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Technology push-over: defense downturns and civilian technology policy

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Abstract

Since the 1960s civilian technology demonstration programs in the US Departments of Transportation and Commerce have manifested a pattern in their initiation, content, and outcomes. Programs are episodic, with long periods of relative inactivity occasionally interrupted by brief periods of budgetary largesse. Program content often emphasizes information and automation technologies and system integration. Outcomes are often disappointing, with few technologies or systems actually implemented. This broad pattern in civilian technology policy can be explained in part by the dynamics of the defense sector. Defense technology suppliers occasionally suffer a procurement downturn, at which times they apply their political influence in support of offsetting civilian projects. This leads to occasional periods of support for civilian technology development. This cross-sectoral technological imperative is here conceptualized as "technology push-over". Evidence of this relationship between defense and civilian technology programs can be found in the repeated US programs in intelligent transportation systems (ITS) and in aggregate R&D data from the defense, commerce, and transportation sectors.

Keywords: Technology policy; Civilian technology policy; Intelligent transportation systems (ITS); Technology push; Iron triangles

1. Introduction

In an article entitled, "Intelligent Vehicle/Highway Systems — A Feeling of Deja Vu", senior transportation consultant Roy Wilshire (1990) noted that technology policy in transportation seemed to repeat itself. To Wilshire, the 1990 US program in intelligent transportation systems (ITS) bore an uncanny resemblance to the technology demonstration programs of the 1970s. Programs in both periods promoted a systems approach to transportation based on the application of information technology, automation, and system analysis to roads and vehicles. With over 20 years in transportation, Wilshire had participated in both programs and experienced the repetition firsthand.

The historical record suggests that such repetition is not limited to one program alone. The broader road transportation sector (which includes highways, urban streets, and mass transit) has manifested a cyclical pattern, with similar projects flourishing in the 1970s and again in the 1990s, and at least one other civilian sector, the US Department of Commerce, has also experienced similar trends. Both the 1970s and the 1990s witnessed a blossoming of advanced technology projects for such systems as automated vehicles, command and control transit, and advanced manufacturing and industrial technologies. In both periods projects were based on the application of automation, information, and system technologies, and in both periods projects experienced difficulty in implementation.

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This pattern in civilian technology policy presents both a challenge and an opportunity. The challenge is to understand and explain it. Why do such policies apparently flourish at some times and nearly disappear at others, and why is it that they seem to develop characteristic technologies? The opportunity is to learn to craft better policies by recognizing and mastering the factors that influence civilian technology policy.

In what follows, I begin by offering evidence of this cyclical pattern. Most of the evidence comes from the US program in ITS and from aggregate spending data from the US Department of Transportation (DOT) and Departments of Commerce (DOC). I argue the cyclical pattern in these civilian technology policies is caused by the institutional dynamics of the US defense sector, home to most federal technology capabilities (consistent with other scholars' conception, the defense sector here is broadly conceived to include the Department of Defense (DOD), the Department of Energy (DOE), and NASA (Mowery and Rosenberg, 1991)). Historically, after the US wins a technological contest, be it the race to the moon or a hot or a cold war, the defense sector experiences a budgetary downturn. Such downturns create political pressure for counter-cyclical technology spending in other sectors, which often takes the form of transportation or other civilian technology policy. The downturns lead to "technology push-over" from defense to civilian systems. Such institutional influences do not shape any one program completely, but their influence can be discerned in many programs.

2. The pattern in civilian technology policy

The type of program of interest here is most often known as a "demonstration project" (RAND, 1976; Cohen and Noll, 1991). Different writers refer to it under different names, including "socio-technical systems" (Lambright, 1976), "large scale demonstration projects" (Branscomb, 1993), and "technology commercialization programs" (Eads, 1974). Such programs may develop entire systems or simply component technologies. They may develop technology for either commercial or public application. Well-known examples include the supersonic transport (SST, a commercial system demonstration; Horwitch, 1982), personal rapid transit (a public sector system demonstration; Burke, 1979), and the advanced technology program (a commercial components demonstration; Hill, 1998).

The most common unifying theme in all such programs is their justification in terms of market failure. In this view, the federal government initiates such programs where a technology is too uncertain, too unfamiliar, or too risky to be adopted either by the private sector or by the non-federal public sector (Cohen and Noll, 1991; Eads, 1974; RAND, 1976). By *demonstrating* a technology, the federal government can reduce the uncertainty that inhibits private investment and governmental deployment (Myers, 1979). Although such arguments have received skeptical treatment at times (Eads, 1974; Hill, 1998), claims of market failure accompany most demonstration programs.

Research into this class of programs is hindered by the fact that federal R&D reporting also does not single them out as a distinct category (NSF, 1993; NSF, 1996). Most existing studies have relied instead on compendiums of cases rather than on comprehensive data (RAND, 1976; Cohen and Noll, 1991; Hill, 1998). Thus, the phenomenon I seek to explain here — a broad pattern in demonstration projects extending back over 30 years — is difficult to even identify, because comprehensive historical data is unavailable. Lacking immediately appropriate data, I use a variety of incomplete sources to assemble an approximate picture. I first examine in detail the one set of civilian programs known as intelligent transportation systems (ITS). Next, I survey multiple demonstration projects that unfolded parallel to the ITS program. Finally, I examine aggregate data for *all* R&D spending by the DOT and DOC, two historically active departments in demonstration projects. This data does not provide a comprehensive record of all projects, but it gives an indication of broad trends in two important civilian sectors.

The pattern in demonstration projects is visible in their initiation, content, and outcomes. Program initiations are episodic. There are periods of activity, when clusters of programs are launched, and periods of inactivity, when no programs are underway. During periods of activity, programs often have a characteristic content. Many civilian systems in transportation are based on electronics technologies and system integration. Finally, the outcomes are all too predictable.

The civilian programs rarely advance to implementation, leaving development incomplete and unfinished.

