Aligning policy and practice in science, technology and innovation to deliver the intended socio-economic results: the case of assistive technology

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Abstract: This paper recommends that science, technology and innovation (STI) policies intending to address socio-economic problems, properly align their chosen implementation system to the intended solution's requirements. Society typically relies on the industrial sector to supply product and service innovations through the free market system. In cases of free market failure representing national interests governments may apply alternative innovation systems. The procurement contract system delivers tangible products meeting pre-determined performance criteria (e.g., military weapons; orphan drugs). The exploratory grant system delivers conceptual discoveries advancing the state of science (e.g., scholarly publications). The field of assistive technology (AT) exemplifies those social problems requiring technology-based solutions, for which governments around the globe consistently and inappropriately apply the exploratory grant system. The example reflects a broader government bias towards applied scientific research by the academic sector, at the expense of delivering practical solutions through engineering development and industrial production by the private sector.

Keywords: triple helix; linear model; science; technology; innovation; STI; market failure; assistive technology; procurement contract; exploratory grant.

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1 The business of innovation is business

After decades of analysis and refinement, the European Union settled on a definition for the term 'innovation' (OECD, 2005), and the USA eventually adopted the same definition (National Science Board, 2012). This shared definition is an important refinement for terminology used in policy and practice, because it restricts use of the term innovation to the context of products and related activities within the industrial sector:

> "An innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations."

The definition corrects the countervailing trend of using the word innovation to mean insight, improvement, discovery or invention in all forms manner of marketing materials and media promotion. Efforts to make the term more objective are important for it to have utility within empirical analysis of science, technology and innovation (STI) policy and practice. Parenthetically, this definition could be further restricted to mean "new to the world" products and related activities, so that it's meaning would be absolute rather than relative. At present, it can still be subjectively applied to describe something new to an individual, organisation or some other unit of analysis.

The shared EU and USA definition does recognise that use of the term innovation should be restricted to the context of the industrial sector – also called the corporate, business or enterprise sector – of national economies. The 21st century's array of market-based innovations (products and services) arose from the industrial sector's practical demonstration, generation and rapid commercial deployment of prior seminal innovations in agriculture, manufacturing and transportation (Smil, 2005). These advances relied on the insights and breakthroughs of individuals who were the pioneers in their chosen fields of investigation. Anecdotes about individuals contributing innovations from their garage workshops are factual but fail to account for the limitations on such contributions. These limitations are only overcome through expansive effort and investment by a broader team of stakeholders representing science, engineering, marketing and management – all pursuing a shared goal. As technology became more complex, the range of expertise needed to comprehend and advance, build and test, manufacture and deploy the envisioned technology-based products and services, became equally complex. Even those legendary independent inventors were eventually compelled to underwrite the operation of science and engineering laboratories when their 'cut-and-try' efforts reached their limits of enabling knowledge (e.g., Thomas Edison's Menlo Park in 1876; A.I. DuPont's Easter Dynamite Corporation in 1895).

This shift from individual inventor to teamwork within corporations explains how the innovation growth curve was sustained throughout the 20th century. The essential scientific research and engineering development was still conducted by brilliant individuals who combined practical upbringings in rural America with advanced degrees. But now all of the project-level 'R&D' activity occurred under the supervision of higher-level corporate managers with similar backgrounds who had risen through the ranks.

The American Telephone and Telegraph Corporation (AT&T) serves as the quintessential example of systematic technological innovation, because it amassed sufficient financial and human capital to deliver breakthroughs across all fields of application, during the largest period of economic expansion in the past century. The AT&T Corporation became a leader in global technological innovation by concurrently operating a science and engineering laboratory (Bell Labs), along with a new product and service development facility (Western Electric). Project staff in both facilities conducted their assigned activities and earned greater latitude by demonstrating expertise and contributions – a merit-based system of tenure. Staff recorded their progress on projects in notebooks that were witnessed by co-workers. These lab notebooks were reviewed on a weekly basis by successive levels of managers for current and future project reference (Gertner, 2012).

This reporting and review process within the company's context provided continuity across multiple projects and over long-term timeframes of decades. The best and brightest people were recruited as employees from around the world, and those who excelled were encouraged to rotate through related positions in academia and government, often continuing to teach or consult after returning to AT&T. This open-door approach continuously expanded the organisation's breadth of knowledge, and network with potential partners and customers.

The AT&T Corporation pioneered the formula for sustaining successful product and service innovations, which is replicated by leading technology-oriented companies to the present time (e.g., IBM, Apple, Google). This formula contains three elements:

1 operate a facility conducting both scientific research and engineering development (both basic and applied)

2 operate a facility conducting engineering development activity focused on generating new products and services

3 provide managerial oversight to coordinate the two facilities, to preserve and protect proprietary information, and to connect the internal enterprise to the external network of relevant stakeholders.

The AT&T Corporation clearly understood that a company or even an industrial sector does not operate in isolation but instead draws inspiration and support from other economic sectors. Corporate demands for efficiency necessitate engaging external sources of expertise, the application of multiple methodologies (e.g., scientific research, engineering development, financial investment); and substantive contributions from all three economic sectors (i.e., industrial corporations, government agencies, academic institutions). We see the same intensive engagement by contemporary corporations characterised as market leaders due to their record of sustained high-level technological innovation activities.

To that point, the European Union characterises all actions and processes that either culminate in specific innovation outcomes or generally contribute to the capabilities underlying innovation potential as innovation activities. These are defined in the context of the business enterprise because they are concerned – not with the exploration or testing – but instead with the implementation of innovations in the market context:

> "Innovation activities are all scientific, technological, organizational, financial and commercial steps which actually, or are intended to, lead to the implementation of innovations. Innovation activities also include R&D that is not directly related to the development of a specific innovation." (OECD, 2005).

2 Addressing market forces in innovation

While business drives innovation, market conditions conducive to successful operations drive business. The historical precedents for industrial innovation activities – such as those pioneered by AT&T and contemporary information technology companies - typically represent business opportunities arising under the free market system, where companies can foresee a return on their investment. Specifically, the free market requires willing buyers in the private marketplace with the necessary resources to acquire the products and services offered by a seller at a price that permits the seller to sustain its internal operations. Under those conditions, the sale price can repay the company for its costs and leave an additional margin of revenue to invest in R&D personnel and infrastructure necessary to support innovation-oriented activity. Companies lacking that margin of revenue cannot conduct internal R&D activity nor are they positioned to absorb the outputs from R&D conducted by external stakeholders. Fortunately, most modern economies are healthy enough for the free market to support innovation in the areas deemed important to national interests such as public health, welfare, safety and consumer satisfaction.

However, there are instances where society deems a need for technological innovation to address a national need, but the project's scope falls outside the conditions necessary to support the delivery of solutions through the competitive free market. These instances are called 'market failures' because the private sector cannot build a compelling business case despite the presence of a legitimate societal need. These legitimate instances of market failure may be due to insufficient capacity within a company to address the scale of the enterprise (e.g., military weapons, space exploration), or insufficient financial return on the required corporate investment (e.g., fundamental scientific research; orphan drug development).

Governments intervene in cases of market failures when the delivery of product or service solutions to the identified problem is deemed critical to national interests, such as those examples cited in the prior paragraph. Governments substitute public resources for those absent in the private free market, so government becomes the supplier of the investment revenue at the front end of the innovation process, in order to underwrite the scale-up costs involved. Governments may also become the buyer of the product or service outputs at the back end of the innovation process, in order to provide the sales revenue necessary for the company or industry to sustain the business enterprise addressing the market failure.

