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Author(s): Andrew B. Hargadon and Martin Kenney
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Misguided Policy?

Following Venture Capital into Clean Technology

Andrew B. Hargadon
Martin Kenney

In a search for Schumpeterian solutions, the Obama Administration has made venture capital a cornerstone of its Clean Technology policy, adopting a strategy of providing large loan guarantees to a few venture capital-financed firms. This article argues that three key conditions are necessary for venture capital to successfully open new economic spaces and then it applies them to assess the viability of venture capital investment in clean technology. The article concludes that large loan guarantees are unlikely to be effective. Other government policies such as SBIR grants, university R&D support, certain (de)regulatory actions, large-scale demonstration projects, and/or procurement decisions can better encourage both incremental and Schumpeterian innovation without distorting the turbulent dynamics of new market creation. This analysis can also be applied to other sector- and market-specific innovation policies. (Keywords: Venture capital, Innovation, Policy making, Clean technology)

Rising concerns over climate change, energy pricing, and geopolitical conflict recently have led policy makers to guarantee billions of dollars of private investment in the commercialization of clean technology innovations. The current administration embraces the perspective that the commercialization of clean technology innovation is a critical policy lever in addressing these issues. As President Obama stated, "In no area will innovation be more important than in the development of new technologies to produce, use, and save energy—which is why my administration has made an unprecedented commitment to developing a 21st century clean energy economy." The question is how to best pursue this goal. One of the recent policy tools to advance clean tech involves providing massive loan guarantees to venture capital-backed firms. However, the phenomenon of venture capital investing in clean technology is recent, has little

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outcome data, and what data exists is mixed. Moreover, the boundary conditions delimiting effective venture capital investing remain relatively underdeveloped. This article explicates these boundary conditions and then considers the viability of venture capital in leading a clean technology revolution.

Andrew Hargadon is the Soderquist Chair in Entrepreneurship at the Graduate School of Management at the University of California, Davis and Director of the Child Institute for Innovation and Entrepreneurship.

Martin Kenney is a Professor in Human and Community Development at the University of California, Davis and a Senior Project Director at the Berkeley Roundtable on the International Economy.

The current global energy system resists change as it is the outcome of a technological trajectory that is now more than a century old, thoroughly integrated into our everyday lives, and literally at the core of all political economies. As a result, government actions at all levels are omnipresent within nearly every energy system.[1] With the accretion of decades of political, social, and economic decisions, today many, if not most, of the subsidies to the existing system are indirect, hidden, and, indeed, appear as part of a "natural order." The failure of the UN climate summit in Copenhagen in late-2009 demonstrated the challenge of mitigating a climate crisis through committed and coordinated national policies. Achieving similar targets through unilateral federal policy, whether regulations (e.g., more stringent emissions requirements), taxes (e.g., a tax on carbon), or subsidies (e.g., rebates to solar or electric vehicle customers) played out in the zero-sum arena of federal expenditures is an equally daunting goal. Richard Lester calculates meeting targets for change would require annual expenditures of $250-500 billion, and entail adding roughly 120 gigawatts every year of new low-carbon energy supply.[2] In 2008, by comparison, U.S. developers installed 8.5 gigawatts of wind and 0.338 gigawatts of solar. Moreover, the greatest historical increase in installed energy supply occurred in 2001, with the addition of 67 gigawatts of new, mostly natural gas, energy capacity. For clean technology innovations, the incumbent competition occupies a terrain built by and upon these arrangements.

Such a massive and difficult goal makes the prospect of a self-financing clean technology revolution appealing, and the venture capital model has recently been promoted as a means for directing federal support for clean technology spending. In information and biomedical technologies, venture capitalists played a prominent role in identifying and funding the new ventures that created what Schumpeter termed "new economic spaces." Such new economic spaces represent the early stages of new and high-growth industries, in which such growth and large-scale transformation become a virtuous circle—attracting additional capital, entrepreneurs, and new ventures in a chain reaction of rapid innovation. For the government, the prospect of investing (relatively) small sums in "Schumpeterian ventures" that could ignite a clean technology revolution is alluring, not in small part because it would eliminate the need to make far harder political choices.