Consider the history of US national programs in ITS. The Federal Highway Administration (FHWA) in the US DOT has engaged in two programs in ITS, one around 1970 and the second beginning around 1990.[1] Their similarity is striking. Both programs emphasized systems technology. At the core of each was the premise that electronic communications and control could be applied to vehicle/highways operations to transform the road network from a collection of autonomous vehicles into an integrated and centrally controlled traffic system (Saxton, 1993; pp. 11–12). Each program consisted of a diverse collection of development projects for such systems as electronic navigation consoles to guide drivers through city street networks, mobile communication systems to warn drivers of traffic congestion and suggest alternate routes, and automated merging systems to smooth traffic flows at highway on-ramps (IEEE, 1970; IVHS America, 1992).

Development of ITS was episodic. Launched in the late 1960s, the first program constituted "a startling departure from past research activities — in size, vision, and content" (Saxton, 1993, p. 11). A rapid rise in activity around 1968 was followed by some 4 years of research and then a rapid decline in activity. In the early 1970s, individual demonstration projects were one by one denied continued funding, with the flagship electronic route guidance system (ERGS) terminated in 1971 (Saxton, 1993). There followed a period of quiescence from the mid-1970s until the late 1980s during which the FHWA hosted little or no systems development. Then in 1990 spending took off again. Equally sharp in its initiation, the second program was much larger in scale, spending on the order of US$ 200 millions per year as opposed to the earlier program' less than US$ 10 million (GPO, 1970, 1971).

Despite their separation in time, the two programs had comparable outcomes. The first ended without implementation of any of its advanced systems. One technologically conservative system for the centralized control of traffic signals escaped complete termination and was installed in a few cities around the US. Overall, however, the first ITS program had little impact. Likewise, the second program saw its most advanced system canceled within a few years and its emphasis shifted away from research. The biggest single research stream, a demonstration of a hands-off automated highway systems suffered abrupt and complete termination when Congress denied its appropriation in 1998 (NAHSC, 1998). Overall, the second ITS program evolved to emphasize more established technology like traffic management and variable message signs.

This pattern appeared in other civilian programs as well. Alongside the two ITS programs the federal government launched numerous other demonstration projects, many of them also in transportation. For the most part, they began abruptly, they applied automation and communication technologies, and they experienced difficulty with implementation.

The first wave occurred in the late 1960s. The Department of Housing and Urban Development demonstrated automated transit systems (Burke, 1979) and computerized "dial-a-bus" system (RAND, 1976). The Federal Aviation Administration, which had begun conceptual work on a supersonic transport (SST) in 1963, sharply increased SST funding in 1969 (Rosenbloom, 1981). Other programs of that period demonstrated advanced technology for manufacturing, medical claims processing, and maritime navigation (RAND, 1976). Then there followed a period of inactivity. In the late 1970s and 1980s, few programs were launched, as the lull experienced in ITS development occurred in most civilian sectors.[2] Then in the late 1980s and early 1990s, history repeated itself as civilian technology development programs again blossomed in civilian sectors. Beginning in 1988 and getting underway in 1990 the DOC hosted

[1] The name of programs and agencies were less consistent than presented here. The term "intelligent transportation systems" only arose in the 1990s; the demonstration projects of the 1970s did not carry an overarching title. The name of one early system, electronic route guidance system or "ERGS", is sometimes used to refer to the entire collection of demonstration projects. Likewise, the name of the federal agency that oversaw these programs has also varied. Some of the projects in the earlier program were begun in the Bureau of Public Roads in the Department of Commerce, which later evolved into the FHWA in the DOT.

[2] The program to develop synthetic fuels from coal was somewhat of an exception to the overall pattern. That program occurred later than other programs, picking up momentum from 1973 to 1978 oil shocks, and it did not employ system technology (Cohen and Noll, 1991).

the advanced technology program (ATP; Hill, 1998), which developed base technologies for commercial applications, such as intelligent monitoring systems for manufacturing, fast 3-D image processing, and massively distributed databases (NIST, 1999). This was followed by the technology reinvestment project (TRP), in which the Defense Advanced Research Projects Agency (DARPA) undertook a multi-billion dollar development program for civilian and dual use technologies (Cohen, 1991). The TRP supported manufacturing-related research and dual-use technology development. Multiple other civilian programs launched around the same time, such as state-level consortia that in partnership with DARPA sought to develop advanced technology for transit propulsion (CALSTART, 1999) and the partnership for a new generation of vehicles, in which US national laboratories participated in automotive technology development (RAND, 1998). The pattern discernible in the ITS development program was evident in numerous other civilian projects.

Further evidence of a pattern comes from aggregate data for R&D spending (Table 1 and Fig. 1).[3] Table 1 shows total R&D spending in constant dollars by the US DOT and DOC. Since neither DOT nor DOC conducts much basic research (almost never more than 10%), the total R&D figures can be used to approximate technology development spending (NSF, 1999a). In the case of DOT, additional data confirms that the profile of the R&D curve is determined primarily by variations in spending on system technology for "national needs", such as advanced inter-city and urban systems (DOT, 1999). Thus, although the data is not exclusively for demonstration projects, it is roughly indicative of spending on civilian demonstration projects in those departments.

The profile of this aggregate data gives a sense of long-term dynamics of federal spending on civilian technology. Two features of Fig. 1 merit special notice. First, the chart confirms programs' episodic nature. The data show two broad periods of rapid growth, one beginning around 1966 and peaking in 1971, and a second beginning in 1989 and peaking in 1995. In the early 1960s and again in the late 1970s and 1980s spending was flat or falling. The programs were episodic. Second, the graph shows how such upturns were little more than short-lived spikes. Funding sometimes went up sharply, but it quickly came down again. Between 1969 and 1971 civilian spending nearly doubled, only to drop the next year by a third. Likewise, between 1993 and 1995 spending grew by some 50%, but half that gain was withdrawn the following year. Commitment was short lived. Presumably, implementation was difficult.

