PILGRIM FATHERS, MORMON PIONEERS, AND SPACE COLONISTS: AN ECONOMIC COMPARISON

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GOVERNOR WILLIAM BRADFORD of the Plymouth Colony, President Brigham Young of the Church of Jesus Christ of Latter-Day Saints, and my friend Professor Gerard O'Neill of the Princeton University physics department, have much in common. Each of the three is a man of vision. Each believes passionately in the ability of ordinary men and women to go out into the wilderness and build there a society better than the one they left behind. Each has written a book [1] to record for posterity his vision and his struggles. Each has his feet firmly on the ground in the real world of politics and finance. Each is acutely aware of the importance of dollars and cents, or pounds and shillings, in making his dreams come true.

In this article I am saying that the human and economic problems which the space colonists of tomorrow will face are not essentially different from the problems faced by Bradford in 1620 and by Young in 1847. Unfortunately, the extravagant style and exorbitant costs of the Apollo expeditions to the Moon have created in the minds of the public the impression that any human activities in space must necessarily cost tens of billions of dollars. I believe this impression to be fundamentally mistaken. I shall argue that, if we reject the style of Apollo and follow the style of the *Mayflower* and the Mormons, we shall find the costs of space-colonization coming down to a reasonable level. By a reasonable level of costs I mean a sum of money comparable to the sums which the Pilgrims and the Mormons successfully raised. To give this argument substance, I must begin by establishing the true costs of the *Mayflower* and Mormon expeditions and the proper rates of exchange for converting these costs into 1977 dollars.

Bradford and Young provide abundant documentation of the difficulties they faced in raising funds. Bradford emphasizes in his book that the toughest problem in the whole venture of colonization was to define a set of objectives upon which the brethren could agree.[2]

> But as in all businesses the acting part is most difficult, especially where the work of many agents must concur, so was it found in this. For some of those that should have gone in England fell off and would not go; other merchants and friends that had offered to adventure their moneys withdrew and pretended many excuses; some disliking they went not to Guiana; others again would adventure nothing except they went to Virginia. Some again (and those that were most relied on) fell in utter dislike of Virginia and would do nothing if they went thither.

Without agreement upon objectives, the task of fund-raising becomes impossible. This is a fact of life which remains as true in 1977 as it was in 1620. Bradford and Young devote more pages of their histories to the preliminary battles over objectives and finance than they devote to the description of their voyages. For both of them, it came as a blessed relief when the miseries of indecision were over, the expeditions were ready to go, and they were finally able to turn their attention away from political and financial matters to the simpler problems of physical survival. Here is Young [3] writing from his winter quarters in February, 1847, six weeks before starting his journey across the plains:

> I feel like a father with a great family of children around me, in a winter storm, and I am looking with calmness, confidence and patience, for the clouds to break and the sun to shine, so that I can run out and plant and sow and gather in the corn and wheat and say, children, come home, winter is approaching again and I have homes and wood and flour and meal and meat and potatoes and squashes and onions and cabbages and all things in abundance, and I am ready to kill the fatted calf and make a joyful feast to all who will come and partake. We have done all we could here and are satisfied it will be all right in the end.

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[1] William Bradford, *Of Plymouth Plantation, 1620–1647*, ed. Samuel E. Morison (New York, Alfred A. Knopf, 1952). Brigham Young, *History of the Church of Jesus Christ of Latter-Day Saints, Period II, from the Manuscript History of Brigham Young and other Original Documents* 7, ed. B. H. Roberts (Salt Lake City, Deseret News, 1960). Gerard K. O'Neill, *The High Frontier, Human Colonies in Space* (New York, W. Morrow and Co. Inc., 1977).

[2] Bradford, *loc. cit.*, p. 39.

[3] *Messages of the First Presidency of the Church of Jesus Christ of Latter-Day Saints, 1833–1964*, ed. James R. Clark, 1: p. 318 (Salt Lake City, Bookcraft, Inc., 1965). Young crossed the plains to Utah twice, in 1847 with an advance party to choose the site for the colony, and in 1848 with the main body of colonists. The numbers that I have collected here refer to the 1848 crossing, but I used 1847 prices since most of the purchasing and provisioning must have been completed in 1847.

