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> Exploration is in our nature. We began as wanderers, and we are wanderers still. We have lingered long enough on the shores of the cosmic ocean. We are ready at last to set sail for the stars.
>
> *Carl Sagan, Cosmos, 1980*

The matrimony between statecraft and the conquest of the cosmos birthed the space industry in a concerted effort to seize the final frontier. A triumvirate of government, academia and corporations found common cause in the geopolitics of the Cold War to mobilize minds and machines against the Soviets whose Sputnik orbited the earth by 1957. This shot across the bow of a lone satellite in the outlands of the stars rattled American exceptionalism insofar as policymakers perceived it to be an existential threat over their monopoly of the sciences. The slender orb of 83.6kg evoked paranoia due to how swift the Soviet Union transitioned into a knowledge-based economy. Any robust space industry cultivates a panoply of ancillary sectors from vast spillovers to fabricate composite metals, semiconductors, liquid fuels and other things of this ilk. Prima facie the coup was prodigious by itself but the infrastructure behind it left Washington reeling. Manifestly the communists confirmed themselves to be lightyears ahead of their counterparts in the research of science, technology, engineering and mathematics (STEM). The postwar propaganda value of boasting the know-how of rocketry to escape earth's gravity rallied brains and brawn around the flag in a species of a Manhattan Project redux.

In the infancy of the space derby the torrent of Soviet victories intensified rivalries in the bipolar world. The canine Laika became the first mammal to voyage through the ether in 1957. Luna 2 probed the moon's surface on the maiden trip of its kind in 1959. Luna 3 purveyed to the world its first glimpse of the far side of the Moon in 1959. Venera 1 established a record as the first interplanetary vehicle to effect a flyby of Venus in 1961. Cosmonaut Yuri Gagarin followed suit by entering the firmament as the first human in 1961. Cosmonaut Valentina Tereshkova defied gender norms as the first woman to orbit earth in 1963. Cosmonaut Alexei Leonov partook in the first spacewalk in 1965. Mars 3 captured immortality as the first manmade craft to land on the Martian planet in 1971. The string of triumphs and their rapid succession aroused awe and dread on terra firma amongst the cognoscenti in the Beltway. Such a truncated turnaround from the ravages of WWII called into question whether in fact the communist model of governance was indeed leaps and bounds ahead of free market capitalism. The gulf of a knowledge gap that differentiated the Soviet space program from the amorphous one in America left skeptics of the former agog. For a time the legion of scientists under the auspices of the politburo's central planning seemed omniscient.

Such centralization of the bureaucracy unmolested by partisanship or a farrago of stakeholders created small skunkworks under the nomenclature of OKBs wherein discoveries were made at the cadence of a metronome. Not at all enigmatic in retrospect this quantum leap also stemmed from its piracy that was more rapacious than America's. Whereas Washington acquired intellectual assets via Operation Paperclip the Soviet's variant of Osoaviakhim in 1946 conscripted a whole brigade of German minds to catapult space exploration. Wernher von Braun and a cohort of his scientists from Peenemünde were spirited away to Washington whilst Moscow's dragnet repatriated exponentially more in human capital and technology (Neufeld 2004). The poaching of knowledge midwifed the series of records monopolized by the superpower in the incipient years of the space race. The spoils of war from German heuristics wedded to indigenous capabilities proved to be a boon for the Soviets who were keen to parade the merits of communism. Indeed the Kremlin's industrial complex revolutionized space travel for the sake of ideological warfare against its nemesis. The disparities were quite vast. America's Project Mercury sought to put an astronaut in orbit as the Soviet's Luna missions were already plumbing the Moon in 1959.

In the prelude to the moonshot of Apollo the saga of America's space industry begins with the importation of V-2 rockets from the Nazi regime which whetted the enthusiasm for escaping earth's gravity. Under Project Hermes the autopsy on these missiles saw the technology reverse engineered in an effort to breach the Karman Line of the upper atmosphere. A whole 300 boxcars of miscellaneous V-2 hardware smuggled from Germany made their way to the White Sands Proving Ground in New Mexico where 67 units were reassembled between 1946 and 1951 (Buchanan et al. 1984). Telemetry data from subsequent tests telescoped the learning curve to spur the development for Apollo's workhorse known as the Saturn V rocket whose pedigree veritably traces back to the V-2s. At this early juncture it was the firm General Electric with which Washington rendezvoused so as to scrutinize these artifacts for their ballistics and gyrostabilized guidance systems. A constellation of scientists were contracted to harvest the secrets hidden within the entrails of the V-2s in a bid to marshal propulsion and re-entry technologies into maturity. Borne from this fact-finding mission did GE design avionics that later computed the terabytes of data for the Apollo moonshot. The firm would be the first embraced in the bosom of the space program.

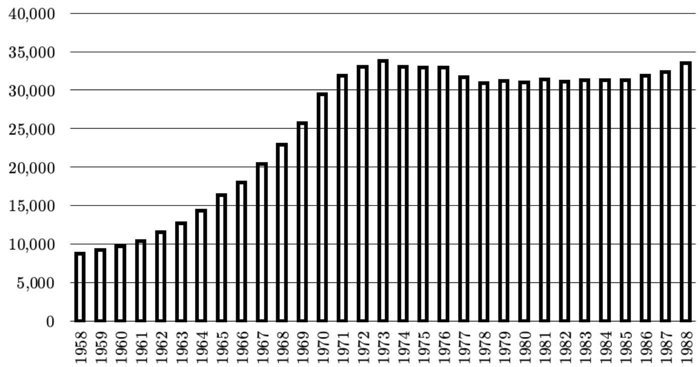
Post the industrial policy of this public-private partnership the space industry sired the National Aeronautics and Space Administration (NASA) as its guardian in 1958. The institution's formation heralded a departure from space's militarization towards its exploration to demystify the mysteries of the cosmos. The separate track charted a course to the stars for civilian ends at variance with the Defence Advanced Research Projects Agency (DARPA) that put a premium on technology for martial use. Founded fourth months prior to NASA this other agency's mandate was written in rebuttal to the USSR's launch of Sputnik. Within this bifurcation the raison-d'être for each hinged on war in the case of DARPA and peace in the case of NASA. The civilian program's prime directive as distilled in section 102 of the National Aeronautics and Space Act of 1958 empowered the institution to one end alone of making America a leader in the Olympics of science. NASA wasted no time in engineering a stepwise roadmap between the triad of Projects Mercury, Gemini and Apollo in this chronological order. Each unique phase rested along a spectrum in the mastery of technology beginning with a manned craft in space to orbital docking and finally a lunar expedition. NASA summarily evolved into a hive of innovation.

