (*Billington*, 1963; *Merck*, 1978). In circumstances where capital requirements and economies of scale favored or mandated large enterprises like the cash-crop plantations of the Old South, these too were private ventures. Although the states and the federal government played vital roles in support of private ventures—exploring new territory and providing surveys, Army protection, direct and indirect subsidies of the construction and operation of canals and railroads, etc.—most settlers supported themselves in the private sector economy. Typical American pioneers sought farmland not too far removed from river, road, or railroad. Their goal was to produce, as soon as possible, food surpluses that could be sold to the Eastern cities and even to Europe in exchange for the goods they could not produce locally. Although retained Calvinist/English attitudes toward central authority and land ownership were important factors in deter-

mining the dominant pattern of American settlement, above all it was the abundance of good farmland and the accessibility of large markets that shaped the American experience. Good land and low-cost transport allowed individual farmers, even at mid-continent, a considerable share in the fruits of the industrial age. By and large, settlers provided their own import capacity through their individual ability to directly produce exportable goods. Not all settlement ventures have had a comparable means of support.

ALASKAN SETTLEMENT

The history of Alaska illustrates an alternative pattern of development. The territory's early nonaboriginal settlement episodes resulted from the fur trade and from a series of gold and copper discoveries. However, unlike California, Alaska had no agricultural potential to take up the slack when the gold began to run out (*National Resources Committee*, 1937). For a variety of social, economic, and legal reasons, even salmon—a renewable fixed-based resource that had been the basis of aboriginal settlement—has played only a limited role in subsequent Alaskan development. Taxes on salmon production provided the majority of revenues available to the Territory of Alaska—72% in 1940 (Cooley, 1966)—but, since the industry employed a nonresident, seasonal workforce, it provided little basis for permanent settlement. Other than those towns that owed their origins directly or indirectly to mining, almost all Alaskan settlement has resulted from public expenditures of one form or another. The city of Anchorage, for instance, started as a construction camp for a government railroad built for the express purpose of encouraging settlement. However, because of the lack of agricultural potential and other factors, it was the railroad itself, via salaries and other expenditures, that provided the economic support for Anchorage and a handful of other towns along the route (Wilson, 1977). Before 1940, Alaska's nonaboriginal population never exceeded 30,000. Among Alaskan boosters, this state of affairs was often attributed to Federal "neglect," but was more a consequence of local economic realities.

However, beginning in 1940, population and import capacity began to increase dramatically because of military construction and other government activities that came with World War II and the Cold War (Rogers, 1962). In essence, Alaska began to make a living by providing government service, particularly service to the national defense effort. Further expansion, beginning in the 1960s, resulted from oil discoveries, related construction activities, and, particularly, from oil revenues that poured into the Alaskan treasury. As part of statehood legislation, Alaska acquired ownership of potential oil lands at Prudhoe Bay and, after oil was actually discovered, began to reap enormous revenues. Although Alaska invests (mostly out of state) a significant fraction of its oil earnings in a Permanent Fund—a pool of money that might, at some future date, provide support for some public-sector activities should earnings for nonrenewable resources dry up—most oil revenues are spent on government salaries, public works, and even a Permanent Fund dividend paid annually to every year-round resident. Oil revenues ultimately pay for about 80% of Alaska's imports, and fuel most of the local economy.

For a variety of reasons, Alaska has yet to develop any alternative means of paying for imports and, indeed, there is very little local manufacturing of any kind. Since 1940, a combination of relatively inexpensive imports and a very high wage scale have made it impossible for locally produced goods to compete. Alaska's

internal economy depends almost entirely on the service sector. Incentives toward local production of goods have been weak or nonexistent.

The circumstances of lunar settlement will differ in obvious ways from both the classic American and recent Alaskan experiences. In particular, while a very high cost of transport will severely restrict the range of economic options—for instance, making it virtually impossible for individual settlers to make a living as private exporters—those same high costs will put a premium on local production capacity. This combination of circumstances bears close resemblance to the early settlement of Australia, an important historical case that suggests how growth of a private sector economy might be stimulated in the lunar or martian case.

THE AUSTRALIAN ANALOG

Before the advent of clipperships and steam, the only products that could compete in global markets were those with very high value per unit weight. Examples included precious metals and gems, silk and certain other manufactured goods, spices, and drugs like tea, rum, and tobacco. Grain and other ordinary foodstuffs could bear the cost of transport across the North Atlantic, but certainly couldn't be shipped profitably to Europe from as far away as Australia (Blainey, 1966).