But I must come back from these idyllic sentiments to questions of dollars and cents. Two years earlier, Young reported: [4]

> For an outfit that every family of five persons would require: one good wagon, three yoke of cattle, two cows, two beef cattle, three sheep, one thousand pounds of flour, twenty pounds of sugar, one rifle and ammunition, a tent and tent-poles—the cost would be about $250 provided the family had nothing to begin with, only bedding and cooking utensils, and the weight would be about twenty-seven hundred [pounds] including the family.

The arts were also included in Young's budget. On November 1, 1845, he paid [5] $150 to purchase instruments for the brass band. This was a wise investment, for the band [6]

> Was sometimes invited to give concerts at villages near to the line of march, which did much to change the feelings of hostility which occasionally was manifested in such places. Thus this band proved a very great benefit to the marching column, besides cheering the spirit of the pilgrims.

The actual numbers that crossed the plains with Young were [7] 1,891 souls, 623 wagons, 131 horses, 44 mules, 2012 oxen, 983 cows, 334 loose cattle, 654 sheep, 237 pigs, 904 chickens.

So we can estimate the total payload of Young's expedition to be 3,500 tons, mainly consisting of animals on the hoof, and the total cost to be $150,000 in 1847 dollars.

Bradford unfortunately does not provide such an exact accounting for the *Mayflower*. He quotes a letter [8] from Robert Cushman, dated June 10, 1620, in London, two months before the sailing. Cushman was one of the people in charge of provisioning for the voyage:

> Loving Friend, I have received from you some letters, full of affection and complaints, and what it is you would have of me I know not; for your crying out, "Negligence, negligence, negligence," I marvel why so negligent a man was used in the business. —Counting upon 150 persons, there cannot be found above £1,200 and odd moneys of all the ventures you can reckon, besides some cloth, stockings and shoes which are not counted, so we shall come short at least £300 or £400. I would have had something shortened at first of beer and other provisions, in hope of other adventures; and now we could, both in Amsterdam and Kent, have beer enough to serve our turn, but now we cannot accept it without prejudice—£500 you say will serve; for the rest which here and in Holland is to be used, we may go scratch for it. —Think the best of all and bear with patience what is wanting, and the Lord guide us all.
>
> Your loving friend, Robert Cushman.

This letter shows that Cushman was personally responsible for meeting expenses to the tune of £1,500. It does not say whether all the expenses, and in particular the rental fee for the *Mayflower,* were included in this figure.

Three weeks later, on July 1, 1620, an agreement [9] was signed between the Planters and the Adventurers. The Planters were the colonists. The Adventurers were the shareholders who invested money in the enterprise and stayed at home. The agreement stipulated "that at the end of the seven years, the capital and profits, viz. the houses, lands, goods and chattels, be divided equally betwixt the Adventurers and Planters." The word "equally" is here ambiguous. It probably meant that the assets would be divided among Adventurers and Planters alike in proportion to the numbers of shares that they held. Alternatively, it may have meant that half of the assets would be divided among the Planters and half among the Adventurers. Another clause of the agreement gave one share to each of the Planters as a bonus for their seven years of hard labor: "Every person that goeth being aged 16 years and upward be rated at £10, and £10 to be accounted a single share." Any cash that the Planters contributed would entitle them to additional shares.

The 1620 agreement proved unsatisfactory to both sides and caused constant friction. In 1626, a year before the planned division of assets, the whole matter was renegotiated and a new agreement was signed,[10] "drawn by the best counsel of law they could get, to make it firm." The 1626 agreement stipulated that the Adventurers sell to the Planters, "in consideration of the sum of one thousand and eight hundred pounds sterling to be paid in manner and form following—all and every the stocks, shares, lands, merchandise and chattels—any way accruing or belonging to the generality of the said Adventurers aforesaid." Having bought out the Adventurers' shares, the Planters were left with a debt of £1,800 which they finally succeeded in paying off twenty-two years later.