Government interventions fall into two alternative innovations systems when addressing cases of market failure:

1 *Contractual procurement system* – a government agency sponsoring the R&D determines the outputs to be generated, and the performance parameters to be achieved. The contracting organisation – typically an industrial corporation – is chiefly concerned with delivering a product or service that meets the government's specified performance criteria within the corporation's time and cost parameters. The contract-based procurement system supports relevant engineering development and industrial production activity, to achieve a pre-determined advance in the state of the practice, in service to the nation. The sponsoring government agency often both underwrites the R&D activities and services as the primary customer for the project's output. Product and service innovations in military weapons, advanced energy

facilities and space exploration all typically fall within the contractual procurement system.

2 *Exploratory grant system* – the recipient of government funding – typically a university faculty member – determines the output to be generated within an investigator-initiated proposal. A peer-review process involving other scholars determines the general merit of the area of conceptual knowledge to be advanced, while the government agency focuses on the quality and rigor of the activity conducted. The grant-based system of scholarship supports rigorous scientific research activity of general value to the state of science to advance civilisation. The funding agency underwrites the process but is not directly engaged in consuming the project's output, typically embodied in a scholarly publication.

These two alternative innovation systems share a common point of origin: public monies collected by national governments from organisations and individuals through the taxation process, then disbursed through policy and program systems to address the identified yet unmet needs of society. From that point of origin forward the two alternative innovation systems differ in every meaningful way. The methods applied within the two alternative systems are different and therefore their respective outputs are different: scientific research methods generate knowledge in the state of conceptual discoveries, engineering development methods generate knowledge in the state of prototype inventions, while industrial production methods generate knowledge in the state of commercial innovations. While all three states may contain the same kernel of knowledge, they are as different in form and function as are the matter states of gas, liquid and solid, respectively (Lane and Flagg, 2010).

The procurement contract system concentrates the design, testing and delivery of new products or services for deployment within society. The process draws upon scientific knowledge as an input to both engineering development methods to reduce concepts to tangible prototypes, and industrial production methods to manufacture the finished products and services. In contrast, the exploratory grant system generates new to the world knowledge that is communicated within the scientific community through the peer-reviewed publication and author citation process. The knowledge outputs are not necessarily – or even often – intended for immediate application but instead are viewed as a resource for use by other stakeholders. How the knowledge transitions from the source to application remains a matter of debate, although logic models are frequently applied to explain the mechanisms involved (Stone and Lane, 2013).

3 Proper alignment between ends and means ensures success

Both of these alternative innovation systems serve important roles for progress in individual nations and for advancing civilisation and a whole. However, it is equally important to note that their respective roles in addressing national needs are only fulfilled when the government program's mission and the alternative innovation system selected for application are properly aligned. As a general rule, solutions to problems requiring the delivery of products and services should implement the procurement contract system, because it is properly aligned with the processes, incentives and outputs of the industrial sector, while solutions to problems requiring the delivery of new conceptual discoveries should implement the exploratory grant system, because it is properly aligned with the processes, incentives and outputs of the academic sector. Solutions to problems requiring technological innovations are typically driven by policies that implement some hybrid of the two systems, but the policymakers should be aware that the lead sector will determine the form and substance of the actual results achieved.

4 The penultimate hybrid success case – World War II

The role of the two alternative innovation systems grew as central government's increased their engagement with technological innovation systems. This engagement coincided with an upward shift in the nexus of innovation activities, from individual organisations to entire economic sectors during the middle of the twentieth century. This rise and consolidation presented governments with fewer points of contact, each with greater influence over innovation practices, which simplified the task of leveraging innovation resources through government policies (Rosenbloom and Spencer, 1996).

These changes proved fortuitous and permitted nations to demonstrate the effectiveness of a hybrid approach to technological innovation led by industry under conditions of dire national need. World War II offers history's clearest example of successful technological innovation across a wide range of application, under tight constraints, short time horizons and imminent threats. Allied Governments – particularly the US and UK – identified threats posed by the advanced capabilities of Axis military weapons (Armytage, 1965). The Allied Governments demonstrated high congruence between their mission requirements and the innovation system applied, because they organised the scientist from academia, the product managers from industry and the engineers from both sectors, to generate technological-based solutions to counter the threat from Axis powers (Klein, 2013; Carew, 2010).

This example of government's approach to technological innovation for the purpose of generating new or improved products and services, replicated the formula that was working successfully for AT&T. Not surprisingly, some of AT&T's top scientists, engineering and executives serving as advisors in the USA. As is the case for all procurement contract systems, government agencies performed the dual roles of financing product development and serving as customer for the manufactured products. The time constraints forced the parallel progress of scientific discoveries, engineering prototypes and industrial production, all through a hybrid version of procurement contract and exploratory grant systems sponsored by governments and led by industry.

5 Economic expansion underwrites government expansion

After World War II, the economic expansion in the USA and Canada, following by the economic recovery in Europe and then Asia, provided all of those governments with a windfall of revenue collected through taxation. The ever-expanding public treasuries allowed governments to sustain the two alternative innovation systems for sponsoring innovation-oriented programs under conditions of market failure.

For example, the procurement contract system continued to work well when national needs for advanced products and services were properly aligned with the industrial sector. The relationship supplied governments with required products and services, and permitted entire industrial sectors to flourish in technology-intensive fields such as military, energy, aerospace and medicine. The breakthroughs in scientific discoveries and engineering inventions resulting from international competitions in military conflicts, the subsequent cold war and then the space race, supported entirely new categories of goods and services for both mainstream and niche markets.

A supplemental economic benefit of successful procurement contracts was the creation of competitive market opportunities where none previously existed. Once government's provided the front-end investment and acquired the back-end products and services, the companies in that industry had sufficient expertise, infrastructure and inventory to offer those products and services to other nations. These transactions generated new net wealth for the host country while providing the customer nations with the option of direct acquisition or forming a competitive industry within their own borders. In many instances, this growth spawned highly lucrative free markets supported by multi-national corporations in the same fields of military, energy, aerospace and medical technologies.

In a parallel fashion, national governments applied the exploratory grant system to direct unprecedented levels of funding through state, provincial and regional governments to institutions of higher education. These institutions met a nation's requirements for a labour force in technical fields (two-year colleges), general liberal education (four-year colleges) and graduate-level professionals (universities). This global network advanced human civilisation by establishing a base of knowledge in the arts and sciences, which in turn serves as the foundation for continued exploration, experimentation and expression (Altbach et al., 2009).

A supplemental social benefit – at least in the short-term – was an unprecedented increase in the number of institutions of higher education, because the government expenditures fuelled capital construction projects, spurred peripheral business growth, and employed an entire cadre of salaried faculty, staff and administrators for each new campus. The global increase is reflected in statistics collected in Europe and the USA: Europe maintained an average of about 220 universities for the prior 250 years (1700–1945). That number *more than tripled* to almost 700 universities in the next 60 years (European University Association, 2011). The USA followed a similar pattern with 1,700 degree granting post-secondary institutions in 1940, *nearly tripling* to near nearly 5,000 by 2012 (National Center for Education Statistics, 2013).

Free market forces operated in the education and training side of these institutions, where people were willing to pay tuition to obtain the advanced degrees and related credentials available only through higher education. On the other hand, scientific research could not promise a market return to either the students or to the public. So all of the new and existing universities pursued increased government funding in support of their scientific research programs, over and above their agenda for funding education programs.

As a result, government allocations for scientific research programs through the exploratory grant system grew along with the growth in universities. The larger sums drew more attention from those eligible to obtain them. The academic system relies on peer review that combines rigor in project design with reputation of lead investigators, to determine which proposals to fund or reject. This becomes a highly competitive process similar to others because it creates a star system whereby leading luminaries in the academic field attract money and promising scholars. Universities and their managers must participate in this competitive system because governments provide funding for direct expenses to the scientific investigator, while also providing funding to the host institution for indirect expenses associated with administration, facilities and infrastructure. The funds for indirect expenses are a percentage of the funds for direct expenses, which for the most prestigious public and private institutions can be more than half of the direct expenses awarded. In other words, a $10 million award to a faculty member at Stanford University or Harvard University generates an additional payment of about $7 million to the institution for overhead costs.