In summary, available evidence suggests that Mr. Wilshire's feeling of deja vu contained an important truth. Although the ITS program and other demonstration projects provide an incomplete picture of federal activity, they do suggest a pattern of episodic starts, high-tech contents, and sudden finishes. This pattern merits explanation. Interestingly, it has not been the focus of scholarly attention. It is to the existing literature that I now turn.

3. Literature

Two bodies of literature are relevant to this topic. The first examines civilian technology policy for demonstration projects, analyzing case studies of system development (RAND, 1976; Burke, 1979; Nelson, 1982; Branscomb, 1993) and occasionally examining political and structural factors shaping policies (Eads, 1974; Cohen and Noll, 1991). This paper seeks to contribute most directly to this literature. A second body of literature examines the defense-related agencies of DOD, NASA, and DOE; it includes numerous case histories of system development (Logsdon, 1970; Sapolsky, 1972; Morone and Woodhouse, 1989; Lambright, 1976) as well as analyses of defense procurement (Adams, 1982; McNaugher, 1989).

Each of these literatures offers some explanation for system initiation, content, and outcomes. As mentioned earlier, among the most common reason given for program initiation is some kind of market failure caused by uncertainty (Cohen and Noll,

[3] Source: National Science Foundation, 1999. The original data (NSF, 1999) has been converted to 1987 constant dollars using NSF gross domestic product price deflators (NSF, 1996, p. 102). The NSF data adjusts for changes in the institutions hosting the spending. Thus, energy spending figures from 1960 to 1998 combines data for the Atomic Energy Commission, the Energy Research and Development Administration, and the Department of Energy. Likewise, transportation data for years prior to the 1966 (the founding year of the US Department of Transportation) assembles data from other agencies hosting transportation.

Table 1
Defense (DOD, DOE, NASA) and civilian (DOT, DOC) R&D spending (1960–1998)[a]

Year	Defense spending (millions)				Civilian spending (millions)		
	DOD	NASA	DOE	Total defense	DOC	DOT	Total civilian
1960	21900	1400	2900	26200	120.3	183.5	303.8
1961	25000	3000	3200	31200	122.9	183.4	306.4
1962	25100	5400	3800	34300	149.6	247.1	396.8
1963	26800	10500	4000	41300	192.1	306.9	499.0
1964	26300	15500	4500	46300	195.0	227.5	422.5
1965	24000	17500	4400	45900	216.7	227.6	444.3
1966	24100	17400	4200	45700	189.6	590.2	779.8
1967	26700	16200	4200	47100	248.6	942.2	1190.8
1968	24700	14200	4400	43300	268.9	550.2	819.1
1969	23500	12100	4300	39800	219.7	706.8	926.5
1970	21300	11000	3900	36100	351.4	947.4	1298.8
1971	20700	9000	3600	33300	395.9	1369.7	1765.6
1972	21800	8300	3400	33400	490.2	812.8	1303.0
1973	20900	7600	3400	31900	474.1	772.7	1246.9
1974	19400	6900	3400	29800	417.1	854.0	1271.1
1975	18900	6400	4300	29700	452.5	654.5	1107.0
1976	18900	6700	4800	30400	447.0	575.2	1022.2
1977	19800	5700	6400	31900	441.7	640.1	1081.8
1978	19400	5600	7100	32100	475.9	685.0	1160.9
1979	19300	5500	7200	32000	478.1	572.0	1050.2
1980	19800	4600	6700	31100	485.2	511.7	996.9
1981	21200	4600	6300	32200	421.5	534.1	955.6
1982	24700	3700	5600	34000	402.2	370.9	773.2
1983	26400	3100	5200	34700	385.0	399.7	784.7
1984	27900	3100	5100	36200	394.1	493.2	887.3
1985	31600	3500	5300	40400	422.9	454.8	877.6
1986	33900	3500	4800	42300	411.1	397.0	808.1
1987	35200	3800	4800	43800	402.2	325.0	727.2
1988	34000	4200	4900	43100	375.4	294.0	669.4
1989	34700	5000	4800	44500	367.7	280.3	648.0
1990	33300	5800	5000	44100	391.2	327.3	718.5
1991	27500	6200	5100	38900	419.5	325.6	745.1
1992	30100	6400	5100	41600	542.2	370.5	912.7
1993	29100	6500	5100	40800	533.6	443.4	976.9
1994	27600	6600	4800	39000	658.8	495.0	1153.8
1995	26200	7000	4800	38000	882.0	564.4	1446.4
1996	26000	6500	4000	36500	805.1	416.6	1221.7
1997	25500	6800	4100	36400	734.9	386.0	1120.9
1998	24900	7000	4200	36100	699.0	474.8	1173.9

[a] Constant (1987) dollars. Source: National Science Foundation, "Federal Funds Survey, Detailed Historical Tables, Fiscal Years 1951–1999", Document nsf99347, June 8 1999 (http://www.nsf.gov/cgi-bin/getpub?nsf99347). DOD: Department of Defense; DOE: Department of Energy; DOC: Department of Commerce; DOT: Department of Transportation.

1991; Chapter 2). Some new technology seems to present an opportunity for the provision of useful goods or services, but uncertainty about benefits together with the prospect of uncaptured value deter individual actors from investing in development. Government development programs reduce uncertainty and pay for knowledge creation beneficial to society as a whole.