I do not know how much profit or loss the Adventurers took in the 1626 settlement. I also do not know how large a fraction of the original cost of the expedition was paid by the Planters. As to the first point, it is unlikely that the Adventurers took a loss, for the colony was not bankrupt in 1626 and the Adventurers were not in the habit of lending their money for nothing. As to the second point, it is unlikely that the Planters paid as much as half of the original costs. If they had been in a position to pay half, they would probably have managed to squeeze the expenses down to such a point that they could do without the Adventurers altogether and avoid the innumerable headaches that the partnership brought

[4] Young, ref. 1, p. 447.
[5] Young, *ibid.*, p. 510.
[6] Young, *ibid.*, p. 606.
[7] Young, *ibid.*, p. 627.
[8] Bradford, *loc. cit.*, p. 45.
[9] Bradford, *ibid.*, p. 41.
[10] Bradford, *ibid.*, p. 184.

with it. I therefore conclude from the evidence of the 1626 settlement that £3,600 is a safe upper limit to the original cost of renting and provisioning the *Mayflower*. The evidence of the Cushman letter implies a lower limit of £1,500. I shall arbitrarily adopt £2,500 as my estimate of the cost of the expedition in 1620 pounds. This figure can hardly be wrong by a factor of two either way. The payload of the *Mayflower* is stated explicitly by Bradford.[11] It was 180 tons.

My next problem is to convert the 1620 and 1847 cost figures into their modern equivalents. A good source of information about the history of wages and prices in England is the work of Ernest Phelps Brown and Sheila Hopkins,[12] published in two articles in the journal *Economica* and reprinted in a series called *Essays in Economic History* put out by the Economic History Society.[13] The first article deals with wages, the second with prices. It is a question of taste whether one prefers to use wages or prices as the basis for comparing costs between different centuries. If we use wages, we are saying that an hour of a working man's time in 1620 is equivalent to an hour in 1977. If we use prices, we are saying that a pound of butter in 1620 is equivalent to a pound of butter today. With wages, we compare costs by the magnitude of the human effort needed to get a job done. With prices, we compare costs by the quantity of goods needed. My personal opinion is that wages give a truer standard of comparison than prices. My purpose in making the comparison is to try to define in a roughly quantitative fashion the size of the human efforts that the *Mayflower* and the Mormon expeditions demanded. But since economists are accustomed to deflate costs using price indices rather than wage indices, I will do the calculation both ways and you can choose whichever set of numbers you prefer.

First let us look at wages. According to Phelps Brown and Hopkins,[12] the wages of workers in the building trade in 1620 were in the range from 8 to 12 pence per day. In 1847 the range was from 33 to 49 pence. These numbers refer to England. Wages in America were usually higher, but I did not find any comparable figures[14] for American wages during this period. I take for American wages in 1847 the range 65 cents to 1 dollar per day, obtained by converting the English rates at 5 dollars per pound. For the modern equivalent of these numbers I take the minimum rate of $9.63 per hour[15] imposed by building trade-union contracts in New York in 1975. The exchange rates on the basis of wages are then:

£1 (1620) equals $2,500 (1975),

$1 (1847) equals $100 (1975).

These are very approximate numbers. A rough check on the numbers for 1620 is provided by the fact already mentioned that each Planter received a credit of £10 for going to Plymouth and working for the community for seven years without wages. If £10 were really the equivalent of seven years of work in the building trade, the exchange rate would be

£1 (1620) equals $14,000 (1975).

Obviously the Planters were badly paid, even by the standards of 1620. But this check shows that my figure of $2,500 for one 1620 pound is more likely to be too low than too high.

Next I examine the evidence concerning prices. Phelps Brown and Hopkins[12] define a consumer price index normalized to 100 for the third quarter of the fifteenth century. This index is 485 in 1620, 1257 in 1847, and 3,825 in 1954, the last year included in their table. All these numbers refer to England. The American price index published by the Bureau of the Census[16] is normalized to 100 in 1967. This index is 28 in 1847, 80 in 1954, and 169 in 1976. Taking these numbers at face value, we find on the basis of prices

£1 (1620) equals $67 (1976),

$1 (1847) equals $6 (1976).