Cursory examination of the Australian coasts during the seventeenth and eighteenth centuries had revealed no obvious products of value in international trade. Even after Captain Cook noted the relative fertility of the southeast coast, there wasn't much British interest in Australian settlement for the two simple reasons that (1) private settlers could find easier outlets for their energies in the United States and Canada, and (2) His Majesty's government was preoccupied with the American Revolution and ongoing European conflicts. Australia would certainly have been settled eventually, but probably not until well into the nineteenth century had not other events intervened.

The roots of Australian settlement are to be found in the British practice of sending convicts to the American colonies. Although the number of convicts comprised only a tiny fraction of total eighteenth century immigration into the Americas, a refusal by the colonies to accept any more convicts after 1774 created serious problems for the British government. By the mid-1780s Britain's local jails and the country's few prisons were becoming very overcrowded. The government was under considerable public pressure to devise a solution but had a difficult time finding one it thought it could afford. Finally, in 1786, the Pitt government decided to establish a penal settlement in Australia (Mackay, 1985). Although no one of that time would have described the venture in the following way, we might say that His Majesty's government decided that an Australian settlement could earn its keep by providing a public service, namely operating a prison. The First Fleet arrived at Sydney Cove in January 1788. On board the 11 ships were about 1000 people: 750 of them convicts, and the rest government employees and their families.

Planners in London had assumed that the convicts would grow on government farms all the food that the colony would need. As it turned out, the government farms were never very productive. Fortunately, within a few years, some of the employees and a few ex-convicts were producing surpluses on private farms. The penal establishment, which typically was responsible for feeding about half the population at any one time, began buying

food in quantity and at prices less than those of imports (*Fletcher, 1976a*). These purchases by government, together with salaries paid to its employees, provided hard cash with which the private sector could satisfy its import needs.

Because of the great distance from Europe, imports were always expensive, and there was plenty of incentive to produce goods and services locally. For a quarter century, development of the private sector was fueled both by growth of the population and by the need to replace imports. Agriculture was the first priority, but most people in the colony had neither the skills nor the opportunity to make a living from farming. Indeed, farming required at most about one third of the labor force, convict or otherwise. Had everyone been a farmer, the colony would not have prospered as it did, since there would have literally been no markets for two thirds of the potential output. However, the colony was blessed with a labor force that, although burdened with a disproportionate number of unskilled people, otherwise represented a fair cross section of the contemporary British talent pool. There were craftsmen of almost every description, along with clerks, tradesmen, and assorted professionals. Some were ex-convicts, some were convicts given permission to support themselves (thereby reducing the penal establishment's costs), and these were eventually joined by people born in the colony (*Shaw, 1969*). In one way or another most of these people helped diversify and strengthen the local economy.

At any one time, the colonial population could be divided roughly into three groups. One group consisted of the people entirely supported—fed, clothed, and housed—by the penal establishment. As mentioned previously, for many years this included about half the population. Although the colony had no viable export, government expenditures to feed these people and otherwise support the penal establishment provided the private sector with the essential hard cash with which it could pay for imports. Government monies entered the colonial economy in the form of salaries and of payment for goods bought by the Commissariat. The second segment of the population comprised those people to whom these monies were paid. It was a relatively small group, mostly civil and military officers who were joined later by a number of ex-convicts who prospered in the colony. This group played a central role in the economy through access to and control of the colony's supply of hard cash (*Butlin, 1985*). The officers could have used the cash solely to support themselves with imports, but that would have been an inefficient use of the cash resource. Many of them had come to the colony intending to get rich, so they bought less expensive, locally produced goods and services from the remaining segment of the population, those people without direct economic connection with the penal establishment. These local purchases freed capital for investment in enterprises that would yield additional hard cash through sales of meat and grain to the penal establishment; many of the officers did very well for themselves but, by spending money locally, they helped stimulate and diversify the economy. Finally, as the nonconvict population grew, those people without direct access to hard cash nonetheless had considerable dealings with each other. Through the process of import replacement, the economic impact of government expenditures was greatly increased; by the 1820s the gross domestic product had increased to about four or five times the level of government expenditures and, hence, of the level of imports (*Butlin, 1985*). By early nineteenth century standards the Australian settlement enjoyed a very high standard of living.