Arguments about market failure suffer from a number of problems, however. First, they are either non-falsifiable or universally confirmable. Since the alleged market failure relates to a system or a

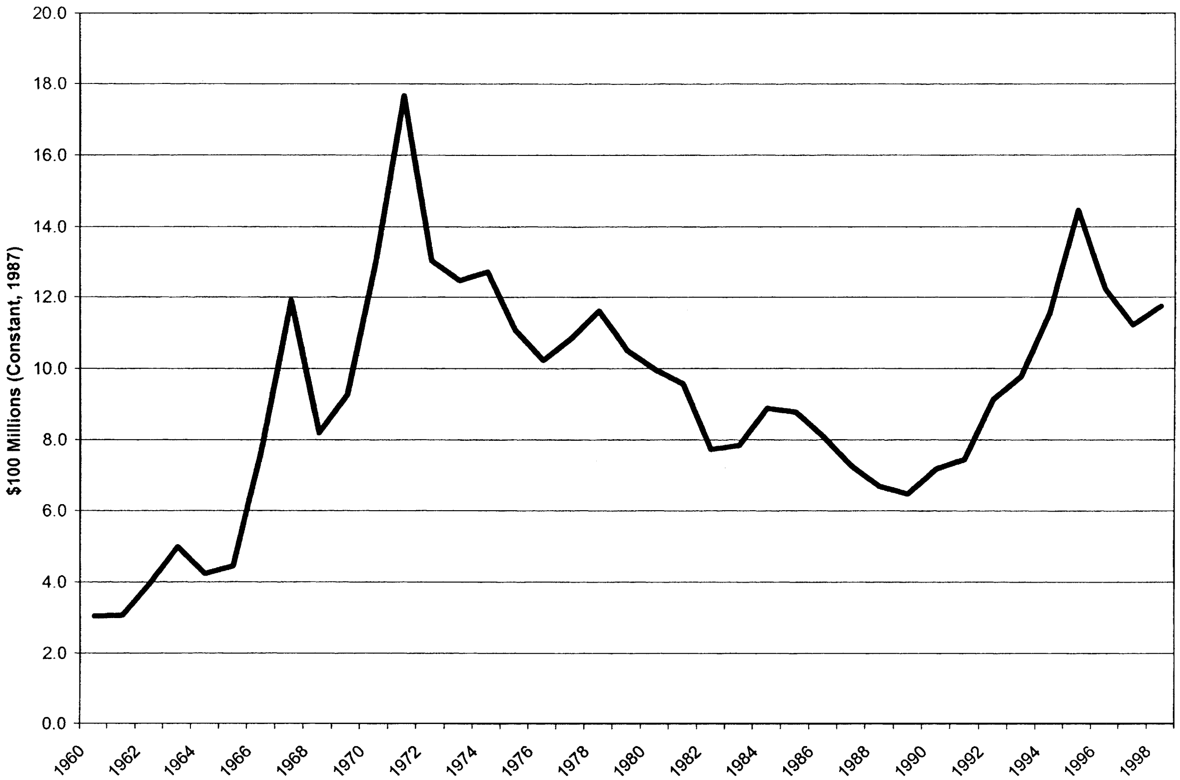

Fig. 1. Combined R&D spending by the US Departments of Transportation and Commerce, 1960–1998 (constant 1987 dollars).

market that does not yet exist, assertions about such projects cannot be falsified. Moreover, once development is completed, all outcomes support the market failure justification: demonstrations of both working and non-working systems reduce uncertainty and generate information needed for rational economic decision-making. Thus, market failure provides little guidance to either policy-makers in their ex ante predictions or to social scientists in their ex post explanations.

Other factors also render this explanation suspect. Cohen and Noll (1991) document how economic evaluations rarely persuade policy makers to terminate programs. Therefore, the power of economic ideas to justify *initiating* development also seems questionable. More concretely, market failure cannot explain why technology development is episodic. As noted above, system initiation often occurs in bunches. Yet market failure explanations draw on the characteristics of individual systems and technologies, which would lead us to expect a steadier flow of projects over time.

Cohen and Noll suggest an another ideas-based explanation for program initiation: culture. "American public policy has a long history of technological optimism.... In the public sphere technological optimism leads government officials to respond to a serious national problem by throwing technology at it. Even when science provides no basis for believing that a 'technical fix' is feasible, scientists and engineers are called on...." (Cohen and Noll, 1991, p. 1). Program initiation may not so much reflect rational ideas of market failure as irrational ideas about technology.

If we consider culture as something uniform within one society, differentiated between societies, and relatively stable over time, then its ability to explain program initiations is weak. Within a common culture, it is difficult to explain why some sectors (e.g. defense) initiate more technology projects than do others (e.g. transportation). Within a stable culture, it is difficult to explain why periods of activity and inactivity alternate. Finally, across dissimilar cultures, it is difficult to explain why projects often unfold in parallel. Passing fads, rather than culture, may explain some observed variability, but they seem too weak to explain the expenditures of billions of dollars.

If ideas cannot convincingly explain program initiation, perhaps material interests can. Adams (1984) provides an interest-based explanation for the initiation of system development in the defense sector. He explains defense procurement in terms of the interests of the suppliers. Applying the familiar model of "iron triangles", he accounts for defense technology development in terms of the interests of executive branch agencies in the Department of Defense, congressional committees, and defense industry vendors. In the defense sector, where much procurement goes to advanced technology, iron triangles give rise to regular procurements of technologically advanced weapon systems.

However, iron triangles cannot explain the observed pattern in low technology civilian sectors like road transportation. Established actors in civilian sectors are unlikely to push for spending on high technology that they do not traditionally use. Established players in road transportation may support new programs in highway construction, a staple procurement item in their sector, but they are unlikely to push for procurement of electronics from non-transportation vendors. Furthermore, iron triangles cannot explain the episodic nature of civilian programs. Enduring political constellations promote stable spending, not the kind of waves and spikes seen in Fig. 1.

If the existing literature is weak on explaining initiation, it largely ignores program content. As observed above, civilian programs often develop information and automation technologies, pathbreaking technologies (rather than existing, proven technologies), and systems with centralized command and control capabilities. Some normative literature touches on technology design in terms of "dual use" technology, appropriate for both civilian and defense purposes (Alic, 1994). Only rarely, however, is an historical instance of technology design seen to merit explanation. Mackenzie's (1990) institutional perspective suggests that established sectors tend to develop technologies that they already know and that serve the enduring goals of their sector. Today's technology tends to look the same as that of yesterday. Such an account may partially explain the observed repetition in civilian programs. Repeated attempts to develop the same system can be explained in institutional terms as the repeated assertion of an enduring capacity. This does little to explain development programs of novel systems, however.