After GE's forensics upon reconstituting the hodgepodge of V-2 rocket paraphernalia amidst Project Hermes the next private firms entrusted with reifying America's curiosity with outer space were Chrysler and McDonnell Aircraft. Industrial policy shovelled $277m or $2.9t in real value for its pecuniary commitment towards the first phase christened Project Mercury (DiLisi et al. 2019). The industrial heritage of Chrysler hitherto as a marque of Plymouths and Dodges appears paradoxical for such high-tolerance engineering but the firm proved its poise in WWII when it mass-produced 25,000 M4 Sherman Tanks (Davis 2007). To segue into this highbrow application the company collaborated with the prodigy von Braun who was the doyen of rocket science. Chrysler would be the proverbial blacksmith for the single-stage Redstone booster whose propulsion from 78,000 pounds of thrust bore astronaut Alan Shepard into suborbital space in 1961 (Bentley 2009). It fell to McDonnell Aircraft to manufacture the spacecraft itself meant to house the life support systems for a solitary occupant in the antipodes of space. Everything from the heat-shield for re-entry to the escape system that jettisoned the capsule with a parachute should the mission be aborted in the event of a catastrophic failure was designed by the firm.

THE ROAD TO APOLLO

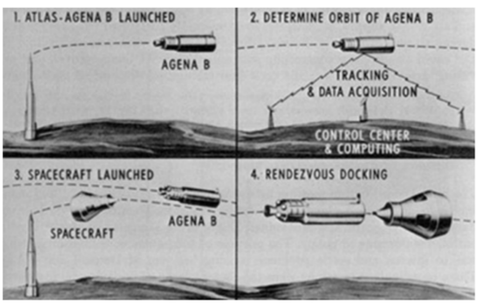
A Cambrian explosion in STEM research succeeded the seminal innovations of Project Mercury as one of many externalities wrought by President Dwight Eisenhower's Space Act of 1958. This single industrial policy would be hailed as the wellspring for America's knowledge-economy at a watershed when scientific inquiry was integral to the country's growth. Fiscal infusions to sophisticate human capital begot a sort of awakening where a crop of minds seeded a pivot from an era of iron and steel towards one of binary code for computations. Such a tectonic shift witnessed a groundswell of doctoral matriculations, intellectual property and academic papers whose knock-on effects embraced a fecund culture germane to innovation. A phalanx of professionals lettered in the physical sciences saw a cross-pollination between academia and industry where partnerships were brokered in a modern renaissance. The zeitgeist of the time privileged intelligence over the analogue ways of the past to form the prime currency in the Information Age that superseded industrialism's old traditions. A new breed of workers inundated the labour market to steer the economy in the direction of a postindustrial society wherein technology became the prime mover of growth. This legion of engineers and scientists built the future.

PhD Matriculation in America, 1958-1988

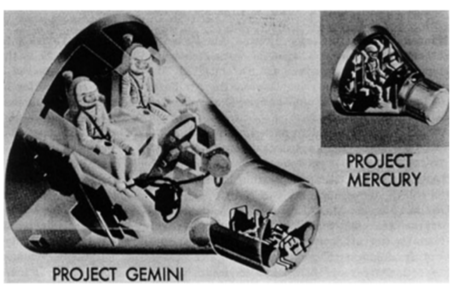


Source: U.S. Department of Education

In the intermediary phase between Projects Mercury and Apollo the sophistication of technology was ratcheted up in the gestation of Gemini. The predecessor Mercury sought to affirm the feasibility of manned flight into the unknown which it did by placing an astronaut in orbit to experience microgravity for five-minutes (Kranz 2001). The sibling Gemini manifested as an entirely different beast. The escalating complexity to rendezvous two discrete spacecraft in orbit with mathematical precision akin to a pair of ships finding each other in the open sea at night was paramount if a lunar sojourn was intended. Rather than imitate the series of coups by the Soviets the enterprise upstaged the latter by pioneering the requisite technology to dock the duo of spacecraft which was later imported into the moonshot mission. Amongst the consortium of firms charged with Gemini's success was IBM which wired the on-board computer wizardry for this delicate manoeuvre. GE engineered a quantum leap for power generation with its fuel cell technology in a liberation from the yoke of batteries to supply a source of electricity. The longevity of this energy density sustained missions for long durations as the benign byproduct of the internal reaction was potable water to hydrate astronauts. Technology's frontier was indelibly pushed.



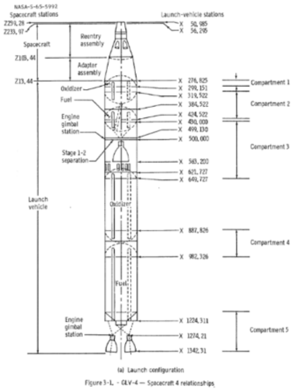
NASA's illustration of Project Gemini coupling to Agena, 1962.



NASA's comparison between Projects Gemini and Mercury, 1962.

The ensemble of the corporate powerhouses under the fiscal stimulus of $1.3b or $13t when adjusted for inflation was the real protagonist of the Gemini saga. The technology buildup verging on alien in virtue of its advancement bespoke the byzantine nature of this proof-of-concept that accumulated 1,940 man-hours of flight (Willis and Maynard 1967). Protocols learned in this laboratory were instrumental in the forthcoming moon missions. This learning-by-doing process trialled methodologies to foreclose any chance of mishap for Apollo. Gemini's docking to the secondary Agena vehicle suspended in space with pinpoint accuracy would be simulated anew between the Command and Lunar modules in the moon's orbit. Incremental lessons honed techniques to scaffold Apollo between spacecraft rendezvous, pressurized spacesuits and spacewalks to mimic moonwalks. The practice here scribed a blueprint for man's footprint upon the faraway satellite. As a nursery for innovation Gemini accelerated the science of physics, mathematics and engineering by decades. The collaboration with private firms spoke to the efficacy of Eisenhower's industrial policy which he skillfully plied in an atavism to his 1956 Highways Act whose cascade of spillovers revolutionized the economy as well.

The investment's utility can be measured in the mobilization of the private sector to land a man on the Moon within the abridged span of a little over a decade. The ensuing eleven years from the 1958 National Aeronautics and Space Act set about a flurry in breakthroughs as a function of R&D intensity. The scale of ambition fraught with a panoply of moving parts beggars belief. Even a Pollyanna would see Apollo as whimsical. To moor a craft in the moon's orbit where it would await the return of a rowboat vessel after its controlled touchdown upon the regolith of the lunar surface and then recouple for the trip home seemed unrealistic. Indeed the gravitas of this mission was so avant-garde that humanity has yet to brave a return to the Moon in over fifty years. The audacity of capital in such a project could have only followed the Black Swan event of Sputnik which galvanized Gemini. Monetary allocations into the catacombs of this program named for its two-man crew funnelled $797.4m towards the spacecraft's development, $409.8m in launch vehicles and $76.2m for personnel and facilities (Wilford 1969). The great convergence of many firms under the sanctum of Washington's largesse created an ecosystem for mission-critical cogs. August companies still in operation today populated the list of affiliates.



Project Gemini Spacecraft, 1962.