The exchange rate for 1847 can be checked against the first-hand testimony of Brigham Young.[17] Writing on January 6, 1847, Young reports:

> In the fall, wheat in Upper Missouri was worth 18¾ to 25 cents per bushel, corn from 10 to 12 cents. By our stopping at this point, they have taken occasion to raise wheat from 40 to 50 and corn from 20 to 25, and the clerk says "Woe unto you, ye Missourians," but we are independent of them and can live without them, for we have thousands of cattle left yet. A few brethren have gone to Missouri and paid high prices because the people have asked it. Pork has been worth at this point from 3½ to 5 by the hog, but we have now engaged to supply the market at 2½.—Good corn and meal are tolerable plenty at 40 and 50, and if the Missourians don't sell us cheaper than that, pretty soon they will not sell us at all, for we have means to support ourselves.

[11] Bradford, *ibid.*, p. 47.

[12] E. H. Phelps Brown and Sheila V. Hopkins, "Seven Centuries of Building Wages," *Economica* 22 (1955): p. 195; "Seven Centuries of the Prices of Consumables, compared with Builders' Wage-Rates," *Economica* 23 (1956): p. 296.

[13] *Essays in Economic History* 2, ed. E. M. Carus-Wilson (London, Edward Arnold, Ltd., 1962).

[14] In *Historical Statistics of the United States, Colonial Times to 1970* (Washington, D. C., U. S. Bureau of the Census, Govt. Printing Office, 1975), p. 163, it is reported that average wages of farm laborers in 1850 were $10.85 per month with board. This is equivalent to 45 cents or 22 pence per working day, below the range quoted for 1847 by Phelps Brown and Hopkins. But farm laborers were no doubt paid less than building workers in England too.

[15] *Statistical Abstract of the United States, 1976* (Washington, D. C., U. S. Bureau of the Census, Govt. Printing Office, 1976), p. 383.

[16] *Loc. cit.*, ref. 14, p. 211 and ref. 15, p. 439.

[17] Young, ref. 3, p. 310.

TABLE 1

COMPARISON OF FOUR EXPEDITIONS

(Cost exchange rates based on building trade wages).
(K means thousands, M means millions).

Expedition	*Mayflower*	Mormons	Island One L5 Colony	Homesteading the Asteroids
Date	1620	1847	1990+	2000+
Number of people	103	1891	10,000	23
Payload (tons)	180	3500	3.6 M	50
Cost (old money)	£2,500	$150 K	—	—
Cost (1975 dollars)	$6 M	$15 M	$96,000 M	$1 M
Payload (tons per person)	1.8	2	360	2
Cost per pound (1975 dollars)	$15	$2	$13	$10
Cost per person (1975 dollars)	$60 K	$8 K	$9.6 M	$40 K
Cost in Man-years per person	3	0.5	500	2
Cost in Man-years per family	7.5	2.5	1,500	6

Young's numbers can be compared with the prices[18] of wholesale farm commodities in 1977, which are $2.36 per bushel for wheat, $1.92 per bushel for corn, and 49 cents a pound for pig bellies. So far as these particular commodities are concerned, we find

$1 (1847) equals $5 to $20 (1977).

But Young's narrative shows how the vagaries of real life make nonsense of any single price index.

To summarize the results of these calculations, I will merely say that in my opinion the exchange rates based upon prices enormously underestimate the real human costs of the *Mayflower* and Mormon colonies. The rates based upon wages are not free from uncertainties and ambiguities, but I believe they come much closer to the truth. I shall therefore adopt without further discussion for the remainder of this article the rates based upon wages, namely £1 = $2,500 for the *Mayflower* and $1 = $100 for the Mormons. The estimated total costs in 1975 dollars are then 6 million for the *Mayflower* and 15 million for the Mormons. On this basis I have drawn up the first two columns of table 1. The point I am trying to emphasize with these numbers is that both the *Mayflower* and Mormon expeditions were extremely expensive operations. In their time, each of them stretched the limits of what a group of private people without governmental support could accomplish.