The centerpiece of the strategy that the Department of Energy developed was to select a few VC-backed ventures and extend them huge loan guarantees to build production facilities. Such loans are, to startups, the functional equivalent of equity-free investments, as they provide unsecured capital to the company without diluting the ownership of the original investors. Failure of such ventures results in their dissolution and defaults on their debts. The DOE Loan Programs Office describes its mission as "to accelerate the domestic commercial deployment of innovative and advanced clean energy technologies at a scale sufficient to contribute meaningfully to the achievement of our national clean energy objectives—including job creation; reducing dependency on foreign oil; improving our environmental legacy; and enhancing American competitiveness in the global economy of the 21st century." The decision to offer loan guarantees is, in some respects, understandable in that it does not require a direct appropriation, as it assumes that the loans will be repaid—failure (and therefore the cost) is not considered. The sheer size of the loan guarantees is remarkable. For example, electric vehicle startups Tesla and Fisker received $465 million and $539 million, respectively, to open factories, and solar panel manufacturer Solyndra received $535 million.[3] Given the size of these loan guarantees, there can only be a few bets on individual firms.[4] Moreover, nearly all of these firms are early in their lifecycle and thus extremely risky. As Table 1 indicates, in many cases the loan guarantees are as large as the amount of venture capital invested, which are themselves among the largest that venture capital funds have ever made in any firms or industries. As a result, both venture capitalists and now public policy makers have much riding on securing successful outcomes for these particular firms.[5]

The presumed effectiveness of such large loan guarantees to VC-backed firms depends on several critical assumptions. First, that venture capital has the potential to open new economic spaces in any sector in which it is invests. It is not enough that any single investment returns profits; with the backing of large public guarantees, it becomes necessary to assume that such investments have the potential to create self-sustaining industrial transformations. Yet without a clear understanding of the boundary conditions for effective venture capital investing, this assumption rests on a sweeping generalization with little supporting data. A second assumption follows the first: that public money can effectively leverage private investments to fuel a clean technology revolution that quickly grows independent of further federal support. Finally, a third assumption follows: that enormous loan guarantees to individual VC-backed firms are an effective mechanism.

This article explores the wisdom of this particular policy by considering the validity of these assumptions. Ultimately, we are not concerned with whether a venture capital fund provides positive returns to its investors; nor with whether individual venture capitalists, as professional investors, make money. We are concerned with whether venture capital, as an asset class, working through VC-backed firms, offers an effective public policy tool for advancing clean technology innovations. To this end, we consider the emergence of venture capital as a (policy) framework for advancing innovation; explicate the general boundary conditions within which venture capital investing is likely to be successful at opening new economic spaces; and evaluate the particular conditions of the clean technology sector to gauge the wisdom and efficacy of the current government policy.

TABLE 1. U.S. Venture Capital-Backed Greentech Firms Receiving Federal Subsidies*

Firm (Nationality)	Technology	Location	Date Formed	VC Invested ($M)	Public Offering Date	Capitalization at Exit (in $M)	Stock Market Capitalization 4/26/2011 (in $M)	Type of Federal Government Subsidy
Novomer	Polymers	Ithaca, NY	2004	17	No	N/A	N/A	$18.4 million stimulus funds
Abound Solar Manufacturing	Solar	Loveland, CO	2007	266	No	N/A	N/A	$400 million loan guarantee
A123	Batteries	Watertown, MA	2001	243	9/24/2009	1,325.4	644	$249 million matching grant
BrightSource	Solar	Oakland, CA	204	572	Registered	N/A	N/A	$1.6 billion loan guarantee
Codexis	Biocatalyst	Redwood City, CA	2002	129	4//2/2010	363.7	365	$4.7 million ARPA-E
Fisker Automotive	Electric Car	Irvine, CA	2007	209	No	N/A	N/A	$528 million loan guarantee
Abengoa Solar (Spain)	Solar	Spain (AZ)	N/A	N/A	Not VC	N/A	N/A	$1.45 million loan guarantee
SoloPower	Solar	San Jose, CA	2005	164	No	N/A	N/A	$197 million loan guarantee
Miasole	Solar	Santa Clara, CA	2001	79	No	N/A	N/A	$102 million loan guarantee
Silver Spring Network	Smart Grid	Redwood City, CA	2002	283	Registered	N/A	N/A	>$600 million grants
Solyndra	Solar	Fremont, CA	2005	970	Registered	N/A	N/A	$535 million loan guarantee
Tesla Motors	Electric Car	San Carlos, CA	2003	306	6/29/201	1,583	2,590	$465 million loan guarantee
INEOS Bio (UK)	Biorefinery	Vero Beach, FL	N/A	N/A	Not VC	N/A	N/A	$75 million loan guarantee
Coskata	Biorefinery	Greene County, AL	2006	101	No	N/A	N/A	$250 million loan guarantee
Enerkem (Canada)	Biorefinery	Mississippi	2000	>60	No	N/A	N/A	$50 million DoE, $80 million loan guarantee
Range Fuels	Biorefinery	Broomfield, CO	2006	163	No	N/A	N/A	$80 million loan guarantee