Amongst this company of sterling firms was McDonnell Aircraft whose brains conceived the conceptual flesh of the Gemini spacecraft. North American Aviation supported the vessel by affixing its thrusters for navigation into higher orbit and for coupling to the Agena vehicle. The real workhorse in Project Gemini would invoke the wealth of knowledge from Martin-Marietta in its chassis design cocooned by high-strength alloys for the Titan II GLV. This two-stage rocket furnished the desiderata in escape velocity to forsake the clutches of earth's gravity. The duo of engines manufactured by Aerojet for the first stage counted 430,000 pounds of thrust to propel the craft beyond the densest part of the atmosphere. The single engine by the selfsame firm on the second stage boasted another 100,000 pounds of lift (Turchi 1998). No less in importance was the radar system devised by the Westinghouse Electric Corporation which paid dividends from the reduction in the margin of error to spot and dock with the Agena. The system epitomized a beacon in the dark vacuum of space with real-time data informing astronauts on range and angles for the hair-raising manoeuvre. Lockheed Martin next brandished its repository of knowledge to build the Agena whilst the Dave Clark Company fabricated the spacesuits.

In the prologue to the Apollo moonshot the mastery of spacewalks, rendezvous, docking, long-duration flights, reentry and precision landing had to be mastered first by the workhorse of the Gemini Project. The practical application of theoretical physics cultivated by a series of tutorials was the risk mitigation needed to thread the needle of docking in orbit and to walk atop the lunar surface for the Apollo excursion. Over twenty months as each new mission's complexity became more edifying than the last NASA laid the groundwork for this big exploit. Rendezvous entailed station-keeping and docking between two craft in a zero-G environment. The moonwalk although etched in civilization's hagiography with the iconic images of Neil Armstrong and Buzz Aldrin cavorting about on the Moon would only materialize after Gemini's 12 hours and 25 minutes of spacewalks (Machell 1967). Multiple redundancies of backups were also exported into Apollo to eschew primary-system failures. In the gospel of engineering such failsafe devices are critical to isolate malfunctions that can cascade into catastrophe. Amidst the Gemini VIII mission a runaway thruster convulsed the vehicle into an uncontrollable spin until the last-minute Hail Mary pass by astronaut Armstrong arrested the rate of rotation. Learned mistakes then bolstered Apollo.

As the apotheosis of the space programme Washington's industrial policy did not exercise any austerity for the successor to the Mercury and Gemini projects. In its Keynesian stimulus for a dash of Cold War bravado NASA mobilized over 20,000 industrial firms at the cost of $25.4b or $186b in real value (DiLisi et al. 2019). This fiscal demand mimicked the audacity of landing a man on the Moon versus splitting the atom in the Manhattan Project which was monetized at $2b or 34 billion in constant dollars. Nuclear fission at the Los Alamos Laboratory at its zenith saw a headcount of 130,000 personnel in a foil to the moonshot's 400,000 (Huges 2003). Therefore in Apollo's anatomy a bevy of august firms were conscripted into service for the three million working parts of the Saturn V rocket whose power could be analogized to the output of eighty-five Hoover Dams (Bilstein 1999). It was this crown jewel of the space programme dwarfing Mercury's Redstone and Gemini's Titan II that brought humanity to the Moon and back. Washington's calculated use of public funds architected an entire industry from the ground up in the space race. Between the creation of the bureaucratic mechanism in the guise of NASA and pecuniary investments in R&D an Industrial Revolution was co-authored by state-driven capitalism and firms.

Apollo embodied the Everest of engineering across the gamut of rocketry, metallurgy, thermodynamics, aerodynamics and astrophysics to cement man's presence onto the distant orb of the moon. But success is not at all the default of industrial policy when bureaucracies are prone to beget sinkholes of profligate spending. Where Washington excelled was to marshal a uniformity of purpose for the high stakes of President Kennedy's promise to plant America's flag atop the moon. A delegation of contracts solicited expertise from Boeing, Chrysler, Rocketdyne, North American

Aviation's Space and Information Systems Division (S&ID), Douglas Aircraft, IBM and Grumman. NASA's Marshal Space Flight Centre in Alabama helmed by the feted von Braun and his retinue coordinated all these discrete nodes of operations. Boeing and Chrysler were tasked with integrating the five F-1 engines abreast of fuel tanks and avionics for the first stage of the Saturn V rocket. Rocketdyne designed those mainstay engines together with its J-2 variant. These smaller units were married to the upper stages whose in-flight restarts parked Apollo into earth's orbit whereupon a second controlled burn pushed the craft into its Trans-Lunar Injection path. Reawakening an engine in the cold vacuum of space was fraught with complexity.

Within this leg of propelling astronauts beyond earth's upper atmosphere it was S&ID that fitted the five J-2 powerplants to its second stage vehicle. These furnaces of thrust catapulted Apollo into orbit to await its manoeuvre towards the alien plains of the moon. Inside the cylindrical hull fabricated from alloyed aluminum were vast reservoirs that cradled the propellants of liquid hydrogen and oxygen. Next to this coup of engineering would be the third stage manufactured by Douglas Aircraft whose import hinged on slingshotting the crew on its final approach to its mission objective. This smaller sibling of the Saturn V rocket innovated the bulkheads separating fuels with a substantial cut in mass for greater efficacy of operations when weight was at a premium. Right above this third stage sat IBM's magnum opus. Wrapped around the circumference of the Saturn V there stood a three-foot high ring of digital computers and sensors in miniaturized form computing trajectories across the sky and into the sea of stars. Micro-adjustments in milliseconds remedied thrust deficits and directions across the battery of engines should one fail. Directly abutting the foregoing nerve centre of the Saturn V there nestled in the upper stages of the rocket was the Lunar Module under the stewardship of the Grumman Aircraft company.

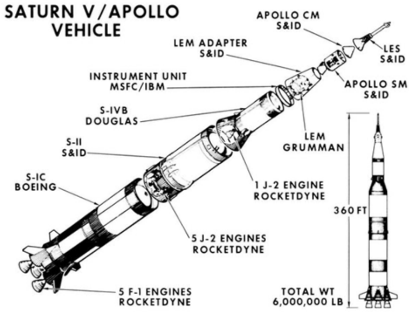


Diagram of NASA's Saturn V Rocket, 1968.

This vehicle draped in Kapton foil since the want of an atmosphere fails to mediate extreme temperatures would descend upon the moon's regolith with a form factor resembling an arachnid. Outfitting the spacecraft with four spindly legs and an engine with modulated thrust ensured a soft landing on the alien world where the streamlined shapes of aerodynamics had no currency. Once ensconced on the surface courtesy of the vehicle's throttleable velocity the second stage launched the explorers and their soil samples back out into space to rendezvous with the Command and Service Modules. Whilst each facet of the mission proved precocious the mission was greater than the sum of its parts. The alchemy of coordinating a phalanx of companies towards one end of landing a man on the Moon cannot be extolled enough. In this seminal act of innovation not only did a whole industry manifest from nothing but also America's production shifted wholesale towards a knowledge economy. President Kennedy's foresight to align industry and academia in colonizing the Moon became the verve and vim behind the boom in innovation that ushered in the era of postindustrialism. The return on investment would be a boon to technology in the crucible of Apollo as the brainchild of Washington's industrial policy.