The influx of such enormous sums changed the role and status of universities along with their internal actor's calculus for pursuing and securing these sums. Before World War II, most universities were private and depended heavily on private donors, foundations and corporations for the sponsorship of scientific research. After 1945, all existing institutions and the hundreds that followed turned their attention to securing funds from agencies within their national governments. The scope and scale of this system grew over time, largely through advocacy from university presidents and luminary professors. Even the traditional quality standards of peer review have given way to the politics of lobbyists and special funding allocations called 'earmarks' (Savage, 1999). Under the guise of objective scientists, these policy advisors exercised their enlightened self-interest through a fiction now called *the linear model of innovation*.

5.1 The linear model of innovation – a bias in policy

Simply put, this linear model of innovation asserted that the level of future societal innovation was wholly dependent on the level of sustained investment in scientific research (Godin, 2006). That meant that public funding allocated to innovation activities should first and foremost be channelled through science-oriented government agencies and from them out to academics in universities and government laboratories. Further, if funding some level of scientific activity was good for society, funding even more was even better.

At its inception, the linear model of innovation was a blatant convolution of Vannevar Bush's argument in his famous book, *Science: The Endless Frontier* (Bush, 1945). The experience of World War II had taught that technological innovation depends on careful coordination between all three sectors: government, academia and industry. Dr. Bush forthrightly recommended that the same formula be repeated to address other social and economic issues. However, special interests advocating the ascendency of public research universities and government-operated laboratories in the USA, along with growth in the government agencies sponsoring their activities, coopted Dr. Bush's idea in order to channel tax revenues from the booming post-war economy into their own coffers.

The logic of the linear model of innovation was compelling, at least it was to the government and university sectors that stood to benefit most from this flow of funding. There is little evidence that the private sector was paying attention to this bias, probably because they were accruing enormous wealth through gainful competitive market activity. As a result, the mission for science-based policies gradually expanded through the mid-century until they became the de-facto umbrella under which elected officials gathered public expectations for addressing national needs, growing the economy and improving quality of life. In Europe, the Organization for Economic Cooperation and Development documented this science-driven collaboration as a means to inform public policies and private practices (OECD, 1963), which eventually was given the topic name of STI across all developed nations. The nomenclature was embraced by each economic sector for their own purposes, so that STI policies gradually came to represent the solution for all socio-economic problems.

All of these socio-economic benefits are laudable goals, but the claims for science-based policies became exaggerated along the way to justify their continued expansion. More significantly, the actors, organisations and sectors who gain most from the exploratory grant system – predominantly led by university faculty – managed to successfully position it as the primary and de facto system to apply when addressing national needs. By creating this bias towards the exploratory grant system – and therefore away from the procurement contract system – the academic advisors and their government counterparts, placed scientific research as first among the three methods that contribute to technological innovations – scientific research, engineering development, industrial production. This first among equals perception that became ingrained in national policies regarding innovation.

Citizens and their elected officials European countries and the USA consented to allocate continuous and increasing shares of public funds to support science-based programs. This consent dramatically increased the flow of public revenue to the organisations and actors operating under the umbrella concept; that is, to the government agencies that administer science-based programs, and the non-profit institutions that implement the scientific research programs. These public and non-profit sectors both grew in terms of staffing, stature and influence. Quite naturally, the very organisations and actors who benefitted directly from this transfer of revenue became the chief proponents for sustaining and expanding policies based on the linear model of innovation. As European and Asian countries rebuilt and their economies rebounded, they too adopted the linear model of innovation under advisement from the government and academic sectors that stood to benefit most from funding allocations.

6 The costs of biased policies and programs

The direct cost of bias is a loss of promised socio-economic benefits to society. The very act of proclaiming that a policy or program will generate ‘beneficial socio-economic impacts’ does not by itself increase the quality of life for its citizens, nor does it generate a single dollar of new net wealth. Saying something doesn’t make it happen. Policies and programs must actually deliver the promised benefits, and the advisors to governments should be the first ones to establish the milestones and metrics for demonstrating results. There is very little evidence to suggest that advocates for the linear model of innovation have ever done so. In fact, there are actually examples to the contrary such as the US National Science Foundation’s ‘TRACES Project’ as a rebuttal to the US Department of Defense’s ‘Hindsight Project’ (Bozeman and Melkers, 2013).

There is also an opportunity cost associated with any allocation of finite funding. A public dollar invested in one sector cannot be invested in another, just as a private dollar invested in one field of application cannot be invested in another. A government’s ability to initiate, sustain or increase funding in any area happens at the expense of other areas. Further, future levels of available funds depend completely on the government’s ability to replenish funds through the process of taxation. It is important to remain mindful that public funds allocated to support any government-operated programs – included scientific research programs – are drawn from a nation's repository of tax revenues. Public support for government investments is an exercise in trust regarding the future benefits. If the policies and programs fail to deliver, it is society that suffers the loss.

For programs designed to generate economic benefits, it is only if and when a program becomes successful in the commercial marketplace, do such programs add revenue to a nation's coffers. Programs responding to social needs are not expected to generate new revenue, but instead are expected to deliver the defined benefits to society as a result of the revenues expended. When the investment is made and neither result occurs, governments should have mechanisms in place to cease further investment or adjust the parameters under which the investments are made. Modern societies have no such mechanisms in place, but instead rely on guidance from so-called experts, who may have no incentive to establish such mechanisms if the system's benefits already accrue to themselves.

The paper noted earlier that success in technological innovation requires a proper alignment between the intended outcomes (goals) and the methods applied to achieve them (means). The presence of a bias disrupts the alignment between goals and means. For example, the goal of deploying new or improved products and services in the marketplace is misaligned with the means of the exploratory grant system. While there is always a role for scientific research as well as engineering development activity, the leadership role must be assigned to industry, because only industry is willing and able to design, manufacturer, deploy and support products and services in the marketplace. And, one would expect both government and academic sectors to champion industry's lead role, since both sectors stand to gain revenue from the taxation of private corporate activity.

This perspective would have required government and academia to accept their positions in the flow of funds, as downstream recipients of public funds collected from upstream commerce. But they did not. Instead they positioned themselves above the upstream commerce as the font of knowledge from which industry drew inspiration for commercial innovations. Government agencies gained increased budgets for science-based programs, and universities gained by accruing a larger share of the public funds intended for distribution between the academic and industrial sectors.

The unintended consequence of this short-term windfall is a long-term decline in socio-economic health such as is occurring at the present time. Those who advocate for allocating indefinite and ever increasing support to non-profit and public sectors don't often acknowledge the source of the funds they seek to allocate. Or perhaps they are simply unaware of basic economic realities. That is, government revenues are generated by imposing taxes on corporate profits and private-sector wages, all resulting from activity within the industrial sector. Government agencies do not pay taxes. Neither do public universities or government-operated laboratories. Even corporations receive tax relief for expenditures on research and development activities. Tax revenues that fuel the public and non-profit sectors all come from income generated through private sector commercial transactions.

Private for-profit corporations have the capacity to generate new net wealth through internally financed ventures in response to free market opportunities, which government supplements for instances of market failures. Corporations can leverage the government funding to create additional markets that eventually become self-sustaining, generating sufficient revenue to internally fund future R&D activities. This means that government funding for the private sector can be episodic, limited and concluded over time. This ability to establish self-sustaining enterprises is not shared by the public and non-profit sectors, where government funding is the lifeblood of their existence. To the extent they deny wealth-building support to industry, overtime industry's ability to generate new net wealth and taxes declines. Healthy public and non-profit sectors rely on a healthy private sector. That fact is seldom raised in academic circles.