* Investment data compiled from Thomson VentureExpert, U.S. Department of Energy, and media. Bolded firms are loan guarantees from USDA.

Venture Capital and Innovation

The role of venture capital in fostering innovation has fascinated public policy makers since the specialized asset class first emerged in the aftermath of World War Two.[6] Venture capitalists funded firms such as Amgen, Applied Materials, Apple, Biogen, Cisco, eBay, Federal Express, Genentech, Google, Intel, Netscape, MCI, Oracle, PayPal, Skype, Southwest Airlines, Sun Microsystems, and Yahoo!. The scholarly literature typically characterizes innovations by their ability to either strengthen or disrupt current practices (e.g., evolutionary versus revolutionary, continuous versus discontinuous, and incremental versus radical). Disruptive innovations displace old economic institutions, creating new ones in their place, and entrepreneurial ventures have typically been credited with bringing such revolutionary technologies to market. Joseph Schumpeter observed, for example, that such revolutionary innovations are "as a rule, embodied, . . . in new firms which generally do not arise out of the old ones but start producing beside them."[7] Such new firms succeeded where established firms could not, it's been argued, because they were able to embrace and organize around emerging technologies, unencumbered by the sunken investments, entrenched interests, and preconceived structures and biases of established industries.[8] Such new ventures create new economic spaces, and the venture capital firms that invest in and support them play a critical enabling role.

Several reasons explain venture capital's outsized effect in the Schumpeterian process. First, venture capitalists commit significant tranches of capital to firms with much potential but few assets beyond their founders' intellectual capital and business plans. This is an investment strategy that banks or other financial intermediaries are not organized to undertake. Second, venture capitalists undertake an extensive due diligence process before deciding in which firms to invest.[9] Third, because the diligence process is itself iterative, entrepreneurs continually improve their business plans and, with the venture capitalists, develop a collective vision of how the firm should evolve.[10] Finally, once the investment is made, the venture capitalist(s) become partners in the venture and commit significant time to each portfolio firm by serving on its board of directors, making introductions, helping craft overall strategy, assisting in the recruitment of members of the management team, and monitoring the growth of the firm.[11] Because seasoned venture capitalists have been involved in a number of startups, they can provide valuable advice on avoiding the myriad pitfalls a rapidly growing firm can experience. In a point to which we shall return, it should be noted that because venture capitalists depend on profitably liquidating their investment within a time frame driven by their own fund's lifecycle, the interests of venture capitalists and founders are not always aligned.

Of particular interest to policy makers is how venture capital can be harnessed and directed toward public goals of solving persistent social ills—such as revolutionizing particular industries, bolstering national competitiveness, driving local economic development, and creating new jobs. In the last twenty years, policy makers have increasingly considered venture capital firms as allies in achieving public policy goals including regional economic development and, most recently, global climate change. Venture capital offers a convenient means for identifying and supporting early stage economic activity that rapidly commercializes new technologies, a skill which public policy makers often do not have. Public policy most easily invests in the pursuit of incremental innovations, where political support from established interests resides. Public investment in revolutionary technologies, on the other hand, threatens established interests yet represents nascent interests that are too early and ill-formed to have a countervailing influence. This presents the challenge of establishing policies that support tomorrow's interests at the expense of today's.