Space Race Knock-On Effects

The accelerant of the moonshot informed a litany of industries between advanced materials, precision manufacturing, miniaturized electronics, semiconductors and computers. When Kennedy in 1961 sired Apollo to deliver humanity from the yoke of terrestrial bonds in plumbing the cosmos he galvanized a wave of kinetic energy towards modernity. As the President took to the rostrum before a joint session of Congress to pontificate of man's expedition to earth's satellite within a decade he signalled a brisk cadence of innovation to follow. Much of the scaffold for this bold enterprise was erected three years prior however. Under Eisenhower's incumbency industries were long primed for the febrile race for the stars in a tit-for-tat with the Soviets. Not only was NASA the progeny of the statesman but so too was the National Defence Education Act of 1958 (NDEA) crafted two months later. Although little fanfare abounds for this softer variant of industrial policy it became a lodestar for the gestation of the space program over the next decade. Sputnik precipitated a pipeline of STEM researchers within postsecondary institutions when the Cold War would be contested not in trenches but inside classrooms and research laboratories. The NDEA epitomized high octane fuel for the human capital of America's economy.

With the advent of computers a marked scarcity of mathematicians to program software hamstrung the efflorescence of the industry. Eisenhower's NDEA troubleshot the pittance of supply for this competency in the labour market by injecting over $1b to revamp higher learning (Carlson 1959). An epistemological shift in pedagogy subsequently set a premium in the sciences to foster a new class of professionals in the inchoate years of America's knowledge economy. This legislation's prescience was in large measure the wellspring for the technology mecca of Silicon Valley and its legion of startups. Appropriations were methodically parcelled out to low-interest loans for tertiary education, scholarships and the construction of centres for postgraduate matriculation in specialized instruction. A new era of enlightenment blossomed across academic departments across America. Eisenhower thereby created a fertile sanctuary for a new generation of intellectuals and entrepreneurs who would steer the economy in the postwar years. This braintrust of scientists and engineers marked a departure from the manufacturing of yesteryear at a time when a digital revolution pared down lead times for all sorts of innovation. Corporate America reaped great dividends from the alumni of Eisenhower's education push.

In the halo of the space race whose function was to regain ground upon the ignominy of Sputnik and the spillover of the NDEA it would be the myriad of companies from Intel to IBM that forever altered the American economy's DNA. The soul of these firms were indelibly informed by Washington's predilection for the sciences. Infusion of federal dollars into the ecosystem of advanced technology incubated a surge of talent most notably in the verdant cradle of Silicon Valley. This epicentre stood at the intersection of Stanford University, a cerebral workforce in the region and private firms jockeying for contracts in the storied chapters of the early space program. The home for many of NASA's contractors and subcontractors was within this El Dorado of innovation not too far from San Francisco. In anatomizing the value-added of firms to Apollo the first atelier of repute would be Fairchild Semiconductor whose miniaturized Integrated Circuits powered the guidance computer aboard the Command Module. Bereft of the compact and reliable nature of these microchips where transistors, resistors and capacitors all cohabited on one tiny piece of silicon real estate the mission might have been scuttled. Older vacuum tubes would be a minefield for the plethora of computations that made such a system liable to overheating.

Fairchild's microchips hedged against a meltdown whilst they allowed the computer the bandwidth to prosecute mission-critical tasks in spite of an overload from real-time data. In the Lunar Module's descent onto the extraterrestrial surface lesser tasks were shunted to the periphery so the muscle of algorithms could execute a safe landing at full capacity. Apollo's guidance computer boasted 4,100 of these infinitesimal microchips pioneered by Fairchild (Hall 1996). Another firm in the bosom of California reaping economies of agglomeration from the cluster of businesses for ease of scalability owed to the cross-pollination of supply chains was Thompson Ramp Wooldridge or colloquially TRW. This outfit was entrusted with the fabrication of the descent engine for the Lunar Module to alight upon the Moon with utmost delicacy. Hitherto the canon of propulsion hinged on either full thrust or shutdown whereas the desiderata for this mission was far more nuanced. With the albatross of anomalies in the moon's gravity and craters littering the surface this powerplant brought to life by TRW navigated altitude, speed and landing site with the precision of a surgeon. The feature to modulate thrust coupled with the use of exotic fuels that automatically ignite upon contact made for the lightest of touchdowns. Ergo Silicon Valley was a linchpin.

A third innovator as a resident of this technopolis went by the appellation of Ampex whose magnetic tape and data storage chronicled Apollo for posterity. Between bytes of information from telemetry signals, radio transmission and video frames all was captured on bespoke products for later dissemination and analysis. Ampex plucked from the fertile ground of Silicon Valley would be the keeper of history leaving no record lost to humanity. Some of the words registered on this archive of data would be spoken into headsets manufactured by Plantronics whose operations were also based in California's hive of technology. The MS50 model was NASA's darling that catered to verbal communications aboard the spacecraft between astronauts and the brain of the mission in Houston where an army of engineers sifted through telemetry. The acoustic clarity and ergonomics of the device furnished a great degree of autonomy to crew members whose voice commands would not perish in the profound silence of space. No ambiguity hobbled radio exchanges across this void for listeners on terra firma. The next firms of note to be involved in Apollo hailing from Silicon Valley was Hewlett-Packard and IBM. HP's computers oversaw the testing of rockets whilst IBM's behemoth mainframes dotted the Mission Control Centre.

These outlets under the umbrella of the Space Act of 1958 and the

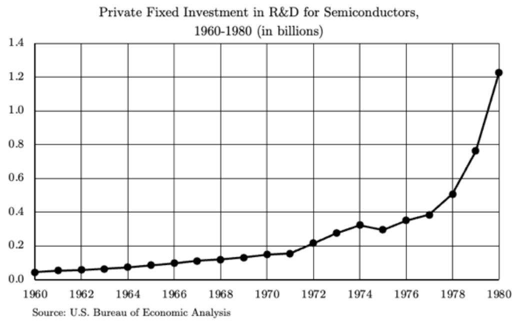
NDEA from the selfsame year conspired to create a space industry. Wrought by the presidencies of Eisenhower and Kennedy were the dollars and direction for a new sector in its fledgling years. The former laid the groundwork by seeding the industry with investment and human capital as the latter personified a carnival barker coaxing the public to sail across the stars. Analogous to Apple's co-founders between Steve Wozniak and Steve Jobs the one built hardware whilst the other was a showman whose vision transformed a commodity into a cultural icon. Similarly the taciturn General who won WWII built the infrastructure whereas the playboy inspired a country to land on the moon. The return on investment of their industrial policies was quite lucrative when the econometrics are placed under scrutiny. For each dollar of funding in the space program's R&D did the economy grow by an additional seven dollars (Livingston 2006). This multiplier effect buoyed a cornucopia of business activity that saw commercial success upon demonstrating utility in Apollo. A windfall of technologies permeated the economy between inter alia water purification systems, insulation materials, scratch-resistant lenses, memory foam for mattresses, cordless power tools, or fire-resistant textiles.