Let me call your attention especially to the numbers in the bottom row of table 1. These numbers give an estimate of the number of years an average wage-earner would have had to save his entire income to pay the passage for his family. The average size of family on the *Mayflower* was 2½ (41 heads of families signed the *Mayflower* Compact at Cape Cod on behalf of the 102 surviving passengers), and I have assumed that the average Mormon family size was 5, the number that Young[4] used in planning the expedition. You see that there is a difference of a factor of three between the two figures, 7½ man-years per family for the *Mayflower* and 2½ for the Mormons. This difference had a decisive effect on the financing of the colonies. An average person, with single-minded dedication to a cause and with a little help from his friends, can save two or three times his annual income. An average person with a family to feed, no matter how dedicated he may be, cannot save seven times his income. So the Mormons were able to pay their way, while the Planters on the *Mayflower* were forced to borrow heavily from the Adventurers and to run up debts which took twenty-eight years to pay off. Somewhere between 2 and 7 man-years per family comes the breaking-point, beyond which simple do-it-yourself financing by ordinary people becomes impossible.

You will probably have noticed that I said nothing yet about the last two columns in my table of costs. These represent two contrasting styles of space-colonization, both taken from O'Neill's book,[1] "The High Frontier," with some changes for which I am responsible.[19] Column 3 comes from O'Neill's Chapter 8, which he entitles "The First New World," describing space-colonization organized by the American government in the official National Aeronautics and Space Administration (NASA) style. Column 4 comes from O'Neill's Chapter 11, with the title "Homesteading the Asteroids," in which he describes space-colonization done in the *Mayflower* style by a bunch of enthusiastic amateurs.

The first thing you will notice about the "Island One" project is that the cost is 96 billion dollars. When you see this number you may well say, "This is preposterous." I happen to agree with you. It is preposterous. But still we have to take this number seriously. It was arrived at by a group of competent engineers and accountants familiar with the ways of the government and the aerospace industry. It is probably the most accurate of all the cost estimates that I have included in table 1. For this 96 billion dollars you can buy a great deal of hardware.

[18] *New York Times*, September 14, 1977.

[19] The main change I have made is to reduce drastically the weight estimate of the asteroid expedition. O'Neill's estimate of 2,500 tons consists mainly of a layer of sand enclosing the ships and shielding the crews from radiation. I have cut the weight to 50 tons since I wish to leave open the possibility of a take-off from Earth. O'Neill (ref. 1, chap. 7) gives a detailed account of the pros and cons of radiation shielding. There is a good chance that colonists could travel to the asteroid belt without shielding and without noticeable adverse effects.

You can buy a complete floating city to house and support 10,000 people with all modern conveniences at the magic point L5 which is just as far from the earth and from the moon as these bodies are from each other. You can buy enough synthetic farmland to make a closed ecological system which supplies the colonists with food and water and air. You can buy a space-borne factory in which the colonists manufacture solar power-stations to transmit huge amounts of energy in the form of microwave beams to receivers on the earth. All these things may one day come to pass. It may well be true, as O'Neill [20] claims, that the investment of 96 billion dollars will be repaid in twenty-four years out of the profits accruing from the sale of electricity. If the debt could be paid off in twenty-four years, that would be four years quicker than the *Mayflower* Planters could do it. But there is one inescapable difference between Island One and the *Mayflower*. In the bottom row of table 1 you see that the Island One colonist would have to work for 1,500 years to pay his family's share of the costs. This means that Island One cannot by any stretch of the imagination be considered as a private adventure. It must inevitably be a government project, with bureaucratic management, with national prestige at stake, and with occupational health and safety regulations rigidly enforced. As soon as our government takes responsibility for such a project, any serious risk of failure or of loss of life becomes politically unacceptable. The costs of Island One become high for the same reason that the costs of the Apollo expeditions were high. The government can afford to waste money but it cannot afford to be responsible for a disaster.