Because venture capitalists can, and indeed even seek to, invest in revolutionary new ventures, it is hoped they will perform a critical function—alongside entrepreneurs—in Schumpeterian creative destruction in and around clean technology.[12] Past success is not, however, an accurate predictor of future success. Venture capital's role in fostering innovation in industries such as semiconductors, information technology, and biotechnology may not accurately predict its success in other markets where we desire similar revolutions.[13] Not all revolutionary technologies have been advanced by Schumpeterian ventures, and not all successful Schumpeterian ventures were backed by venture capital. For these reasons we should exercise caution and seek to better understand the boundary conditions under which venture capital does effectively contribute to the opening of new economic spaces.

Boundary Conditions for Successful Venture Capital-led Transformation

The particular boundary conditions of markets, in addition to differences among individual ventures, determine the success of VC-backed ventures. In other words, not all markets are susceptible to transformation by small VC-backed firms. In one study that looked at which firms developed the most important innovations of the 20th century, new firms contributed almost half of the innovations. These contributions, however, were greatest in immature industries.[14] As Joshua Lerner argues, venture capital has had "relatively little impact on those [industries] dominated by mature companies . . . [V]enture investors' mission is to capitalize on revolutionary changes in an industry, and the well-developed sectors often have a relatively low propensity for disruptive innovation."[15] Successful firms and sectors for venture capital investing can be reduced to three interdependent conditions—rapidly growing markets, scalable technologies and ventures, and large and rapid pay-offs. By extension, if these conditions are not sufficiently satisfied, then the sector is unlikely to be transformed through venture capital support. It is valuable to examine each of these separately to understand how they affect venture capital's role in differing sectors of the economy and different moments in time.

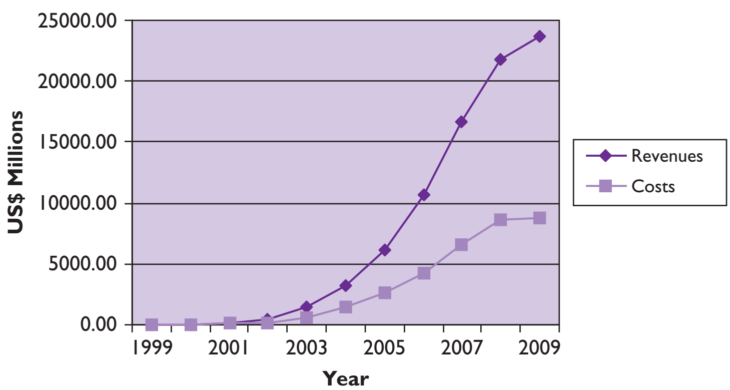
Large and Rapidly Growing Markets

While venture capital is often linked to ventures that gave rise to new markets and industries, VC-backed companies have not, in a strict sense, created those new markets. The growth of a market is typically represented as the S-curve of adoption, with a leading edge that can last for decades before a rapid rise in the arrival of new customers (the tipping point) signals the beginning of a phase of extremely rapid growth. The very first microcomputer firms, for example, were established in the mid-1970s by hobbyists and not funded by venture capitalists.[16] Venture capital funding of microcomputer firms began in January 1978, when a consortium of venture capitalists invested in Apple Computer.[17]

New ventures entering a market in or just before its rapid growth phase can grow rapidly by attracting newly arriving customers (rather than wresting existing customers from incumbent technologies and competitors). The markets for Netscape, Yahoo!, Excite, and Amazon, for example, depended on the rapid migration of new users to the technology platform that supported them: the internet. The early internet, however, had been in use for over 30 years by an initially small, but steadily growing, population of academics and hobbyists prior to the mass-market growth that began in 1993 and 1994. Figure 1, for example, illustrates this exponential growth in Google's revenues from roughly its inception in 1999 through 2003 and its public offering.[18] Its market (in terms of users, hosts, and domains) was growing extremely rapidly and Google's revenues were growing with it. Similarly, as did Facebook itself, the applications running on the social networking platform Facebook quickly emerged into a billion dollar market. Playdom, one game maker for this platform, was purchased by the Disney Corporation for $763 million[19] and another, Zynga, has been recently valued at over $5 billion. The multiplex nature and the richness of the internet as a platform provided new ventures and their venture capital investors with wave after wave of opportunities. So, as new users/consumers discovered the internet, they also discovered new uses, in what some have termed "user-led" innovation.[20] These early user-innovators transformed their use into new businesses—a classic illustration of what Schumpeter termed the opening of "New Economic Spaces."[21]

Such moments may occur in existing markets, when a technological or other discontinuity is large enough, occurs rapidly enough, or is legally protected in ways preventing incumbents' reactions. Such situations can arise for a number of reasons.