Stated succinctly to frame the point of this paper's recommendations, the industrial sector produces tax revenues while the government and academic sectors consume tax revenues. Given this reality, STI policies intended to generate socio-economic benefit through the creation of new net wealth should be biased toward funding activity in the industrial sector. But they are not. Few policymakers seem concerned about this misalignment, while scholars who serve as thought leaders are reinforcing the existing systems.

7 The triple helix concept – placing the STI policy bias in a stakeholder's context

In the 1990s, scholars added a new label to the tripartite relationships underlying STI policies and programs, by calling it the triple helix system of innovation (Etzkowitz and Leydesdorff, 1995; Leydesdorff and Meyer, 2003). They posited that the three sectors were becoming more closely intertwined. Continued advances in industrial sector innovations were increasingly dependent on a fundamental understanding of our physical world. Advances in fundamental understanding relied on scientific research conducted in universities, which in turn depended heavily on sustained funding from government agencies.

Under the triple helix paradigm, nations can sustain targeted 'systems of innovation' – each focused on a particular topic area, with each system containing representatives from the three major sectors:

1. government agencies
2. academic universities
3. Industrial corporations.

The general notion that these three sectors collectively determine progress in innovation may be valid – if not even obvious – at a conceptual level. However, this generality lacks explanatory utility at the operational level, because it does not account for the relative contributions of each sector within each instance of interaction. The dynamics of these interactions determines the specific trajectory and outcome of each innovation-oriented project. These dynamics are largely driven by the preferences and behaviours of key actors within each sector, so understanding their interplay at an operational level requires a greater understanding of the three cultures in which these key actors operate:

- *Government sector actors* – government organisations at national, state and local levels all operate programs funded through budget allocations from their cognisant body of elected officials. Elected officials operate on multi-year terms while the funded programs are established for long-term operation. Career government staff members obtain permanent employment, which permits them to take a long-term perspective towards their mission, while pursuing promotions through time in grade, program/agency expansion and work performance. These career employees typically occupy positions within on-going and stable programs, so their training is concerned with preserving the legacy components they inherent, as amended by elected and appointed officials in each new administration. Thus, expertise in program planning, design, implementation, budget allocation, activity administration and management are central to their careers. They may also bring expertise in mission-oriented fields of science, medicine or law, but their focus is on maintaining the government's central bureaucracy, so they see issues in structural and procedural terms.

- *Academic sector actors* – colleges and universities obtain revenue from student tuition, extramural grant and contract overhead fees, athletic programs, alumni contributions and endowments, and license fees and royalties from intellectual property. Public institutions receive line item allocations within state operating budgets, as well as funding for capital expansion/improvements. University administrators seek to achieve their institution's tripartite missions of scientific research, student education and community service, while increasing their own size and stature within the broader academic sector. Top management determines school and department level budgets annually, while middle managers (deans and chairs) encourage faculty to pursue supplemental funding through expanded enrolments and extramural grant or contract awards. Individual faculty members pursue permanent employment (tenure) and promotion through a competitive system of publication, citation and peer approval on five to seven year terms. Professional staff members are typically employed through civil service or similar permanent employment status. Tenure-track university faculty are trained to the doctoral level in a field of science or medicine, requiring the preparation of a dissertation demonstrating mastery of a field of knowledge, and expertise in the application of scientific research methods. Their content expertise results from intensive study through a master's level post-graduate degree, which becomes the basis for conducting original and independent scholarship. Through their training, acculturation and incentive structure, faculty members perceive issues as opportunities for applying the scientific research method.
- *Industrial sector actors* – private corporations seek to generate new net wealth that they then distributes as expenses to employees and suppliers, profits to owners and taxes paid to all levels of government. Top management work to deliver new or improved products and services to the competitive commercial marketplace, to create new markets, expand their share within existing markets, and thereby increase gross revenues and net profits. Corporate employees do not have the long-term job security enjoyed by career government and university faculty employees. Instead middle managers and line staff focus on short-term job performance that may be tracked and evaluated on annual, quarterly and even monthly basis. Employees in sales and marketing operate under the shortest timeframe and their performance is highly quantifiable for comparison to their own performance and/or peers for current or prior operating periods. The competitive environment is highly dynamic which adds instability to programs, increases employee turnover, and adds uncertainly to management's inherently risky decisions. Corporate managers typically rise through the organisation's hierarchy based on their demonstrated performance at each successive level of management. While they may enter the workforce with scientific, technical or managerial training at the bachelors or master level, it is the on-the-job

> training within the corporation's context that hones their expertise. Their success is evidence by their organisation's survival and growth. Corporate managers view issues as opportunities carrying an investment cost of time, effort and resources, so their decision-criteria is a cost/benefit calculation of the potential return on the investment.

These three summaries show that the government and academic actors share long-term planning timeframes, permanent employment, and incentives that combine administrative, longevity and performance criteria. In contrast, the industry actors and organisations necessarily focus on the short-term and bottom-line performance criteria. Corporate managers must focus on short-term performance goals because quarterly and annual revenue determines the fate of their employees and the corporate entity itself. In contrast, the actors employed in the government and academic sectors face no short-term financial risks. The operating revenues that fund their positions come from public taxation and private fees, so their planning horizons can comfortably span multiple budget cycles out into future years.

The triple helix paradigm does a disservice to the technological innovation process, by holding all three sectors as operationally equivalent. A more pragmatic perspective would recognise the industrial sector's precarious position in the overall economy, especially when compared to the career and budgetary stability enjoyed by the academic and government sectors. That perspective would orient the STI policy focus and resource distribution towards the actors and organisations within the industrial sector. Instead, a decidedly self-serving consensus among scholars – many of whom function as trusted advisors to government agencies – entrenched an academic orientation within national STI policies. This has resulted in a financial windfall for related academic fields and to the government agencies sponsoring such scholarship, at the expense of the industrial sector. But if the business of innovation is business, how did the academic sector end up in charge?

8 National innovation systems – entrenching the bias in STI policy

The industrial sector's profits underwrite all triple helix processes and the industry sector assumes all financial risks for the commercial deployment of outputs. Yet there is little evidence of industry participation – let alone leadership in agenda setting and resource allocation. Instead STI policies and practices are established by public sector elected officials, with support from career government staff and in consultation with academic advisors (Edler and James, 2012).

Due to the skewed perceptions articulated within the triple helix paradigm, the academic sector is described as performing an increasingly critical and central role within the innovation process. The academic sector is being promoted as first among equals (Etzkowitz, 2008). That position is simply a restatement of the bedrock on which the linear model of innovation remains anchored.

Although it is now widely discredited in practice as overly simplistic and unsubstantiated, the linear model of innovation is remarkably persistent in STI policies (Atkinson and Ezell, 2013). This simple cause and effect relationship – fund science to generate innovations – has proven persistent and irresistible because it served the interests of both the academic and government sectors. Research universities and related government agencies grew dramatically through the allocation of public funds to support innovation-related activities. Elected officials could channel public funds to universities in their home districts while proclaiming them to be selfless investments in society's future welfare. Understandably, both government and academic sectors remain content with their largesse and aggressively defend their position against all critics who dare challenge STI policies by demanding evidence of deliberate and sustained results.

While STI policies promote the promise of economic growth and societal well being, there are not yet any widely accepted metrics established by government funding agencies or public university recipients to track the actual benefits from sponsored projects. The existing metrics are generally limited to measuring disbursements by the government agencies and accrued by recipients (project inputs); the expenditure made within the local and regional economies (project processes); and the publications, presentations and generated within the close group of peer scholars (project outputs).