Finally, most civilian system development programs exhibit unsatisfactory outcomes. Very few development programs succeed; many fail. Here authors show a greater willingness to consider material factors. Lambright (1976) claims that outcomes depend on the structured relationships of developers and users. System development succeeds more often where users are represented in the design process and where there is a small set of interests to be satisfied. This explains the relative success of the defense sector, where both technologists and users are integrated in federal bureaucracies. System development tends to fail in "fragmented" civilian sectors organized along federal lines of national, state, and local government where the multiplicity of interests politicizes the process. Cohen and Noll (1991) touch on the issue of outcomes, but only to examine why manifestly unsuccessful projects nonetheless receive funding. Incentives acting on players render them unwilling to terminate unsatisfactory programs. However, why the outcomes are unsuccessful to begin with is not addressed. The pattern observed is not explained.

4. Technology push-over

Experiences in the transportation sector suggest a different explanation. As noted above, we often understand the political impetus for defense technology procurement in terms of the interests of suppliers, most notably "iron triangles" of industry associations, Congressional committees, and federal agencies (Gordon, 1981). A variant on this supplier perspective helps explain patterns in civilian technology policies in transportation and commerce. I propose to explain the pattern in terms of *technology push-over*.

When the defense sector suffers a procurement downturn, technology suppliers in that sector shift their influence to civilian sectors to promote offsetting civilian procurements. The result is civilian system development — under the name of "demonstration projects". This account helps explain why civilian programs are episodic, why they emphasize certain technologies, and why they rarely achieve implementation.

Despite efforts to maintain stable and high levels of defense technology procurement, larger forces occasionally drive down procurement and cause painful budget contractions. Throughout the 20th century, the alternations of war and peace and of military build-up and drawdown have led to booms and busts for defense vendors. World wars I and II were both followed by sharp reductions in military procurement (Mowery and Rosenberg, 1991; Bright, 1978). Later, during the cold war when defense spending concentrated increasingly on technology development, there were two additional downturns in spending. The first occurred in the period from 1967 to 1971, when NASA completed the Apollo program, and the second came in the late 1980s with the end of the cold war with the Soviet Union (Lambright, 1976; NSF, 1997). Each of these historic events caused declines in procurement.

Each defense decline caused an upsurge in civilian technology policy. Actors at the three nodes of defense iron triangles shifted their influence to their counterparts in civilian sectors. System suppliers, defense agencies, and members of Congress collaborated with their non-defense counterparts to promote the purchase of advanced technology for civilian systems. Civilian actors benefited from defense interests investing political influence on their behalf; defense actors benefited from civilian procurements that softened their downturn.

This model has a number of explanatory advantages over the existing literature. First, it explains how system development programs come to be launched in civilian sectors, even though few constituents advocate such procurement. Members of Congress from defense districts may support civilian initiatives they would normally shun, authorizing budgets and earmarking funds for civilian procurements to offset defense cutbacks. Defense contractors may offer new initiatives for civilian technologies, or they may support initiatives proposed within civilian sectors. Policy makers in civilian sectors may find that their internal R&D advocates suddenly have powerful allies in Congress.

Second, in revealing institutional forces at work this model allows us to reconceptualize an apparently intermittent and variable phenomenon as a continuous and stable one. Defense spending occasionally dips; civilian spending sometimes jumps. Either one, seen in isolation, presents a challenge to an explanatory approach based on enduring structures of material interests and political influence. Seen together, however, the stability and continuity we expect to find reappears. Combined spending in the two sectors is more stable than either one alone. A mystery is solved.

Third, the technology push-over model helps explain content. The content of civilian programs reflects the capabilities of defense firms and agencies, whose expertise is concentrated in certain technologies like aeronautics, computers, communications, and automation. This is manifest in the distribution of federal R&D funding, most of which goes to two sectors: aircraft/missiles (which in 1981 received 50% of the total) and electrical machinery (25% of the total; Mowery and Rosenberg, 1991). With much defense spending going for complex weapons systems, defense contractors are also strong in system analysis and system development (Ergas, 1987). When defense sector actors shift their influence and expertise to civilian sectors, they characteristically promote programs for technology development, system integration, and information, automation, and aeronautic technologies.

Finally, the model also explains the pattern in civilian programs' outcomes. Program outcomes reflect their supporters' interests and capabilities. Programs are biased toward economic benefits to suppliers of advanced technology rather than toward functional benefits for users. Since suppliers may realize substantial benefits from development alone, a failure to achieve implementation may still be a success. True, full implementation is the optimal outcome — but development alone may be good enough to satisfy program backers' immediate interests. Moreover, suppliers' interests may change over the course of a program. Should defense spending revive, firms may lose their interest in smaller and less lucrative civilian programs. Political support for a program many dwindle over time; unless a development project has attracted indigenous support in its own civilian sector, it may collapse. Finally, the technology itself may be better aligned with the capabilities of the suppliers than with the needs of users, which again manifests itself in a failure to implement. Overall, there is a pattern of abandonment in which programs terminate without implementation.

We often characterize policies as "technology push" when they are driven by a new technology seeking application. The technology policies resulting from such cross-sectoral interactions can be said to manifest "technology *push-over*": advanced defense technologies shift *over* to civilian sectors in search of civilian application. This dynamic can explain the observed patterns in technology programs by the DOT and DOC.

5. Technology push-over in the ITS programs

The two programs in ITS illustrate many of the features of technology push-over. The timing of the two initiatives coincided with defense downturns, with actors at all three nodes of the triangle collaborating in program launch. The programs' content and outcomes also fit the model.

The impetus for the first ITS program came from the so-called "R&D depression" of the mid-1960s (Holman and Suranyi-Unger, 1981). With the Apollo moon program approaching completion and conventional warfare in southeast Asia consuming the military budget, defense R&D spending dropped sharply (Table 1). Elected officials, executive-branch administrators, and industry experts began forging links between the defense sector and the transportation sector.