FIGURE 1. Google Revenues and Expenditures, 1999-2009



For example, the pharmaceutical and medical device industries regularly experience the introduction and rapid adoption of novel therapeutics or devices.[22] Another example is when governments deregulate an industry. For example, venture capitalists financed MCI, which began by competing against AT&T in the long-distance phone market that was being deregulated. In this case, MCI entered selected long-distance markets by purchasing lower-cost superior foreign equipment, building microwave towers, and discounting transmission costs to large-volume corporate customers. AT&T, for a litany of reasons, was unable to respond effectively and MCI experienced enormous success.[23]

Here the interdependence of these three boundary conditions can be seen. To create a period of self-sustaining transformation funded by private investments in early-stage ventures, a market must grow in ways that allow new ventures to scale, in turn justifying valuations permitting outsized returns to investors. The returns on venture capital investments depend on the market value of a new company (via IPO or acquisition) and, in new ventures, such valuations are typically multiples of revenues (rather than earnings) that reflect the anticipation of continued rapid growth. For this reason, investments have concentrated in particular industries or industry sub-segments undergoing rapid transformation or growth, or experiencing massive discontinuities.

These sectors naturally change over time. For example, from 1975 through approximately 1985, new firms such as Apple, Compaq, Commodore, Osborne, and many others developing personal computers were of great interest and attracted much venture capital funding. From 1995 onward, internet firms received an avalanche of investment, but within this larger business space different opportunities received investment including browsers, portals, e-commerce, and so forth. Some sectors are hot for a few years and then cool. In semiconductors during the 1960s and 1970s, venture capitalists were willing to invest in startups that planned to design, manufacture, and market semiconductors. After 1980, it became too expensive for a startup to build fabrication facilities so they began investing in so-called "fabless" firms that only intended to design and market semiconductors, manufacturing would be contracted out. Since the late 1990s, venture capitalists funded firms that only design particular semiconductor functions and market this as intellectual property to other firms, e.g., Rambus and Tensilica. Ultimately, the success of venture capital is predicated upon having investment opportunities with large enough potential returns to compensate for the risks.

Scalability

Rapid turnover in customers—through either new arrivals (a growing market), technological obsolescence (a churning market), or radical change in market structure (e.g., deregulation)—creates the conditions for ventures to grow rapidly. However, the ability of a new venture and its underlying production technologies to scale as fast as this market growth is also critical to enable it to outpace late-arriving competitors or slower-reacting incumbents. In other words, new ventures must be able to provision a rapidly growing market without a correspondingly growing need for capital investment; this scalability is a function of both the venture and the technical and market conditions. Software, along with internet services, can increase production of goods and services without a corresponding increase in capital assets. The online retailer Amazon.com illustrates how financial assistance can enable a company to scale with a rapidly growing market. Amazon.com's infrastructure, though at times strained, was able to scale with the growth of internet users and, as importantly, internet shoppers—leaving little room for later ventures or major retailers to enter that particular segment of the growing market. Venture capital was critical to enabling that growth. Venture capitalist Tom Alberg, whose Madrona Venture Group invested $100,000 in Amazon in 1995, explained, "The revolution in thinking was everybody saying you have a great opportunity to grow quickly here, money is available, so let's take advantage of it and use that money to grow quickly even if we lose money [initially]."[24] By contrast, in the life sciences, value derives from product definition and testing; production and marketing is far more costly, so nearly always these small firms partner with large pharmaceutical firms for production and marketing.