For example, a journal issue promoting the value of science to society has a two-page graphic focusing on Switzerland's 'Measures of Success' [Williams, (2014), p.16–17]. The measures consist of the following three metrics:

- *Funding* – defined here as a nation's expenditure on R&D as a percentage of its gross domestic product (GDP). This is a measure of financial input with no causal linkage to outcomes or socio-economic impacts. The conflation of expenditures on scientific research (R) versus expenditures on engineering development (D), to the exclusion of expenditures on industrial production (P), was analysed previously in this journal (Godin and Lane, 2012).
- *Impact* – defined here as influence on the network of peer scholars, measured by the average citation counts – the number of times a Swiss author is cited internationally. While there is also mention of the total volume of scientific papers published, and the number of Swiss Nobel Prize recipients, this measure contains no mention of impact on society in general.
- *Innovation* – defined here as the number of patents and specifically the number of triadic patents, simultaneously held in the USA, the European Union and Japan, presented as a ratio of number per million inhabitants. The Swiss should be commended for their per capita inventiveness, but as noted earlier invention is not synonymous with innovation. Characterising approved patents as a measure of 'real world impact' simply reinforces the fact that the government and academic sectors miss the point that all of this input, process and output yields no new net wealth unless and until it is converted into new net wealth through the sale of products and services in the competitive marketplace. It seems to be more a case of ignoring the point than missing the point. There is little evidence that the government and academic sectors are committed to measure the adoption and application of the project outputs in practice (expected outcomes in the form of products/services), or to demonstrating evidence of beneficial socio-economic results in the context of the targeted problem (intended impacts on quality of life) (Stone and Lane, 2012). And why should they? They internally accrue all the benefits from the current system, so further scrutiny could challenge this status quo.

These circumstances surrounding STI policies, programs and practices would not be an issue to raise and discuss if they were all working well. If the dominant paradigms underlying STI policies (i.e., linear model and triple helix system) were generating the promised returns on public funding investments across all topic areas, there would be no reason to explore them further. Instead, society would be reaping the beneficial impacts of the innovative products and services resulting from 60 years of sustained investment. But that is not the case.

To be clear, some STI areas are working quite well because the mission and system are properly aligned. The US Government applies the procurement contract system in partnership with the industrial sector to successfully generate the world's most advanced military weapons, with other nation's competing within some weapons systems using the same system. Similarly, the USA has applied the exploratory grant system in partnership with the academic sector to establish the world's most prolific cadre of scientific researchers, supported by an infrastructure that attracts graduate and post-doctoral students from around the globe.

The issue addressed in this paper is when governments respond to a market failure of national importance by choosing to implement an alternative innovation system that is not aligned to the required solutions. This issue of misalignment has existed ever since Dr. Bush's thesis was coopted by scholars in the 1940s. Since then, the academic sector has made expansive claims about its ability to address socio-economic problems through the trickle-down effect assumed to be operating within the linear model of innovation. However, the results belie these claims. Despite 50 years of continued government investment in university-based scientific research through the exploratory grant system, the societal benefits promised in aspirational terms (e.g., *these findings may someday lead to, this discovery promises to eventually result in*), are still only supported through anecdotal accounts which themselves are prone to bias (Godin and Lane, 2012).

Current STI policies rely on the linear model of innovation in its current conception as the triple helix within a national innovation system. This house of cards – built from anecdotes and truisms – is not delivering solutions in adequate form or number. The exploratory grant system has not demonstrated evidence of deliberate and systematic innovation in articulated areas of national need, and instead offers metrics based on inputs (money expended), process (project activity) or outputs (bibliometrics). This circumstance holds true across nations and across fields of application where governments support public/private partnerships with academic institutions in the lead. Areas of national need requiring tangible solutions have been left without satisfactory solutions in the form of beneficial socio-economic impacts.

The following example is drawn from the field of assistive technology (AT) devices and services for persons with disabilities and the elderly. The example explains why the STI system has failed to produce outcomes with the promised beneficial socio-economic impacts and what could be done to immediately improve circumstances in this and related fields requiring beneficial socio-economic impacts from technological innovations.

9 Innovation in the field of AT devices and services

The field of AT offers examples and lessons to improve the foundational constructs of STI policies and practices. The AT field works as a case study in STI for three reasons. First, as a small market it is easy to identify the organisations, actors, actions and resources that influence the state of technological innovation. Second, as a defined field targeting a specific population segment one can readily identify all of the stakeholders with a role in generating, supporting and improving these devices and services, while tracing their respective contributions or lack thereof. Third, as a relatively new field of technology application one can see the relative contributions or constraints arising from the various economic sectors involved.

The US Technology Related Assistance Act of 1988 (US Congress, 1988) first defined AT devices as:

> "any item, piece of equipment, or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities."

Note that the definition includes but is not restricted to durable medical devices, as many non-medical devices are needed to support the instrumental activities of daily living, and to engage in education, employment, recreation and community living. Nor is the definition limited to devices dedicated to the needs of people with disabilities, as many mainstream products and built environments can be designed to accommodate a wide range of functional capabilities.

This paper addresses those AT devices and services that are offered within the commercial marketplace. Consumers represent a market comprised of persons with functional impairments of all ages. The aging population means that the number of people acquiring functional limitations through the aging process is increasing. At the same time, the range of non-technological family and community supports are diminishing as fewer people elect to stay within multi-generational families, and the youngest and most able bodied relocate in pursuit of professional career opportunities.

While the need for AT devices and services is increasing in an absolute sense, the AT market consists of small but numerous niches, each containing a widely distributed customer base with limited discretionary income, and who are difficult to identify due to privacy and confidentiality protections. The companies comprising AT product and service markets are mostly small businesses; only one US company (Invacare) exceeds a billion dollars in annual sales. That means that most AT companies have limited capabilities for research and development, with all of their resources dedicate to production, deployment, marketing and support activities. The traditional private market forces of supply and demand, scale and scope, are largely absent, so the field of AT devices and services clearly represents a free market failure.

As noted previously, governments intervene in market failures when they occur in areas of national interest. So over the past several decades governments in the USA, European countries and elsewhere identified AT as an area of national need. The goal was to ensure that people with disabilities of all ages could participate to the fullest extent possible in educational, vocational, recreational, community and independent living activities. The USA established the National Institute on Disability and Rehabilitative Research, through the Rehabilitation Act of 1974 (as amended). This agency has expended between \$25 million and \$50 million per year since that time, on technology-oriented programs intending to improve AT devices and services. Virtually all of that funding has been expended through exploratory grant systems and by university-based projects.

Similarly, the European Union established the Framework Programmes for Research and Technology Development in 1984, which included information and communication technologies as a category, and AT and accessibility as a sub-category with several million dollars allocated per year. The framework program were also designed as exploratory grant systems, with academics leading multi-country consortium of universities and companies. The eighth cycle of funding (2014–2020) has been renamed Horizons 2020 for its end date.

Despite the high level commitment to the field and the sustained government funding of efforts, the AT industry – the actual business of manufacturing, distributing, selling and support – products and services – remains poorly understood. The bias against industry is quite apparent through these shortcomings. Industry's obvious and indispensable role in the value chain of delivering goods and services to persons with disabilities is essentially ignored by the government and academic sectors. If one asks government employees and university faculty who the customer is for their R&D projects within the AT field, they invariably respond that the customer is persons with disabilities and their family members. It does not occur to them that the actual customer for the outputs from their R&D projects is the AT industry – those people and organisations who dedicate their professional lives to delivering devices and services – while the AT industry's customers, in turn, are persons with disabilities and their family members. When pressed to trace the path by which R&D outputs reach the marketplace, and to explain their role in delivering devices and services to their perceived 'customers' – the same government and university personnel refer to phrases such as 'diffusion of innovation' and 'knowledge dissemination'.

Government efforts to characterise the AT field as an industry or as a business sector have failed to adequately capture even a single industry segment let alone the entire field. The US Department of Commerce (2003) conducted a study with three major flaws:

1 it implemented a self-report survey study without clearly defining the inclusion/exclusion criteria (e.g., durable medical equipment vs. daily living aids, implantable devices vs. computer interfaces)

2 it did not compile an exhaustive list of companies as the survey sample

3 inadequate initial survey response rates (>15%) led to the addition of convenience sample of companies only tangentially related to the AT industry.