To soften the downturn, members of Congress and political appointees in the executive branch shifted their political influence in support of civilian R&D spending. Official records give some sense of the process at work. In congressional testimony, one transportation administrator pointedly reminded a budget committee chair of the need to support civilian projects performed by home-state defense contractors: "one of the contracts that would be negotiated (for a highway demonstration project) would be with the Raytheon Corporation, *up in your own State*" (GPO, 1969; emphasis added). Congressional support for Raytheon's freeway on-ramp merging system was soon forthcoming. Elected officials broadly supported increased budgets for civilian spending on defense technology. President Nixon's appointee to the DOT, John Volpe, managed the transfer of NASA's Electronics Research Center to the DOT, where it began applying NASA's electronics expertise to transportation [4] (Shapley, 1971).

Career administrators in executive branch agencies also participated in the shift. The DOD administrator overseeing Federal Contract Research Centers wrote the centers' presidents to communicate "official approval *and stimulus* for you to review your opportunities to help with domestic needs such as transportation, urban redevelopment, housing,. . . . and other fields" (Aerospace Corporation, 1980, p. 152; emphasis added). Defense research centers like Aerospace Corporation soon received contracts for ITS. Agency staff also shifted to civilian sectors. The leading ITS developers at the Federal Highway Administration (FHWA) came to the agency from NASA, carried by staff cutbacks in space research (Saxton, 1993). Sometimes entire facilities were reassigned, as in the case of the NASA Electronics Research Center.

Finally, defense vendors figured prominently in the FHWA program. Paralleling the shift of personnel from defense agencies to civilian agencies in the executive branch, many defense firms created traffic divisions for civilian procurements. Sperry Rand, a leader in radar systems, was soon supplying the FHWA with prototype urban traffic control systems (GPO, 1971) and Raytheon Corporation began developing freeway merging systems (GPO, 1970). The Aerospace corporation actively entered into transportation, medical engineering, and other fields — all the while heeding the DOD mandate that total non-defense activity not exceed 20% of its activities (Aerospace Corporation, 1980). Roy Wilshire, just then experiencing his first iteration of highway demonstration projects, noted the sudden profusion of defense vendors suddenly opening transportation technology divisions (Wilshire, 1990).

The combined influence of actors at the three stations of political influence successfully promoted technology push-over. Biographical sketches of newly-arrived researchers showcased the kind of expertise entering the transportation sector. ITS researchers' previous work lay in aircraft radar target

[4] That center now bear's his name: The John Volpe National Transportation Systems Center.

simulators, fire control systems for B-52s, military identification/friend or foe, electronics intelligence, vacuum tube fuses, and weapons system engineering (IEEE, 1970, pp. 168–172). The content of the ITS program manifested these defense capabilities. Researchers were soon developing automated vehicles, heads-up displays for cars, and command-and-control centers for urban traffic. Defense R&D budgets were buffered from downturn — but the utility of the technology remained questionable. One skeptical transportation professional noted,"....DOT has committed itself to maintenance of the erstwhile NASA electronics research center in Boston, an organization, which, to say the least, will find transportation R&D a brand-new field to till. Its first research crop worth of consumption may well require several seasons to mature — but its requirement for scarce R&D funds is, of course, immediate" (Hamilton, 1970; p. 398).

This first ITS program ended with almost no systems implemented. Promoted and supported by defense actors, the ITS program remained a fringe activity in the highway community. Busy with the planning and construction of the interstate highway system, the FHWA leadership had little commitment to research in electronics and automation. In the early 1970s, as the shock of defense cutbacks subsided, Congress began reducing funding for projects. With little support in FHWA, electronic route guidance was canceled in 1971 and others followed (Saxton, 1993). So ended the first ITS program.

There followed a quiet period. In the late 1970s and 1980s, defense procurement recovered, and defense actors refocused their energies in their own sector. Defense labs and contractors returned to their mission. In 1977, the Air Force signed a memorandum of understanding with the Aerospace Corporation that reconfirmed its dedication to national security interests and support of Air Force space programs (Aerospace, 1980). Technology development in the FHWA languished (Saxton, 1993).

This period of inactivity from around 1975 to 1988 reveals much about the forces driving civilian technology. Of all the factors cited in the literature to explain civilian programs, only one had changed — the political impetus to buffer a defense spending downturn. Other factors remained as strong as ever: new technologies like microcomputers and cell phones presented opportunities for innovation, uncertainty about systems caused market failure, American culture embodied technological enthusiasm, traffic congestion and highway safety cried out for solutions. Technology experts within the FHWA continued to doggedly advocate smart highway research, sometimes to the point of risking the wrath of their superiors (Shladover et al., 1993). Yet technology development languished. Neither economics, technological opportunity, culture, civilian problems, nor internal advocacy could bring about the launch of a new program. All the factors commonly cited in the literature were present, yet no significant programs were initiated.

Not until the defense sector again fell into decline could civilian technology again thrive. In 1989, the Berlin came down, marking the end of the cold war and the beginning of a defense contraction. Defense technology procurements declined sharply, and civilian technology policy experienced a renaissance.

The forces driving the second ITS program are more complex than the first. The end of the cold war coincided with the completion of the interstate highway system, the raison d'être of the FHWA, so leaders in both the highway and defense sectors were seeking new missions to preserve their budgets. When researchers in the FHWA and in universities proposed to apply advanced electronics to road traffic, the idea received an enthusiastic response. Beginning in 1988 a supporting coalition formed, and the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) included funding for what would become a billion dollar program.

The launch of the second ITS program again manifested cross-sectoral linkages. In Congress, lawmakers from defense districts became directly involved in transportation legislation. In the House Science and Technology Committee (a committee not traditionally concerned with highways), a Congressman from a southern Californian defense district added a provision for a demonstration program for "automated highway systems" in which cars would drive under computer control. A senator from New Mexico added language to ISTEA requiring the use of national laboratories. Sandia and Los Alamos National Labs soon received research contracts for supercomputer-based transportation modeling.