In the bailiwick of medicine the use of CT scanners (Computerized Tomography) finds its genesis in the space program. Mapping the anatomy of the Moon would be exported into the diagnostics of human biology. At the time a tour de force was needed to image the mysterious terrain prior to a craft landing on this enigma of a satellite. Hence the digital reconstruction of the lunar surface not only germinated a revolution in medicine but created a branch-plant economy of diagnostic equipment from CT scans to MRIs. Scores of other technology spinoffs and transfers equally percolated into America's modernization from the microcosm of Apollo. Ever the mother of invention the necessity of collecting soil samples summoned the venerable Black & Decker company to invent a cordless drill from its vast library of power tools. A rotary hammer device capable of burrowing the deepest rock in the unforgiving vacuum of space would be the progeny of this enterprise. This high-torque implement graced with low power consumption on the barren wasteland of the Moon came to untether household appliances from wall sockets. A new market sprouted upon the commercialization of this cordless technology. Apollo's spillover then fathered this other multi-billion dollar industry courtesy of Eisenhower's industrial policy.

SCALE ECONOMIES OF MICROCHIPS

Government largesse for the space program turned into a de facto stimulus for technologies that were later commercialized in consumer markets. At the dawn of the digital age Apollo incarnated a gateway to redefine America's economy. Firms began to espouse advanced technologies from the downstream effects of planting a flag on a desolate rock in a facsimile to previous industrial policy like the Air Mail Act of 1925. What government procurement by NASA did therefore was expedite the future. With parity in how air mail contracts prompted innovation in aircraft so too did Apollo incentivize R&D in technology. By 1965 Moore's Law prophesied that the power of computing would double every two years. This prescience issued from the gauntlet of demand thrown down by NASA where none existed before. A rather high benchmark for computing speeds in miniature size was set to create the solution of silicon wafers so prevalent in electronics now. Hence government procurement directly invested in the momentum towards maturing technology so it may be viable for ordinary consumers. NASA's honeypot then was a haven where the knowledge-economy went into hyperdrive. Microprocessors were commodified in large measure due to public investment pairing spacefaring with silicon and software.

In the 1960s Apollo guaranteed the market for microchips. By virtue of this monopsony a quantum leap in production pared down prices from a prohibitive $1000 to $20 upon the decade's twilight (Shellenberger et al. 2008: 109). In exploiting the purchasing power of government a number of firms reified scale economies to appease the space program's bullish appetite. Not only did NASA proffer a test bed for this budding technology but its consumption shifted the commodity from a luxury into a necessity. The Space Act of 1958 veritably kickstarted the revolution in microchips. Through the end of 1963 NASA alone procured the lion's share of America's integrated circuits at 60 percent of manufactures. The remaining 40 percent was earmarked for the Air Force's Minuteman Missiles (Fishman 2020: 126). Companies with trepidations about entering the firmament of semiconductors found solace in the inelastic demand by government procurement. Two of these firms were the startups Intel and Advanced Micro Devices (AMD) whose pedigree traces to when the Petri dish of Apollo spurred technology that would have otherwise been trapped in its infancy. Venture capitalists soon followed NASA's breadcrumbs to equally invest in unique niches of innovation for their application in commercial markets.

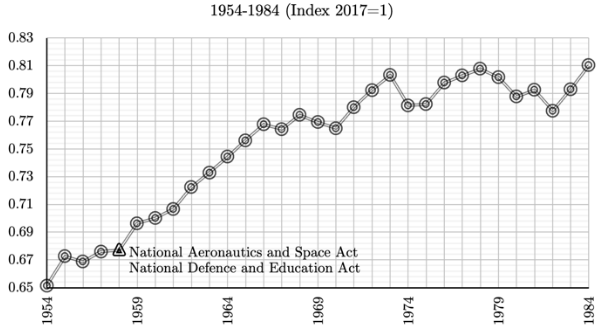


As the patron of advanced technology NASA created the most sophisticated sectors. At its apogee in 1966 this organ of government wielded 4.41 percent of the federal budget in the buildup for the lunar mission (Davis 2019). The ensuing paradigm shift from manufacturing to a digital economy supercharged by the knowledge transfer of incubators in academe gave way to high-tech industries. Bereft of Apollo ratcheting up the production of value-added components much of this niche technology would have withered on the vine. Demand and a copious amount of it was the deus ex machina for a welter of firms groping for their raison-d'être. America effectively evolved into the sovereign of frontier technology because NASA bore the risk of adopting state-of-the-art contrivances like the miniaturization of those old dinosaur mainframes. Computing in compact size saw microchips mass produced as heavy investment ploughed into the untested technology. By 1971 Intel released its first commercial microprocessor that condensed a room-sized computer into a piece of silicon barely an inch across. This novelty and its descendants would not have been viable were it not for Apollo arrogating to itself well-nigh all of America's microchips until scale economies felled prices. Thus the space program's legacy lives in all consumer electronics.

The reason why the semiconductor industry is pregnant with broader implications for an advanced economy alludes to its likeness to a barometer. From the ponderous prototypes of Alan Turing's computers to the ubiquity of electronics today the production of chips and circuits proxies the cadence of innovation. By extension such a culture of lateral thinking telegraphs an economy's affluence. In bygone times when not too long ago agriculture yields or coal output were bellwethers of prosperity a new index was engendered upon the arrival of the space program with a robust presence of a semiconductor industry. A certain threshold precedes this capital intensity as prerequisites encompass vast outlays for factories coupled with a brigade of experts within the labour market. The manufacturing of semiconductors at the apex of technology thereby correlates with high education levels, R&D, or patents on intellectual property. Wherever this industry is domiciled the greater the sophistication of microchips the more capable devices are made otherwise its absence holds an economy hostage from development. Indeed a modern microchip boasts over a hundred billion transistors versus 2,300 of Intel's first halo product in 1971. Ergo Apollo was the impetus for why America flirts with quantum computing, AI and advanced robotics today.

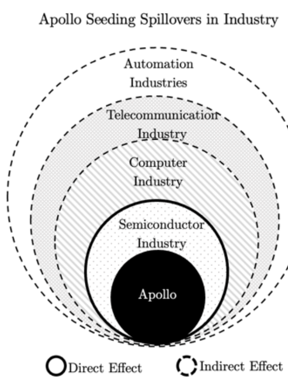
The infusion of capital from industrial policy hastened the maturation of microprocessors for the digital age by compressing the lead time. Apollo's gambit paid handsome dividends. As government emblematized the primary risk-taker new technologies came of age to transform the economy from one of smokestacks to software. In less than a decade of Apollo's monomania for minute circuits did the runaway success of the first personal computer capture the public's imagination in the Apple I. The boom in microprocessors that was symptomatic of the space race was what gave vent to the processing of information as the trademark of the knowledge economy. Thereafter would America's economy be anchored in innovation when traditional manufacturing ceded in prominence whilst tech-sectors soared. Productivity indicators spotlight how society began to do more with less as a derivative of the workforce being steeped in the efficiencies of technology. Likened to the profound impact of the steam engine the profusion of microprocessors swept America up in a frenzy of industriousness: retailers adopted electronic registers for faster checkout; rudimentary production lines were updated with robotics and CNC machines; banks automated services to speed transaction times.

Total Factor Productivity at Constant National Prices for America, 1954-1984 (Index 2017=1)



Source: University of Groningen; University of California, Davis.