By about 1820 the process of replacing imports had gone about as far as it could, and that presented the colonial economy with a problem. Government expenditures within the colony per convict were leveling off while at the same time the proportion of ex-convicts and native-born adults was increasing. In essence, the import capacity—wholly supported at the time by government expenditures—was being diluted. The economic importance of the penal establishment was about to go into decline and with it the standard of living—unless an export could be found. High transport costs limited the options, but sheep breeders gradually discovered that they could make money from wool exports (*Abbott, 1969; Fletcher, 1976a*).

The pastoral industry had arisen because of the potential for large cash earnings from meat sales to the Commissariat. Although the colony became more or less self-sufficient in grain by the end of the 1700s and produced large amounts of pork and chicken, the numbers of cattle and sheep increased very slowly. For nearly three decades the colony imported significant quantities of meat. Indeed, the Commissariat bought no beef or mutton during the colony's first 20 years because the early governors wanted to ensure that the herds and flocks would grow as quickly as possible. However, it was obvious that the Commissariat would start buying meat in quantity once the animal populations had grown large enough that demand could be satisfied out of natural increase. Once the government started buying meat, the level of expenditures in the colony would increase significantly. In anticipation of such sales, a number of the civil and military officers concentrated their private efforts on the development of pastoral operations. As with grain production, they were much more successful in raising animals than was the government. Commissariat meat purchases began in 1808 and sustained expansion of the pastoral industry until the mid-1820s, by which time local supply was satisfying demand.

The colony's first Merino sheep, a Spanish breed developed for wool production, had been introduced into Australia in the 1790s but, because of the anticipated government demand for meat, little effort had been devoted to breeding animals for fleece quality rather than carcass weight. However, as meat supplies caught up with demand, meat prices began to decline relative to wool. This, together with other factors, led to a rapid expansion of the Merino flocks in the 1820s and 1830s. By the end of the 1830s, New South Wales was earning enough from wool exports to end its dependence on the penal establishment; and in 1842 the colony successfully lobbied London to stop sending convicts (*Fletcher, 1976b*).

LUNAR SETTLEMENT

It is extremely unlikely that there will be a lunar penal establishment any time soon—the economics are all wrong, among other things. However, a lunar research/resource development organization could play much the same economic role that the penal establishment did in New South Wales. The only significant difference would be the fact that, unlike the Australian settlement, in the beginning a lunar facility would have no permanent residents.

We will begin with a base camp. No matter whether we commit to a lunar development program for scientific, geopolitical, or other reasons, the very high cost of transport will put a premium on the development of local production capabilities. Let us assume, for the sake of discussion, that the emergent lunar-base

program will be fiscally constrained to the annual delivery to low Earth orbit (LEO) of 900 tons specifically for the support of lunar operations. This is equivalent to six Saturn V launches. Current scenarios (e.g., *Babb et al.*, 1985) suggest these additional ground rules: that staff of the lunar facility serve six-month tours; that the facility consist of about one 20-ton module and 10 tons of CELSS equipment per staff position; and that facilities to produce oxygen, heat shields, and construction material mass about 100 tons each. Within these constraints, the facility could achieve basic self-sufficiencies in the production of food, construction materials, and propellant by the end of the first decade. The facility at that point might have a staff of 30 or so.

Past this point of development, the transport budget would be dominated by deliveries of CELSS and other high-tech equipment, and by staff rotation. The staff size could gradually increase—constrained by CELSS installation—until staff rotation began to consume virtually all the transport budget. If we assume a reusable five-ton, four-passenger transfer vehicle, fueled with lunar oxygen and terrestrial hydrogen, together with a six-month duty tour, the cost of maintaining one staff position is about three tons delivered annually to LEO. The maximum staff size is then about 300.

At some point, and probably at one well short of a 300-position staff, the economics of crew rotation and training should force serious consideration of permanent residency. Much will depend, of course, on the perceived economic, geopolitical, and/or scientific/technical return generated by the lunar facility; but once the facility begins to earn its keep, at least in intangible terms, then a commitment to permanent residency on the part of the operating organization, its sponsors, and the potential residents becomes plausible. At this point lunar settlement would begin.

During the stages leading up to settlement, living and working conditions at a lunar facility will necessarily be spartan but must be acceptable to staff. The Atlantic Richfield (ARCO) facility at Prudhoe Bay offers some guidance. There, each member of the 500-person staff has a private bedroom of about 10 sq m and shares a 7-sq m bathroom with one other person. There are, in addition, about 700 sq m of common areas—cafeteria, dining rooms, lounges, atrium, gymnasium, movie theater, etc.—for a total of about 18 sq m of nonwork space per person (ARCO staff, private communication, 1987). Extensive common areas are particularly important.