There was no further effort to compile an AT industry profile from secondary data sources such as standard industrial classification (SIC) codes, so the effort ended with a small and non-representative sample of responding companies without benefit of standard classification or extrapolated information. The agenda for the report then became politicised. Rather than a profile of the AT industry, it became a platform through which government laboratories could say they had identified new technology-based opportunities for collaborating with a needy and worthy sector of domestic industry. The author characterises this agenda as political because there were no further government efforts to implement the findings.

The European Union has commissioned multiple studies but they too have failed to encompass and delimit the AT industry. They either fail to explicitly define the inclusion/exclusion criteria, or intentionally profile only a subset of the AT industry, such as those focusing on the segment called information and communication technologies (European Commission, 1999, 2009; European Union, 2011). To the author's knowledge, only one study ever attempted to capture the full scope of the AT industry in Europe, in terms of both products and services. That was the Horizontal European Activities in

Rehabilitation Technology – otherwise known as the HEART study, which engaged 21 collaborators from 12 European countries in an effort to capture the entire field (Fagerberg et al., 1995). The lead author recently provided a retrospective analysis about what did and did not transpire in the intervening decades, with many of the prior recommendations still awaiting implementation (Fagerberg, 2011).

One US market research company attempted to characterise the global AT business sector in terms of both enabling technologies and market segments (BCC Research, 2011). The report defined AT devices and differentiated them from related products. It then examined specific types of AT devices within four broad categories: sensory impairment, movement and mobility, classroom/instruction, workplace adaptations. It summaries a range of factors impacting future business growth, conducts a patent assessment, and provides profiles for 30 of the world's largest AT companies. Unfortunately, the values of the report's market projections are limited by their dependence on global estimates of disability or impairment, rather than the specific functional requirements of individual users. Like all other prior reports, it lacks sufficient clarity and data to provide operational-level information to stakeholders in the AT field.

If governments shifted to a procurement contract system led by industry, the AT field would be carefully defined once and for all. The first order of business would to be set inclusion and exclusion criteria for delineating the scale and scope, and then articulate the value chain involved from sources of materials and components, through manufacturing and distribution, and out to assessment, delivery and support of the end customers. With such an exhaustive profile in hand, the leaders could provide government with the information necessary to identify targets of intervention (technology, training, finances), as the basis for planning, implementing and managing a program capable of improving the quality of life for persons with disabilities.

10 STI policy bias fails to deliver results

All told, multiple nations have channelled hundreds of millions of dollars into university coffers for the expressed purpose of generating new or improved AT products and services to improve the quality of life for persons with disabilities and older persons. So what happened as a result? Despite the continuous investment of public resources in the field of AT, there is *little evidence* that the government sponsored R&D activity occurring in universities has directly improved existing AT devices, or caused the introduction of new AT devices. Many of the projects sponsored with millions of dollars over multiple years cannot even demonstrate evidence of reaching the prototype stage, let alone resulting in transfers to the commercial marketplace (Lane, 2008).

According to this paper's thesis, the lack of success in delivering the intended results is due to STI policies and government biases that consistently but erroneously chose to apply the exploratory grant system, even though the historical evidence demonstrates that the procurement contract system was more properly aligned with the goal of delivering new or improved products and services in the marketplace.

In the case of AT devices and services, national governments could have applied the procurement contract system to provide the necessary R&D resources companies operating in the AT field, who were properly positioned, committed and incentivised to build, test, deliver and support AT devices and services with optimal benefit to persons with disabilities. As in the cases of military hardware aerospace components and medical interventions, the AT companies could have then provided the devices and services to persons with disabilities through a program where the government's would reimburse all or part of the costs. Such an instrumental-level intervention system would serve the needs of the target populations and bolster the economic health of the companies. As a result, the AT companies would have sufficient resources to pursue synergistic collaborations with university and government laboratories under the framework of oriented research and development, much as was done by AT&T and all other healthy technology-based companies since that time.

Instead, governments applied the exploratory grant system to expend the resources allocated to AT needs through university-based faculty who typically initiate studies in their own areas of interest, independent of specific industry or market requirements. The discontinuity between means and ends is quite obvious while the disparity in intended and actual results are predictable, calling into question the motives of the policymakers and their advisors.

The authorising legislation intended public funding to generate new or improved AT products and services, while the exploratory grant system is designed to generate scholarly papers and conference presentations suitable for tenure-track faculty. This divergence from the intended goal is because the exploratory grant system's competition for funding involves proposal criteria for scientific research and review panels comprised of peer academics. Companies are not well prepared to compete head-to-head on scientific research criteria, nor are the other relevant stakeholders included as peer reviewers. Scientific rigor is paramount while market relevance is ignored. So, by default, the winning university faculty members apply their training in scientific research methods and respond to their scholarly incentives systems. With the best of intentions, these academic investigators are simply not trained and dedicated to the application of best practices in new product development.

Consequently, few sponsored projects get around to addressing the downstream engineering development, let alone engaging external stakeholders for transfer and commercialisation. A small percentage of projects do manage to generate an early stage prototypes, some performance standards and clinical guidelines, or laboratory instruments and tools, but there is little linkage between those project outputs and the requirements of companies operating in the AT marketplace (Lane, 2008). An increasing number of sponsored projects are generating downloadable software applications – or 'Apps' – where there are no barriers to submission. By placing an application within a digital storage and distribution platform for mobile devices (e.g., Apple's App Store), investigators can claim market deployment while bypassing the stakeholders who screen transfer opportunities for quality and value. This orientation towards 'apps' is the latest approach to gaming the evaluation systems geared towards assessing transfer, deployment and commercialisation of sponsored R&D projects.

Exploratory grant outputs do occasionally demonstrate relevance to the AT field through serendipity, because university-based projects typically lack the foresight or interest to reserve public funding to underwrite the transfer of the technology from laboratory to company, while the companies typically lack the funds or enthusiasm to negotiate a transfer of prototypes from external sources. Government agencies and their academic grantees often argue that beneficial impacts do eventually occur, but often after extended timeframes and through unanticipated mechanisms. These arguments simply reinforce the rationale for applying the procurement contract system in instances of market failure with national importance, because this system focuses on short-term results delivered through pre-arranged mechanisms. Even if one charitably accepts this reasoning, it bears no resemblance to the focused effort and results delivered by the procurement contract system within national initiatives such as World War II in the 1940s or the Moon landing in the 1960s. Why would anyone accept that persons with disabilities deserve any less?

Throughout the same 30 to 40 year timeframe of government largess to the academic community, the small private companies operating within the AT field continued their struggle to fund their own internal R&D activity from the slim profit margins available through the third-party AT reimbursement system. By their own admission, these AT companies cannot afford to pay for any scientific research beyond that required to meet health and safety requirements, and their engineering development is focused on manufacturing their AT devices and services for less cost so they can afford to stay in business. If the public funding had been allocated directly to companies in the AT industry, they could have targeted specific improvements or advances in their existing product lines, which would have resulted in advanced AT being deployed in the marketplace. It is also likely that industry would have allocated some of that funding to university-based faculty; because they recognise that their success – and their very survival as corporate entities – relies upon accessing the most cost-effective approaches to progress. Expending funds on contracts with university faculty members and graduate students possessing relevant technical or clinical expertise is simply routine and proper business practice.

The face validity of applying the procurement contract system for the field of AT, is supported by the fact that virtually existing AT devices and services are made, offered and supported by private sector corporations. Many represent continuous product improvement or incremental advances in mobility, sensory and manipulation devices, while others were clearly innovative leaps in both technology and functionality. Corporate contributions to the field of AT encompass everything from start-up inventor/entrepreneurs, through dedicated AT companies, and on out to international mainstream companies (http://www.kurzweiltech.com/kcp.html).