Defense agencies in the executive branch also secured positions in the civilian program. Shortly after the launch of the program, in August 1993, the Department of Energy (DOE) entered into a formal memorandum of understanding to include DOE national laboratories in the program (FHWA, 1994). Los Alamos National Lab was awarded a project to apply its supercomputer expertise to develop a transportation model of an unprecedented scale. In NASA, the Jet Propulsion Laboratory (JPL) took on a leadership role in developing a nation-wide system architecture for transportation.

Finally, defense vendors received numerous procurement contracts in the program. Twenty defense contractors were among the recipients of US$ 33.3 million funding for automated highway systems. A national system architecture project involved many of the nation's major defense contractors, including Lockheed-Martin, Loral, TRW, Rockwell, and IBM. The aerospace sector's MITRE joined JPL in assisting with the system architecture. By 1994, 50 defense firms were members of ITS America, the association working with FHWA to design and support ITS development (FHWA, 1994).

Defense vendors' expertise in automation, computers, and system analysis was most notable in two sub-programs. In a grand attempt at system analysis, a national system architecture program developed a comprehensive plan for communication and control over automobile traffic, freight, vehicle safety, and transit. A second program for automated highway systems outfitted individual automobiles with sensors, actuators, and computers to drive without human intervention under fully automatic, "hands-off" and "feet-off" control. These two projects provided procurement contracts for nearly two dozen defense contractors, laboratories, and universities. In addition, hundreds of other smaller projects demonstrated myriad electronic applications.

Within 7 years of initiation, the ITS program evidenced implementation problems. Some programs were canceled outright, others were not renewed, and the DOT shifted the program's orientation away from technology development. The most dramatic change occurred in the area of automated highway systems development, the most technologically ambitious activity in the entire ITS program. That activity was canceled outright in 1998. Highway officials at the state and local level had criticized automated highways because they would require the construction of dedicated urban freeways costing billions of dollars (the system development team had deferred consideration of such implementation issues while they focused on technical challenges of automation). Numerous smaller demonstration activities were simply not renewed once their initial funding was consumed. Although less dramatic than a cancellation, decisions not to continue field tests manifested the same redirection away from technically ambitious experiments. The system architecture program also evolved away from a top-down system analysis approach to one that emphasized regional compatibility and national standards-setting. Some defense contractors like Hughes-Raytheon withdrew from some ITS-related development activities (DOT, 2000).

In place of such advanced systems, in 1996 the DOT announced a shift in priorities to such proven technologies as ramp metering (traffic signals installed at freeway on-ramps,) the use of video cameras to gather information about traffic conditions, and electronic toll collection (a technology predating the ITS program; Klein, 1996). In place of automated highways hosting trains of vehicles under computer control, an intelligent vehicle initiative promoted innovations in cruise control and improved auditory warnings (DOT, 2000). DOT also began a concerted effort to identify benefits and to promote implementation.

These two programs in smart highways illustrate the dynamics of technology push-over. In both cases, cutbacks in defense budgets made proposals for civilian technology programs politically attractive. In both cases, the programs emphasized research and development, information and automation technologies, and system integration. Ultimately, the technologies in both programs proved inappropriate for civilian operating agencies whose support was necessary for implementation.

The second program did differ from the first in that it benefited from greater internal support in the DOT. Thus, as defense support weakened and implementation problem appeared, the ITS program evolved rather than died. Although the program showed only limited success with the development of new technologies, 10 years after its initiation it was successfully promoting the diffusion of proven systems. The program's ability to adapt — and the DOT's dogged commitment to ITS

— gave reasons for believing that it could eventually contribute significant benefits to road transportation in the US (Klein, 2000).

6. Technology push-over in transportation and commerce

Lacking consistent historical data for all demonstration projects in the US, it is difficult to broaden investigation beyond one or a few case histories. In this Section, I return to the aggregate data for transportation and commerce for evidence of broader trends. A comparison with the corresponding figures from the three defense-related departments — defense (DOD), energy (DOE), and NASA — supports the claim that technology push-over has wider relevance than just the ITS program.

Table 1, mentioned earlier, lists R&D spending in constant dollars in defense (DOD, DOE, NASA) and in DOT and DOC. The technology push-over model leads us to expect that DOT and DOC spending would vary inversely with defense sector spending. When defense spending is high, we would expect that the civilian agencies' spending would be low. Likewise, when defense spending drops then the civilian spending should increase. We can also predict a lag between corresponding figures. A decrease in defense spending in 1 year sets in motion a political process of technology push-over that pushes up civilian spending the following year. This is probably most true in early periods of defense downturns, when the need for counter-cyclical civilian spending it most urgent. Causality may be weaker when defense is not in crisis. The relative changes in civilian programs may be comparable — spending downturns that are big for defense lead to spending increases that are big for civilian sectors, but the two can different greatly in absolute terms. Clearly, the scale of defense technology spending is much more than civilian technology spending. The ITS program involved "only" a few hundred million dollars — far less than a typical defense program — but constituted a very large increase in technology spending for the sector.

A statistical analysis of the data in Table 1 supports these expectations. Between 1960 and 1998 each year's defense spending figure is a reasonable predictor of the next year's civilian (DOT, DOC) spending figure. The Pearson correlation coefficient between defense spending in 1 year and civilian spending in the following year is -0.41. The negative sign confirms the inverse relationship between defense and civilian data. Likewise, a simple regression model that regresses civilian expenditure against the prior year's military expenditure as the sole independent variable also supports the claim. The regression coefficient on military expenditures is negative, with a t-statistic of -3.5, significant at the 1% level for a one sided t-test. Furthermore the adjusted R-squared for the regression is 0.258, meaning that 25.8% of the variation in civilian expenditures from year to year can be explained by the magnitude of military expenditures in the prior year.

These results are consistent with the technology push-over model. When defense goes down, subsequent civilian spending goes up, and vice-versa. Of course, many other factors are at work, so it would be incorrect to attribute all shifts in civilian expenditures to shifts in commitments to military services; yet the relationship in itself appears robust. Fully one-quarter of the change in civilian spending varies directly with defense changes. The chance that this relationship is coincidental and random appears quite low. The chance of a type one error in attributing a significant effect from military expenditure as a predictor of subsequent civilian expenditure is less than 1%.