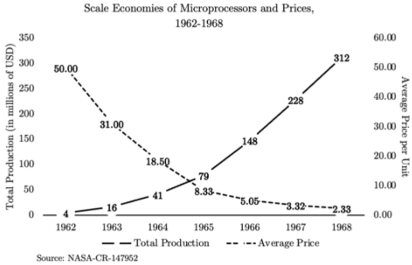
The saga of Apollo's industrial policy between the genesis of microprocessors and the influx of STEM researchers echoes the tenets of economist Paul Romer's (1990) Endogenous Growth Theory. America's postindustrialism can be most felicitously explained by this model which gives credence to how development is a function of investment in human capital, R&D and knowledge. Prior to this paradigm the gestation of an economy was imbibed through the prism of economist Robert Solow's (1956) treatise in which he expounded how capital accumulation and productivity were vectors of growth. But the mere acquisition of machines alone was insufficient lest diminishing returns stifle output insofar as no new technology was introduced. The quagmire might be analogized to adding farmers onto a static plot of land in a futile attempt to increase its yield. So productivity follows from capital and technology. What Solow failed to dilate on however was how the latter would manifest. Romer remedied this lacuna in his monograph by making technology 'endogenous' to growth not 'exogenous'. Direct investment in innovation buoyed an economy and its spillovers could lead to breakthroughs across a myriad of sectors. The springboard of Apollo similarly catalyzed commercial markets with its downstream effects.



COMMERCIALIZING COMPUTERS

A new Industrial Revolution signposted a divergence from sooty factory floors to the sterilized ateliers of semiconductors in the wake of the space program. The Rube Goldberg machines of bulky proportions from yesteryear diminished into relics in the face of digital infrastructure when such analogue computing fell into disrepute. As prices for microchips descended down the cost curve the technology's omnipresence signalled the economy's new currency would be data over tangible goods. Indeed Apollo's industrial policy altered the value proposition of microchips triggering great disruption in traditional manufacturing which was later besieged by a flight of capital. An existential crisis would see the Midwest bear scars of decline as steel mills shuttered when computers supplanted manpower. Although a raft of fissures did predate the demise of steelworkers prior to the digital bonanza in virtue of global competition much of this quiet revolution made blue-collar workers redundant. Intangible assets like software and intellectual property were the new darlings of the knowledge economy as the steel heartland of America's industrial belt haemorrhaged jobs. It was a fait accompli that bits and bytes would replace steel and coal upon Apollo's adoption of microelectronics in its bid to land on the Moon.

Not only was the semiconductor industry's growth intimately linked to the space program but so too was the computer empire that followed suit. By 1968 the average price of the most basic microchip nosedived to $2.33 whose cost efficiencies bootstrapped downstream firms like Apple and Microsoft. Government procurement subsidized the technology to the point where its affordability vaulted a proliferation in the commercial sector. In an atavism to when Washington dumped its surplus planes from WWI at bargain prices onto a market of hobbyists the computer industry's chronology bears an uncanny resemblance. Early adopters of cheap microchips partook of a subculture where enthusiasts in garages soldered kits of disparate parts. When these electronic evangelists congregated in the Homebrew Computer Club whose alumni included Steve Wozniak and Steve Jobs a whole marketplace of schematics and software came to fruition. This iconoclasm of open-source sharing in short order disrupted IBM's corporate monopoly. The user-friendly Apple II and Tandy's TRS-80 then democratized the industry for the layperson with grassroots computing. In a mere two years the sales of the former crested from $7.8m in 1978 to $117m in 1980 (Hynes 2021). Manifestly Apollo's technology trickled down into personal computers.



Whilst Apple graduated into a household name Microsoft was not too far behind. A software boom occurred in lockstep with the groundswell of computers just as hardware prices plummeted. In a clone of Apple's duo the fountainheads Bill Gates and Paul Allen collaborated to author the MS-Dos operating system that was standardized across the industry. What differentiated Microsoft was the longer time horizon of its business model. Licensing software to multiple buyers rather than one lucrative payout from a single source ended the operating system war even before it began. Whereas exclusivity begot great value it was ubiquity that monopolized marketshare. As more manufactures signed on to host MS-Dos the greater was the number of software developers who gravitated towards tailoring their programs to this specific platform. A self-perpetuating cycle emerged. Third-party developers elected to target the market's largest segment populated by MS-Dos computers whereby its growing utility saw Microsoft boast increasing returns to scale as more consumers fancied the product. Much like moths to a flame the herd behaviour of users generated rapid adoption when popularity equated with the endorsement of the software. In retrospect the philosophy of ubiquity over exclusivity proved correct.

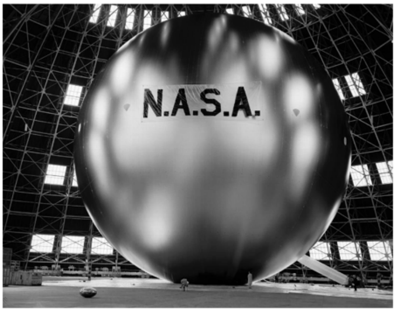
As markets reacted to Apollo's demand for integrated circuits with lower prices per unit over time the seeds of industrial policy germinated into another organic outgrowth. Not only were computers mass produced but the network they plied to interface with each other derived from this wellspring as well. The creation of the Internet vindicates just how much space exploration was not at all a sunk cost but rather the paragon of shrewd investment. The cascading effect was aplenty. As more institutions and households adopted computers in a positive feedback loop the greater was the need for a decentralized method of communication between these monuments to reason. Crowdsourcing information would be a fillip to research whereby the Internet's prototype first liaised the Universities of California, Stanford, Santa Barbara and Utah with each other. Under the government's Defence Advanced Research Projects Agency and its eponymous network the ARPANET computers were interlinked in the first of its kind by 1969 at the cost of $1m in R&D (Lukasik 2010). As chip designs and manufacturing techniques catered to NASA the knock-on effects gave prominence to cyberspace. The Internet's genealogy thus can be traced to the law of unintended consequences wherein Apollo was the chief protagonist.

The very essence of industrial policy is to plant seeds. Create a market where none existed and once it has matured no longer is it needed for government to cosplay a gatekeeper. Being this silent benefactor was how the Internet evolved into the lingua franca of the knowledge economy. The seed money from NASA's procurement that subsidized the semiconductor industry was what staged the advent of the Digital Age. It is not reductionist to posit how the moonshot ushered in a whole new paradigm from manufacturing to curating information whose progenitor was the Saturn V rocket. The true genius of public funds into this program was not to so much a footprint on the lunar surface as much as it was the boom in technology. Once microelectronics diffused into a constellation of industries they quickly became household mainstays in a virtuous cycle where early adopters mainstreamed their use. Were it not for Apollo it is reasonable to assume the trajectory of microprocessors would have been abjectly impaired. The technology might have been buried in the graveyard next to inventor Nikola Tesla's Wardenclyffe Tower whose wireless power found no demand nor immediate application for its use. Once the viability of microprocessors was proven courtesy of public dollars the buccaneers like Intel summarily refined these tiny slivers of silicon for profit.