After this brief visit to the super-hygienic welfare state at Island One, let us go to the last column of table 1. The last column describes O'Neill's vision of a group of young pioneers who save enough money to move out on their own from the L5 colony into the wilderness of the Asteroid Belt. They are going on a one-way trip at their own risk. The cost estimates here describe hopes rather than facts. Nobody can possibly know today whether it will be feasible for a group of twenty-three private people to equip such an expedition at a total cost of a million dollars. Anybody who is professionally qualified to estimate costs will say that this figure is absurdly low. I do not believe that it is absurdly low. All I can say for sure is that a cost in the range of $40,000 per head must be achieved if space-colonization is to become an important liberating force in human affairs. It is no accident that the per capita cost estimates for the asteroid colony turn out to be similar to those of the *Mayflower*. This is the maximum level of costs at which the space beyond the earth will give back to mankind the open frontier that we no longer possess on this planet.

If you compare the third and fourth columns of table 1, you will see that the cost per pound of the Asteroid expedition is not significantly less than that of Island One. The big differences between the two expeditions lie in the number of people and in the weight carried per person. The feasibility of cheap space-colonization in the style of the Asteroid expedition depends upon one crucial question. Can a family, bringing a total weight of only two tons per person, arrive at an asteroid, build themselves a home and a greenhouse, plant seeds and raise crops in the soil as they find it, and survive? This is what the *Mayflower* and Mormon colonists did, and it is what the space-colonists must do if they are to be truly free and independent.

I cannot here embark upon a technical discussion of the mechanics of space-colonization. I will only indicate with some brief remarks why I consider it may not be absurd to imagine a reduction in costs by a factor of 100,000 from the 96 billion dollars of Island One to the 1 million dollars of the asteroid colony. First we save a factor of 400 by reducing the number of people from 10,000 to 23. That leaves a factor of 250 still to be found. I claim that we can save a factor of 10 by accepting risks and hardships that no government would impose upon its employees, and another factor of 5 by eliminating trade-union rules and bureaucratic management. The last factor of 5 will be harder to find. It might come from new technology, or more probably from salvaging and reusing equipment left over from earlier government projects. There are already today several hundred derelict space-craft in orbit around the earth, besides a number on the moon, waiting for our asteroid pioneers to collect and refurbish them.

O'Neill sees Island One as a necessary first step in the colonization of space. He has his pioneers starting out for the asteroids from L5, their transportation from earth to L5 already paid for. His cost estimates assume the asteroid expedition to be equipped and launched at L5. I am a little more ambitious, or a little more hopeful. I imagine that an asteroid expedition with *Mayflower* style and *Mayflower* costs may take off directly from Earth.

The Island One and the asteroid homesteading expeditions are extreme cases. I chose them to illustrate high and low estimates of the costs of colonization. The true costs, if and when colonization begins, will probably lie somewhere in between. In so difficult and long-range a venture, there is room for a mixture of styles. Governmental, industrial, and private operations must all go forward, learning and borrowing from one another, before we shall find

[20] O'Neill, ref. 1, p. 268.

out how to establish colonies safely and cheaply. The private adventurers will need all the help they can get from governmental and commercial experience. In this connection, it is worth remembering that 128 years passed between the voyages of Columbus and the *Mayflower*. In those 128 years, the kings and queens and princes of Spain and Portugal, England and Holland, were building the ships and establishing the commercial infrastructure that would make the *Mayflower* possible. Columbus did not sail across the ocean on private money.[21]

O'Neill and I have a dream, that one day there will be a free expansion of small groups of private citizens all over the Solar System and beyond. Perhaps it is an idle dream. It is a question of dollars and cents, as Bradford and Young well knew. We shall never find out what is possible, until we try it.

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[21] The funding for Columbus's first voyage was partly private and partly public. For details see F. M. Padrón, *Manual de Historia Universal, Historia de América* **6** (Madrid, 1975): p. 154. For this reference I am indebted to Professor John Elliott.