Would-be permanent residents of a lunar facility would expect and demand larger living quarters, including more common areas and a higher standard of living than would be available in the precursor stages. Expansion of the physical plant would probably not be a major expense, provided that several tens of square meters per person could be built (in quantity, of course) at a cost of a few tons of material shipped to LEO. On the other hand, expanded services and access to goods could be quite expensive unless efforts were devoted toward local production. Of necessity, the process of import replacement would continue and, by analogy with the Australian case, could spur development of a local private sector.

A way in which the process could begin is illustrated by the history of Los Alamos, the research town founded during the Second World War expressly to house Manhattan Project personnel (e.g., *Lyon and Evans*, 1984). At first, people put up with some rather primitive conditions, but it was wartime, and few of them expected to stay once the conflict was over. However, after the war, when the federal government decided that the research effort would have to continue, the Atomic

Energy Commission began building permanent housing and providing services that would make life attractive to the kinds of people that the laboratory needed. The AEC was never very happy about running what was, in essence, a civilian town and eventually sold all the housing and businesses to residents. It also began turning public services over to the community, a process that continues even now. The AEC, having been the town's landlord, retained only the more limited role of operating the laboratory, the town's dominant employer. The Los Alamos analogy is only partly relevant because transport costs were never a major factor; from the beginning, the town and laboratory were well integrated into the state and national economies. Other than the laboratory and the schools, the only economic activity in town has been at the retail level. Import replacement was never a major consideration. However, the Los Alamos experience suggests that, at a lunar facility, transfer of support services to residents could be a first step toward the emergence of a private sector economy.

In the early stages, the lunar facility, like the ARCO operation at Prudhoe, could be operated in a cashless mode. Salaries for rotating employees might be substantial by terrestrial standards but would have little relation to the actual cost to the organization of maintaining an individual on the lunar surface. There being no way to spend money at the lunar base, those salaries would be banked on Earth. However, once support services are transferred to residents—perhaps through lease/purchase arrangements—an important second step would be conversion of the lunar facility (at least with regard to permanent residents) to a cash-based operation. This would require payment of salaries commensurate with a lunar cost of living.

Transfer of support functions and conversion of the local economy to a cash basis would not immediately produce savings for the operating organization except in terms of reduced expenditures for staff rotation and training. Permanent residents will require a high standard of living and hence a higher level of imports than would rotating staff, at least until there is more import substitution. However, transfer of support functions and payment of salaries would provide would-be entrepreneurs with sources of capital and, in the longer term, would accelerate the import replacement process. That, in turn, would reduce the cost to the lunar organization of conducting the retained research and resource development functions.

By analogy with the Australian case, a lunar research/resource development organization may be the only means of supporting development of a local private sector economy. Both as an employer and buyer, the organization can provide quasi-export earnings with which permanent residents can pay for private imports. The organization as a buyer—for instance of goods and services to support visiting research personnel (the lunar equivalent of convicts)—would provide the major market that would probably be necessary to stimulate import replacement on a significant scale.

There is one other way in which a lunar community might support itself. Although, in the long term, the private sector may well produce a viable export, the lunar equivalent of wool, there is also a very real prospect that, at a relatively early date, the resource arm of the lunar organization (although perhaps not a martian counterpart) would begin making profits from sales to orbital customers. These export earnings would certainly generate jobs but, as the Territory of Alaska discovered during its formative years, severance (export) taxes are a far more reliable means of forcing investment in community development.

CONCLUSIONS

An appeal to historical analogs suggests that permanent settlements on the Moon or Mars can emerge from a properly structural, sustained program of research and resource development. The things needed in order to reach that goal fall into a few broad categories. These include

1. A capability of launching into low-Earth-orbit—and then on to the Moon or Mars—significant amounts of cargo on a sustained basis;
2. Engineering research that will allow production of food, fuel, and building materials from local resources at the earliest possible date;
3. A research program that will make the best possible use of the facilities and, thereby, provide a substantial scientific and engineering return on the investment in the years before there are commercial profits;
4. An administrative and legal environment conducive to settlement and the emergence of a local private sector economy; and
5. A commitment to the endeavor for long enough to give it a reasonable chance of success.

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