A New Dawn for Telecommunications

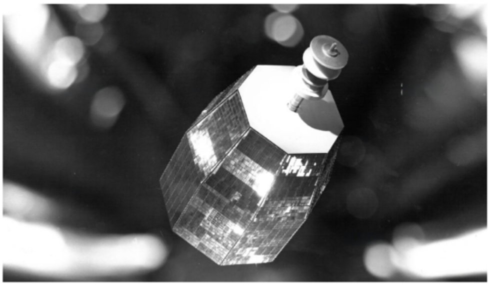
A symbiosis between NASA and the shrinking of the world into a global village informs the provenance of the telecommunications industry. The export of satellite technology from the pages of science fiction into the ether above was first articulated by the polymath Arthur Clark in 1945. Seminal to the industry the white-paper titled 'Extra-Terrestrial Relays' conjured up a world not connected by short-wave radio or a lattice of undersea cables but rather by signals bounced off stations in the void of space. A web of these satellites orbiting the earth unfettered by atmospheric disturbances could be a medium for real-time communication. The sheer audacity of this idea cannot be stressed enough. When the monograph was penned humanity had scarcely pierced the boundaries of space with its primitive technology. The highest altitude recorded by a V-2 rocket topped the distance of 189km in suborbital flight (Lee 2020). Just for Clarke's hypothetical satellite to be entertained it would need to reach the threshold of 36,000km. The grandiosity of this foresight evokes the same futurism gleaned from Leonardo da Vinci's first doodles on the mechanics of flight centuries ahead of their invention. But rather than be dismissed as a fit of daydreaming in less than two decades were these wild speculations of satellite technology brought to life.

America's formal dalliance with transmitting signals into the vast unknown began with President Eisenhower's industrial policy in 1958. Abreast of Projects Mercury, Gemini and Apollo another triptych begot a quantum leap in the separate firmament of global communication during the jet age. Projects Echo, Relay and Syncom each escalating in sophistication came to experiment with bouncing microwave frequencies off passive and active satellites from ground stations below. A diverse consortium of firms brainstormed these instruments under the auspices of NASA. In the halcyon days of adventurism into the cosmos Project Echo became a totem for a proof of concept to test whether radio signals could piggyback on objects in orbit for the sake of long-distance communication. This maiden satellite from 1960 was effectively a monolithic balloon of aluminized Mylar whose reflective properties redirected signals from a laboratory in California to one in New Jersey. Initially the Aeronautics Division of the foodstuff maker General Mills was recruited to build this galactic mirror but when it was discovered that it would fray in the inhospitable vacuum of space the firm was jettisoned for the Schjeldahl company. To stave off premature ruptures of the orb's skin a single fortified seam was introduced versus the previous patchwork.



Echo passive satellite, 1960.

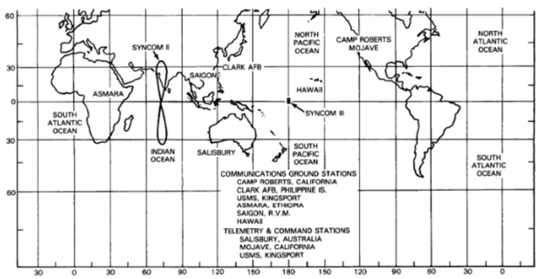
Upping the ante in technical specifications for the sequel to Project Echo was the Relay satellite which sought to undo the tyranny of geography. Communication signals via traditional infrastructure were liable to degradation over long distances at a prohibitive cost in capital. By contrast the bandwidth of Project Relay exhibited a fidelity heretofore unseen with the bonus of transmitting across further expanses. Whereas short-wave radio failed to penetrate the vicissitudes of atmospheric conditions whether it be through fog or rain this alternative had no such deficit that may throttle it. Moreover skeptics had to be reminded about the economies of scope whereby television, radio and telephone signals could be diffused on a single piece of hardware rather than across a multitude of terrestrial stations like in legacy systems. No longer would the geometry of communication be at the mercy of oceans or mountains but instead find deliverance in the airwaves far above. Thus the utility of Project Relay was not lost on policymakers whose analysis of the costs and benefits vindicated the industrial policy to finance it. Project Relay legitimized satellites when operational expenditures were bound to plummet as the onus of maintenance was removed. Telecommunications therefore was the very first technology to commercialize space.



Relay satellite seen in space, 1962.

A jigsaw of private stakeholders pooled resources together to inaugurate this next chapter in the study of satellite technology. One particular enigma that needed to be demystified promptly was the longevity of Relay's testbed as its honeycomb of solar cells would face a barrage of cosmic radiation in the Van Allen Belt. The rate of degradation had to be probed and then mitigated if delicate electronics were to weather the wilds of space. Any viability hinged on ensuring a lengthy lifecycle of the satellite in this minefield of hazards and so advanced measuring hardware approximated 11 percent of the weight for the first iteration (Ezell 1988: 376). The omnipresence of radiation had to be properly understood lest the enterprise become a financial sinkhole. Relay 1 in turn would be the proverbial canary in the coal mine to measure the inimical effects of these energy particles as each critical system was made redundant with a backup in the event of a malfunction. After the first launch in 1962 the second satellite in 1964 boasted upgrades with shielding far more resilient to radiation than the preceding prototype. Relay 2 learned from its sibling and later broadcast segments of the Winter Olympic Games in Austria a few days upon the start of its mission. The program was the first to master real-time communication.

In the saga of Cold War politics America paraded its soft power with the apotheosis of Syncom that followed in the footsteps of the foregoing Relay program. Although less romanticized in the public imagination than the lunar missions but of equal salience this final prototype sought a geostationary orbit above the equator relative to a fixed point on the ground. Such a static position aloft in space relayed signals for one-third of Earth in a revolution for telecommunications. This portmanteau of ‘synchronous communication’ epitomized a giant leap in technology. At an altitude of 35,768km the parity of speed between Syncom and Earth’s rotation intimated the satellite could synchronize with one location on the terrestrial surface and hover above it. In this precise position the system and its solar cells would be continuously recharged by the sun. Whilst minor propulsion difficulties hobbled Syncom 2 with its figure-eight pattern above the sky after its predecessor completely floundered the third iteration nudged itself into the coveted spot of a geostationary orbit. Instant communication was made a reality as Syncom became globalization’s progenitor where citizens were no longer spectators but rather participants to world events. NASA thus created an information super highway for the world.



Syncom II and Syncom III geostationary orbit, 1964.

In the pyrotechnics to explore and exploit the final frontier the connectivity that ensued from transmitting voice, data and video via microwaves irrevocably changed the world economy. Analogous to President Theodore Roosevelt’s industrial policy of building the Panama Canal in 1904 meant to truncate the journey around South America’s Cape Horn did NASA’s satellites induce a similar vector of growth. Government funding coupled with public-private alliances integrated markets akin to how faster transit by ship aroused the same effect although the latter clearly manifested in more analogue ways. The Information Age cultivated by satellite technology came to midwife a multi-billion dollar industry whose downstream effects hastened economic globalization. Traders on Wall Street could navigate London and Tokyo stock exchanges devoid of any lag in financials. Multinationals began to exercise greater agency in managing supply chains. Media transcended borders to diffuse a monoculture of capitalism amidst the spectre of sabre-rattling from Cold War hostilities. A digital Silk Road thereby homogenized markets as transaction times were whittled down from days to seconds. Commerce then seized upon the alacrity at which capital moved since geographical determinism was no longer germane to growth.