An excellent example of an inventor/entrepreneur – suggested by one anonymous reviewer – is the Kurzweil Reading Machine. Mr. Ray Kurzweil graduated from the Massachusetts Institute of Technology, as did many gifted employees of AT&T's Bell Laboratory. He was serial entrepreneur who started his first company while a college sophomore that he later sold for hundreds of thousands of dollars and a royalty stream. Upon graduation, Mr. Kurzweil committed his genius to the private sector by founding Kurzweil Computer Products Inc. (National Inventors Hall of Fame, 2014). The company invented the optical character recognition (OCR) systems, and then wrote computer software code supporting pattern recognition, which enabled the OCR system to recognise any type font. Mr. Kurzweil then combined the OCR and software components with the charge coupled device (CCD) flatbed scanning mechanism – also invented by him – to capture any printed text in an electronic format.

A serendipitous encounter with a person who is blind, led Kurzweil to apply this cluster of inventions to the design of a mechanism to convert text-to-speech through a synthetic voice (Lemmetty, 1999). Reaching the state of a proof-of-concept prototype required a period of intensive collaboration with established corporations including none other than Bell Labs; the R&D component of AT&T (Sproat, 1997). The commercial version of the Kurzweil Reading Machine was unveiled in 1976, as the first device to automatically transform text into speech. It had 64K memory and cost $30,000 to $60,000 each. Mr. Kurzweil's sold the company to Xerox in 1980. A series of mergers and acquisitions resulted in Nuance Communications in 2008, which reportedly supports elements of Apple Inc.'s interactive voice system known as SIRI.

The same pattern of iterative cross-sector interactions holds for mainstream and multi-national corporations that have contributed products and services beneficial to persons with disabilities. A Stanford University student project summarised a historical review of landmark accessible technologies, many of which were launched by leaders in the field of information technology and communications, such as AT&T, IBM, Microsoft and NCR corporations (Hernandez et al., 2005). Many of these contributions were collateral benefits resulting from advances in mainstream system functionality. The limitations of niche markets constituting market failures can create insurmountable challenges even for well-established companies. For example, in 2003, the Johnson & Johnson subsidiary Independence Technology launched the $25,000 standing and stair-climbing wheelchair (iBOT Mobility System) to great fanfare. But a series of marketing decisions (i.e., to by-pass clinicians and sell directly to consumers), and reimbursement limitations (i.e., functional gains not deemed medically necessary), led to halting sales in 2009, and terminating product support in 2013 (Watanabe, 2009).

11 The cost of perpetuating failed STI policies

There are excellent and oft-cited examples where an individual academic is well versed in both the enabling technology and the requirements of the niche market, and where the market timing allows them to make critical contributions as the mainstream market evolves. Vanderheiden (2013) at the University of Wisconsin, Madison is one such person. His sustained efforts ensured that every Microsoft and Apple product now contains key accessibility features and usability interface options for persons with sensory, physical or cognitive impairments. Similar contributions to the AT fields of seating, mobility, hearing, vision and speech technologies are real but less well documented. These lack proper attribution for many reasons including proprietary information, project management transitions, corporate mergers, and the anonymity with which corporate personnel conduct their product-oriented work.

These laudatory exceptions only serve to illustrate magnitude of failure in STI policies. Hundreds of millions in public money invested by government staff, and expended by university scholars over decades of project activity, all for the purpose generating technological innovations in the field of AT, have only demonstrated episodic and marginal evidence of appreciable impacts on the intended beneficiary populations of persons with disabilities and the elderly. The exploratory grant system is not designed to deliver product and service outcomes, so that except for the rare examples noted above, it cannot fulfil the intended mission even under the most favourable conditions. The harsh reality of myriad constraints on niche markets drastically reduces the probability of success through the exploratory grant system.

One can readily imagine a very different legacy from this commitment of funds had governments instead applied the procurement contract system. The AT market constraints would have been resolved through the allocation of public funding at both the supply side and the demand side of the marketplace. Companies working in the AT field would have had sufficient resources to design, test and deploy devices meeting established performance standards, and clinicians would have received adequate reimbursement to deliver services that thoroughly document the functional utility of such devices for all activity domains. People who need AT devices and services would receive them upon request with no concern about medical justification or cost to the individual or family. AT devices and services would be as ubiquitous as public schools and people with disabilities would be enjoying the highest quality of life.

Applying the procurement contract system to the programs addressing the AT field would have also introduced sophisticated scrutiny of both rigor and relevance for the engineering development and industrial production elements of the proposed plan of action. This would have resulted from expanding the peer review process beyond scholars to include experts in product development, business planning and industry requirements. These non-scholars would invoke an entirely different set of criteria beyond the rigor of the research design. They would assess the validity of the functional problem being addressed, the technical feasibility of implementing the solution proposed, the business plan for transferring the project's output, the regulatory and reimbursement environment for the envisioned solution, and AT product or service outcome in the context of existing solutions or alternative strategies. Issues such as purchase intent, price point, time to market, product position and value proposition would be central to the decision regarding proposal funding. These new criteria would at first result in wholesale rejection of submitted proposals, but over time the applicants would learn to involve the appropriate expertise prior to submitting a proposal, and AT corporations they might feel more qualified to compete for the available funding.

So why are STI policies that fail to deliver the intended benefits perpetuated? One must acknowledge the collateral beneficial impacts from these exploratory grant programs in the field of AT. The public government sector directly benefits. The government agencies assigned to administer the exploratory grant programs expanded or at least sustained their own funding levels over decades, which in turn enlarged the bureaucracy within their host government institutions. This result alone exceeds the benefits generated for many struggling AT companies, community-based programs and the people with disabilities they serve.

The academic sector also directly benefits. Hundreds of university faculty and graduate students established and advanced their professional careers by using government grant funds to conduct scientific research studies and publish their results within the scholarly journal system. The government compensated their host institution for the time they devoted to the sponsored activities (salary, fringe benefits and overhead costs), purchased supplies and instrumentation, and paid for travel to professional conferences, organisational meetings, and other networking activities critical to establishing a reputation within the peer-review tenure and promotion system. As noted previously, the scholar's host institution benefitted from monetary compensation for overhead (facilities and administration) expenses amounting to a relatively large percentage of the actual government grant.

On a practical level one can see that these collateral benefits to the government and academic sectors are the actual reasons why the exploratory grant system is perpetuated as a favoured approach to market failures required technological interventions. The bias in STI policy persists despite the absence of evidence regarding its merit and worth. The relevant programs share a trait; a cadre of decision-makers who lack any sense of urgency regarding the solution of problems deemed to hold national interest. If an STI policymaker discovered their house is ablaze would they be more likely to summon the fire department or commission a study on firefighting? Instances of market failure problems representing national needs should be addressed with similar urgency, but they are not.

Government officials and scholars often defend the lack of success within the AT field by explaining that the field is complex, underfunded, highly regulated and involves many disparate stakeholder groups. But is it better to generate explanations for failure in an on-going process or is it better to seek a new process with a historical record of success? All the complexities of the AT field are present in other market failure fields prior to implementing the procurement contract system. The attributes and expertise residence within the private industrial sector are all the arguments necessary to rebut the excuses for the shortcomings of the exploratory grant process, yet the deeply ingrained bias prevents the defenders from perceiving this simple logic.

Not only does the bias persist with support from government and academic sectors, but it continues to be copied in other nations. Two new government-sponsored initiatives emerging to address AT devices in other countries are: Australia's National Disability Insurance System and Brazil's National Research on AT initiative. These new initiatives appear to be emulating the same mistake repeated over decades of funding in the US and in the EU programs. More specifically, they even justify their new program's focus through the same two steps: First, they have their government and academic advisors establish 'technological innovation' as a high priority goal. Second, they apply the exploratory grant system as the mechanism to deliver these innovations. Nowhere do they present evidence that additional innovations are a high priority need identified by the AT industry, AT service providers, or by the consumers and family members who are supposed to benefit from the investment of public funds. If asked, these stakeholders would set the priority as informed access to the entire range of existing AT devices and services, full reimbursement for assessment, acquisition and training, along with a system of follow-along support as consumers implement their AT devices in education, employment, recreation and community living settings.

