An Analysis and Review of Measures and Relationships in Space Transportation Affordability

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- Affordability, Prices and Costs
  - Poor data, $/kg, $ per flight, and many, many caveats
- Productivity, Flight Rate and Yearly Capability
  - Flights, tonnage
- Competitiveness
  - Current vs. Growth
- Direct vs. Indirect Costs
  - Where vs. Why, Comprising vs. Causing
- Closing
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- A typical view of affordability
- Recent data used here
- Poor state of data, many contracts not public
- Causality (X to Y) not implied nor clear

**Figure 1**: US Launchers and recent launch price contracts (2012-2015), using a linear scale and applying a power curve fit.
Figure 2: US Launchers and recent launch price contracts (2012-2015), using a logarithmic scale and applying a power curve fit.

- Shuttle only as reference (more ahead on apples/oranges)
- Poor state of data
- Similar to what an airline would have as CASM-cost per available seat mile
- Relative indicator of competitiveness
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Figure 3: Using a bubble chart to show three variables; average payload capability of a system of launchers, the average cost of entry (or price to a customer), and the total tonnage capability deployed over a recent calendar year, as bubble size.

- Treat common capabilities as a system (all ULA, all SpaceX, etc.)
- Tonnage “capability” (not “actual”; more on this ahead)
- Want the bubble sizes to grow, and want more bubbles!
- US launchers only
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• On Shuttle: Measures of use to stakeholders go beyond cargo, kg, etc.
• Shuttle very “affordable” – by this measure and requirement, people to space
• Many affordability measures beyond $/kg or price per flight
  ▪ Productivity, of some “value”

Figure 4: Courtesy Andy Prince, “Human Spaceflight Value Study, Was the Shuttle a Good Deal?” NASA Cost Symposium, 2012.
Emerging / commercial space of great interest
Visually, a spectrum of being more or less commercial
Can compare two or more players as being more or less commercial
Commercial is not about just being private sector; it’s much more
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• Globally: Appear to be stagnant at about 20 commercial launches/year
• Definition is “competed” or “FAA licensed”
• 2013 - US appearing to see an uptick? (but not the total market)
• What might cause market size to grow? Affordability + Productivity?

Figure 6: Graph created from raw data at the Department of Transportation for launches through 2012, plus 2013 data from the Federal Aviation Administration, “Commercial Space Transportation 2013 Year in Review,”
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Table 1: Basic ingredients for a space exploration element (launch, spacecraft, habitat, etc.) being more commercial. The more these ingredients are captured, the more commercial the element is.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Rationale</th>
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<tbody>
<tr>
<td>Product development and use, amortizing costs</td>
<td>The business case depends on having non-government customers. The product for the government is developed with non-government customers in mind. The product or service is also provided to non-government customers.</td>
</tr>
<tr>
<td>Contracts</td>
<td>The government uses firm fixed price type of contracts.</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Provider applies mostly commercial best practices. These practices or “how” are outputs. Capability, performance, safety, and cost goals are inputs.</td>
</tr>
<tr>
<td>Incentives</td>
<td>Multiple suppliers (industry) and multiple buyers (government and non-government) rationalize incentives, leading to success even when many requirements (performance, safety, cost) appear at odds. No monopoly (single provider) or monopsony (single buyer).</td>
</tr>
</tbody>
</table>

The formal, actual definition of what is “commercial” is expressed in the current space policy: “The term “commercial,” for the purposes of this policy, refers to space goods, services, or activities provided by private sector enterprises that bear a reasonable portion of the investment risk and responsibility for the activity, operate in accordance with typical market-based incentives for controlling cost and optimizing return on investment, and have the legal capacity to offer these goods or services to existing or potential nongovernmental customers.”
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Figure 7: A view combining the launch record with estimated actual payload masses.

“Actual” tonnage being less than “capability” of launcher would mean far more $/kg and price per flight, in practice.

The data here has been compiled from two main sources:

1. FAA Commercial Space Transportation, Year in Review reports
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Figure 8: Technical product design factors (“what”; such as a number of parts, or different fluids, or the type of fluid, and reliability, etc.) distinguished from non-technical process factors (“how”; such as development practices, the flow of information, manufacturing steps, etc.)

Needs:
- Acceptance: Project/program cost data as a necessity, not a cost itself, not a luxury
- Insights, traceability
- Understanding and separating what comprises costs from what causes costs (not the same thing)
- Getting into the less tangible, less “technology” alluring indirect
- Technology that focuses on direct processes/responsiveness, productivity, in all phases from manufacturing to ops and launch; not just in flight
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- What is needed is an ability to discriminate:
  - cost-per-pound of launch vehicle payload capability
  - cost-per-pound of payload delivered
- Specifically, need cost and productivity information:
  - Annual Production and Supply Chain Costs as a function of Unit Production Rate
  - Annual Operations Costs as a function of delivery (flight) rate
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Figure 9: If some fixed resource is dedicated to launch, and a business or government enterprise also wants to go further, for longer, then launcher/transportation affordability must significantly improve.

- Always the same few variables: resources, time, flight rate
- Stretching time/schedule, or dropping flight rate only gets so much
- Assuming budgets as in last 40 years, affordability, productivity and competitiveness must improve to allow space development and exploration