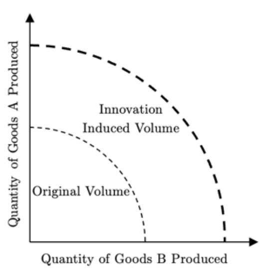
THE DEMAND-PULL ECONOMICS OF SPACE

Investment that seeded the space race opened a number of market opportunities for major firms amongst the cascade of downstream effects visited upon the private sector. In the main what government largesse basically did was stimulate the production of new technology for NASA whereupon each $1 billion earmarked from Federal spending added 20,000 employees to America's payroll (Evans 1976). And yet far more pregnant with consequence than this dynamic of job creation is not this influx of labour so much as its nature. Rather than run-of-the-mill openings like in hospitality or retail what proliferated instead was employment defined by a great intensity of STEM research. What this disruption to the status quo intimates is the reality of how breakthroughs in science go on to parent new technologies whose later use enables an economy to produce more than what it did previously. A distinction then differentiates conventional versus high-tech employment. In the parlance of economists the former maintains the existing Production Possibility Frontier whilst the latter pushes its boundaries outward. The concept of PPF adverts to the maximum output an economy can produce within the parameters of its current technology. A great deal of innovation and productivity thus followed courtesy of public investment in NASA.

The magic of industrial policy here cannot be overstated. Creating jobs in industries informed by a high degree of human capital conduces to an economy becoming a hotbed for innovation. Borne out of this relationship are technologies that migrate into a sundry of other sectors which in turn ply them to increase their proper productivity and reduce costs. Observe the journey of microchips from Apollo's Guidance Computer to robotic manufacturing. A serious revolution on production lines accompanied this technology as labour costs diminished commensurately with higher output whose economies were passed onto consumers by way of lower prices. Elsewhere the ubiquity of these semiconductors saw the exponential growth of computing power when efficiency gains were had from processing data. Whether it be point-of-sale systems like cash registers or the advent of ATMs in the financial industry or perhaps the cordless tools so common on construction sites NASA was a boon to America's productivity. With greater production and its faster cadence which in the foregoing examples would imply more shopping or banking transactions or homes being built came a better standard of living since profits translate into wage growth. Ergo the knock-on effects in the economy were many.

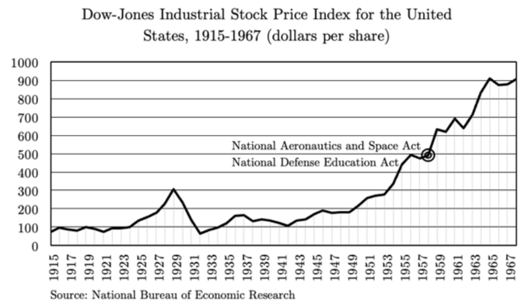
So the genus of employment masterminded by the industrial policies of President Eisenhower in 1958 between the National Aeronautics and Space Act abreast of the National Defence Education Act were critical to America's GDP. Public spending effectively became an investment in R&D thereby spurring new technology whose result elevated America's capacity to produce goods. As productivity jumped in tandem with lower costs for manufactures what summarily followed was the affordability of essentials and luxuries. Households could subsequently exploit the newfound purchasing power of their disposable income to live more comfortably. For the rest of the economy what this dynamic intimated was that lower costs would stimulate consumer spending as dollars were stretched to buy bigger baskets of goods and services. Soon enough a positive feedback loop ensued whereby businesses saw higher sales and profits which created opportunities for further investment and jobs. Again this domino effect found its genesis entirely from pushing the Production Possibility Frontier outwards which proxied for a better quality of life across America. Productivity in short is the offspring of innovation and the embrace of NASA by the public purse invariably became the seedbed for GDP growth in the modern space age.

A Shift of the Production Possibility Frontier from Industrial Policy



Such fiscal infusion trickled down into commercial sectors not far downstream from the incubator that was NASA which itself was the precursor to the knowledge economy. Whether it was descendants like the computer industry or telecommunications much of America's meteoric growth owes its origins to the industrial policies of the Eisenhower presidency. Between the 1950s and 1960s nearly 80 percent of federal R&D outlays derived from the Defence Department and NASA. By 1964 these expenditures accounted for 2.9 percent of America's GDP on scientific research alone (Carlsson et al. 2007). The mobilization of industries across the gamut from metallurgy of superalloys to computer technology begot substantial dividends far exceeding the initial investment in space exploration. This 'Apollo Effect' was the muse for America's hegemony of technology when the miniaturization of electronics laid the groundwork for the computer age. How this reality came to fruition was through the proliferation of public-private partnerships that birthed an ecosystem between government, industry and universities. This collaboration reminiscent of the atomic bomb's development in the Manhattan Project only two decades prior would revolutionize manufacturing and production design. In time these reforms would be the catalyst to a broad spectrum of industrial growth.

Schumpeterian creative destruction that stemmed from the crossover application of NASA's technologies across a gestalt of sectors spoke to America's renaissance. Thereafter intellectual capital was plumbed as market incentives took advantage of new innovations at the behest of eager consumers for the sake of profit. It did not take long before the laboratory of space informed mass consumption. NASA would quickly become a boon to stock markets since lucrative contracts tendered to the private sector galvanized investor confidence. The extensive supply chain that materialized at a brisk clip aroused the rally of stocks around companies poised to benefit from Washington's dalliance with space. With Wall Street so bullish an eclectic mix of firms recruited by NASA revelled in the appreciation of their market capitalization as the seed money fronted by public dollars further attracted private investment. A whole paradigm shift in corporate culture came to pass. Like so often when optimism crescendoes the euphoria from the breakthroughs in technology set loose the animal spirits of markets with high-risk and high-reward ventures being sought by investors. It is unambiguous that the heyday of Apollo with its triumphs in emerging technology initiated the growth of many industries for decades to come.



The economic current wrought by the prime mover of NASA had a considerable demand-pull effect on technology. As new inventions surged Silicon Valley's population exploded since it found an ever greater cluster of kindred businesses consolidating together to reap the economies of agglomeration from their proximity to each other. The spillover into civilian industries was substantial. This result begs a simple question. Why was the industrial policy that sowed the seeds of the space race so instrumental in generating economic growth? One word can be offered for this interrogation: innovation. Such activity is the impetus to industrial development. If an economy should ever find itself in the doldrums its investment in new technologies would reverse its misfortune. A causal link exists between the cadence of innovation and the growth of per capita output. It has been shown how the intensity of research advances technology to the point where economies can produce more with less (Leonard 1971: 232). Innovation therefore is the Holy Grail of industrialization. It is befitting then that the postwar era witnessed America's investment in R&D eclipsing all other OECD economies combined (Mowery and Rosenberg 1993: 29). NASA hence assured a market for technology pioneered by the most innovative of firms.