But such practical solutions are considered mundane by the government agencies seeking access to funding, and leave no leadership role for the academics. The field of AT loses the benefit from the funding because it is not allocated to support the needs of people with disabilities and the AT industry attempting to support them, and even if technological innovations were to become a legitimate priority, the exploratory grant system is designed to support – not lead – the design, testing, delivery and support of innovations in AT devices and services.

It should be no surprise that the same two sectors of government and academia in these other nations will reach the same conclusions, based on the same biases, and will advocate for applying the exploratory grant system to disburse the available funds. If they do, the results will follow the same predictable course of windfall funding to academics that will build their professional careers on the government-sponsored scientific research, while the AT companies and the intended beneficiaries will be left with little benefit from all the money and time expended. The biased STI policies ensure a lose/lose outcome for the intended beneficiaries. As it is in the USA and in the European Union, so it will be in other countries that erroneously implement the STI bias in their innovation programs.

12 A necessary transition in national innovation systems

The de facto approach for delivering innovative devices and service solutions to targeted populations is through for-profit corporations operating within a competitive market environment. However, many of society's needs – such as the need for AT devices and services – do not meet the requirements to sustain a competitive market approach. These needs constitute instances of market failure, where extant commercial forces are constrained. Governments may choose to intervene through STI policies but they should explicitly recognise the implications of choosing to invoke either of two alternative systems: exploratory grants or procurement contracts.

In instances where the market failure requires the generation, deployment, delivery support of devices and services – such as the field of AT – policy makers and political representatives should learn from historical evidence that successful STI-based government interventions apply the contract procurement system led by industry, rather than the exploratory grant system led by academia. Under a procurement contract system operating in direct partnership with the industrial sector, the government would set the performance specifications for all types of AT, companies would bid to fulfil those performance requirements, and the government would buy and distribute the AT to all who need it. This approach would channel public money toward the market-oriented efforts of the AT industry – supported by expertise from academia and resources from government – to define and design the optimal AT products and services.

Once devices and services meet the design and performance specifications established by stakeholders in the field of AT, the government would contract with those same AT corporations to manufacture, deploy and support the resulting AT devices and services. Government would purchase and distribute these devices and related services within the domestic market. The government would also fund the certified AT professionals to ensure that AT recipients receive the right devices, learn to use them and have a source of follow-along support. These changes would transform a fractured and inadequate system into a healthy socio-economic network. At the same time, having access to free AT products and services would eliminate the entire third-party review and payment system, along with the associated medical and legal fees determining eligibility, all of which is funding that could be reallocated to the direct delivery and support of AT products and services.

In a growth curve analogous to the historical patterns for corporations in the military and medical fields, the increasingly solvent and expanding AT companies would be free to market and sell these optimally functioning AT devices and evidence-based AT services on a global scale. The sales of new or improved AT products globally would generate profit for each AT company to reinvest in R&D, would create a trade surplus within that nation's AT field, and would generate new net wealth which the government could tax to recoup some of its original investment. Compare that to the current exploratory grant system requiring a continuous and ever growing level of public funding, with no discernable return on the investment in terms of industrial growth and new net wealth.

The benefits described here for the AT field would also accrue to any other field that current applies the exploratory grant system to address socio-economic issues. The first nation to transition its STI policies and national innovation programs from the academia-driven exploratory grant system, to the industry-driven procurement contract system will capture the global markets in any technology-based fields targeted for this reconversion. Initiating this transition within the field of AT would be a low cost and no risk strategy to test the relative effectiveness of this approach for addressing national needs requiring the delivery of technology-based outcomes with beneficial socio-economic impacts. The documented failure of the current system to demonstrate results makes the alternative approach an attractive option by default. Implementing a procurement contract system for AT products and services can hardly have less benefit than the current approach, and could be implemented within the funding levels already allocated to addressing the needs of persons with disabilities and the elderly. STI policymakers need to recognise the value of the procurement contract system, but that requires overcoming resistance from those government and university sectors benefitting from the failed exploratory grant system.

In the case of AT, elected officials could quickly form a committee led by industry to identify, chart and quantify all expenditures of public funds presently allocated to scientific research and engineering development activities, through the exploratory grant system. The cost assessment would also include all national and regional costs associated with the current AT device and service support system, including regulatory compliance across economic sectors, payment and reimbursement direct and administrative costs, legal request, appeals and adjudication formalities, clinical, education and vocation oriented assessment and training services. This calculation would encompass both the funds allocated through government agencies and non-profit organisations, and the funds expended to operate the AT-related aspects of these government agencies and non-profit organisations. A true cost assessment would even include the personal expenditures made by individuals with disabilities and their family members to acquire AT devices and services.

The sum total of all AT-related expenses would represent the public and private costs of the current system. Unfortunately, it could not include the opportunity cost associated with the lack of AT device and service provision to untold numbers of people who cannot find access or acquire the existing AT devices and services, or who acquire sub-optimal devices and services due to inadequate expert assistance.

The same committee could then design a replacement system modelled on the procurement contract system. The replacement system would factor in the current capacities and capabilities of AT companies, identify potential synergies through partnerships with defence contractors, government laboratories, and existing university-based programs for any necessary research and development activity. However, the primary emphasis would be in ensuring that all AT device and services meet the minimum performance requirements, and that all people in need would receive the appropriate expert support in assessment, training and support. Some initial funding for a pilot program could identify a specific AT topic area, which could either represent a mature industry (wheeled mobility, prosthetics) or an emerging industry (cognitive impairments; brain interfaces). Perhaps the pilot program could include examples from each. The pilot program would then implement the codified process so successful in advancing each new generation of military technology. A three to five year period should be sufficient to span the product development and deployment cycle, with an additional three to five years to comparatively measure beneficial socio-economic impacts. So, after ten years the sponsoring nation could assess the beneficial socio-economic impacts generated for persons with disabilities and for their society as a whole. The evidence would accrue just as the mid-20th century cohort – the baby boom generation – reaches full retirement age. This will be a critical time for AT devices and services to maintain function, and for a broader range of technology-based innovations to create new net wealth in the absence of this highly skilled workforce.

China is the first nation to explicitly express intent to transition its national innovation system across all fields of application. The Chinese Academy of Science acknowledged the reality of global economic competition by re-orienting its 2050 roadmap to be business oriented and market driven (Yonxiang, 2011). These emerging policies will likely lead to a broad shift in budgetary allocations within innovation-oriented programs from exploratory grants led by academia to procurement contracts led by industry. Corporations in industry will then have more control over the funding of scientific research and engineering development intended to support technological innovation. This transition should not affect funding for basic scientific research because that must always continue to advance the state of knowledge across all disciplines, and train the next cadre of scientists and engineers.

It is difficult to determine where a transition in AT innovation systems will occur. The USA and European Union countries have the advantage of advanced technological infrastructures for AT, so the benefits from such a transition could be realised more quickly in these countries. But the persistent bias against corporate leadership could delay such a transition indefinitely. Or countries currently lacking comprehensive AT systems could take the lead. Just as cellular telephone technology proliferated faster in countries where land-line infrastructure did not create barriers to change, countries such as Brazil or Australia could lead the transition in STI policy in the field of AT products and services. These nations could be the first to demonstrate legitimate evidence of beneficial socio-economic impacts, by measurably improving the quality of life for persons with disabilities and the elderly. Whoever leads this transition can serve as an example for other areas of market failure deemed to be of national importance for STI policy and practice intervention.

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