Thus, the aggregate data in the period since 1960 suggests a broad trend. DOT and DOC numbers and defense numbers are correlated in the expected inverse direction, and more than one quarter of change in civilian spending seems attributable to the change in defense spending.

In closing this Section, I offer one final piece of evidence, which suggests that the technology push-over model extends further back in time. The defense downturn following world war I (WWI) gives one clear instance of technology push-over. WWI promoted rapid growth in the advanced-technology field of aircraft. Immediately following the war, there ensued a steep decline in procurement of this technology. Within a few years, however, defense firms successfully championed civilian application of aircraft in another federal agency, the US Postal Service. The Kelley Airmail Act served as the equivalent of a civilian technology demonstration project, promoting the application of new technology in a civilian sector. This counter-cyclical procurement softened the post-war downturn. Application of the advanced technology was facilitated by simultaneous Congressionally-mandated reductions in airmail postal rates, which turned private mail carrying into a profitable business. By 1934 these arrangements generated a backlash and Congress reformed the industry, mandating that aircraft manufacturers divest themselves of their transport subsidiaries and requiring mail contracts be awarded on a low cost basis (Mowery and Rosenberg, 1991). This episode provides an early example of cross-sectoral interactions and technology push-over. [5]

7. Conclusions

The technology push-over model is an institutional model. It focuses on a *single* causal factor — downturns in defense procurement — to explain patterns involving many civilian technology programs. This is not a simplistic explanation of all history with one variable, nor is it a denial of agency in human affairs. In any institutional model actors make their own decisions but within a structured context: "....institutions constrain and refract politics but they are never the sole 'cause' of outcomes" (Thelen and Steinmo, 1992). Unique factors influence programs as well. Still, the pattern of repetition and deja vu in transportation and other civilian programs supports the claim that institutional forces are at work. If policies were exclusively shaped by myriad independent and unique decisions, they would be unlikely to manifest cycles. Institutions do not explain everything about any single program, but they do explain much about many programs. That is the claim here.

Nor does an institutional model imply that human agents are fools or frauds. True, policy makers may not be aware of the linkages between civilian programs and defense downturns or may not recognize the full import of such linkages. Even when they do recognize linkages, however, they may have no choice but to go along. They may knowingly participate in a process that is larger than their sphere of individual influence. Such participation need not be an act of cynicism or resignation. Through participation they may attempt to reap some good from a situation largely beyond their control. In the broad movement of institutional forces there may be numerous opportunities for human agents to influence large events or to fully achieve smaller goals.

The technology push-over model allows for some predictions and recommendations. I close with some policy-relevant observations about the future.

Like most structural accounts of society, the account offered here allows for one basic prediction: the future will look like the past. Technology push-over results from the workings of long-established constellations of influence in the US economy and in its public institutions, and since these constellations are unlikely to quickly change, the phenomena they promote are likely to endure. Already by the late 1990s the last defense technology downturn was passing and new research programs were in the works (e.g. missile defense systems). A future downturn in defense technology procurement would likely lead to another surge of civilian technology programs.

If prediction is easy, identifying promising policy recommendations presents a challenge. At minimum the model here suggests why some commonly-heard policy prescriptions would likely fail. One prescription is to reduce the political power of defense interests. In *The Politics of Defense Contracting*, Adams (1984) provides some suggestions along those lines. However, influential groups are influential precisely because they can resist such challenges, so such a recommendation may be of little utility. Another, similarly unhelpful recommendation is to simply avoid mistakes: "do not develop overly-sophisticated technology", "focus on implementation issues", etc. Such recommendations address the symptoms without confronting the deeper causes. Numerous reports of this kind, some of them of otherwise excellent quality, have had little impact (e.g. RAND, 1976). Powerful forces will likely override any attempt to "do the right thing" (Branscomb, 130, 25n).

Faced with powerful and enduring social forces, we might reconcile ourselves to them, redefining "success" and "failure". Although many civilian programs fail to achieve implementation, they do succeed

[5] Following world war II defense firms again attempted to stimulate offsetting procurements but were not successful. Ultimately, the outbreak of the Korean war raised them from the doldrums. See Bright (1979).

in buffering the defense economy from downturns. Thus, civilian technology demonstration programs may be seen as good defense policy. Not only are they useful, they are arguably fiscally responsible. Their small size relative to defense R&D could be taken as evidence of policy makers' fiscal restraint.

Civilian sectors suffer, however. Although their intermittent technology-hosting service may benefit the national interest, the demonstration projects that they host offer limited benefits within that sector. Such programs may even *undermine* civilian sectors, because they divert scarce resources, and when they fail they may discredit attempts at technological innovation. What approach might yield real benefits for civilian sectors?

Effective civilian programs might begin with the recognition that *implementation* and *utility* rather than technological novelty or feasibility are the crucial issues. Civilian policies might give priority to the diffusion of proven technologies developed by operating organizations. The second ITS program began evolving in that direction after 1995 (Klein, 1996). Moving away from programs to develop vehicles with technologically advanced but not very useful capabilities for "hands-off" driving, DOT began trying to diffuse technologies that had proven their utility. The emphasis on novelty declined, replaced by a new focus on utility.

Effective policies could also begin with recognition of factors that drive the *demand* for innovation. Much surface transportation innovation has been driven by sanctions, which created demand for innovation. Environmental regulations have stimulated innovation. The threatened loss of highway funds because of non-compliance with clean air regulations has led to significant changes in regional transportation. Sanction-based federal policies might work more generally. To create demand for traffic management systems, DOT might threaten to cut federal funding to cities with high congestion.

By recognizing the cross-sectoral institutional dynamics in the US government, we can understand the initiation, content, and outcomes of many civilian technology programs. This institutional dynamic will not soon change, and episodic instances of technology push-over will likely continue. What is needed are additional approaches that emphasize diffusion, implementation, and demand-creation. These hold greater promise to promote innovation in transportation and other civilian sectors.

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