Unless new companies can emerge and become dominant players by scaling faster than competitors (new ventures and incumbents), there is little advantage to investing significant venture capital in them. In markets such as the information and biomedical technologies, the returns on equity are relatively decoupled from returns on assets. In other words, the value of a company (and its growth) is exponentially larger than its capital requirements to achieve that growth. For example, in 1996, venture capitalists funded a telecom equipment startup, Juniper Networks. In 1999, after receiving several more rounds of financing, the company went public and within its first day was worth $5 billion and, within nine months, $50 billion. The original investors received profits of over 10,000%. In part, this was a function of the business opportunity, but it was also a function of the dot-com bubble equity markets. At the time, this scalability and susceptibility to hype was extremely more pronounced for internet companies, where a successful venture could go from 10,000 unique visitors to millions within a few months and needed only to add additional servers at a relatively low cost. This scalability—discussed previously—is a dominant feature of the information technology sector and is also reflected in their performance on the public markets.

Scalability, like market growth, is thus a critical factor in the ability of VC-backed ventures to create new economic spaces sustaining rapid industrial transformation. By growing rapidly (and relatively cheaply) in pace with growing markets, scalable ventures can provide extremely high returns to early investors. Not all technologies (or their industries) are capable of scaling rapidly for a variety of reasons, nor do all technologies and ventures necessarily experience dramatically decreasing unit costs as they scale, making early investors dependent for growth on subsequent funding rounds (and thus less able to maintain favorable stakes in the company as it grows).

Large and Rapid Value Creation

Because of the risk associated with the new ventures in which venture capitalists invest, "winning bets" must pay at least 10 times their investments within a few years in order to earn an adequate return *and* cover losses in other portfolio firms. For example, of the firms that venture capital invested in between 1991 and 2000, 14% had an initial public offering, which typically produces significant returns on equity investments, while 33% were acquired (typically these were not for appreciable returns, though in the 1998-1999 period there were enormously profitable acquisitions as established firms felt they had to buy their way into the new internet industry and newly public firms used their overvalued stock to buy even newer startups). The remaining 53% either failed outright (18%) or remained privately held and quietly failed (35%), essentially losing the venture investment. For this reason, the 14% of VC-backed ventures that did go public provided nearly all of the returns on equity for a given venture fund (and some funds experienced returns on investments of greater than 100% per annum compounded).[25] Considering a venture fund's typical life of 10 years, such winning bets must pay off, or liquidate, within 5-7 years of the initial investment. Obviously, this payoff structure drives venture capital's initial criteria for selecting and managing new ventures: only those with the potential for rapid growth and large payoffs are attractive investment candidates.

While venture capitalists are ostensibly agnostic to the sector within which they invest, there is a path-dependence as they continue and even increase investment in sectors within which they or their competitor venture capital firms experienced success. In fields in which investment returns are too low, there is a marked tendency to decrease investment. For example, there is no longer any venture capital investment in hard disk drive, superconductors, or personal computer firms. What is necessary to initiate or continue the flow of investment is the tangible proof of an ability to earn an out-size return (i.e., there must be successful exits) or significant interest on behalf of their own limited partner investors. Gompers et al. highlighted the critical importance of stock euphorias in particular market sectors, in which frenzied investor have "irrational" interest in stock offerings by new startups.[26] In these periods, stock prices are often bid up to exorbitant levels, allowing venture capital investors to sell their equity holdings for substantial capital gains. For example, in late 2010, social networking-related internet companies experienced dizzying rises in valuation: game maker Zynga is currently worth more than $5 billion; Twitter is worth roughly $4 billion; in December 2010, Groupon declined a $6 billion offer by Google (after being valued at $1.35 billion 8 months earlier, and only having launched in 2008); and in January 2011 Goldman Sachs was arranging a private placement outside normal IPO channels for the six year-old Facebook valuing it at $50 billion. Investment euphoria increases the number of successful offerings and even weak portfolio firms can be listed or are purchased by existing firms because investors are so eager.[26] When there are successful exits, an avalanche of investments in firms having similar characteristics often ensues—as long as there are successful exits the investment continues and investment only stops when the exits wane—but as with all manias the reduction can be abrupt.

In sum, these three interdependent characteristics of markets—growth, scalability, and rapid payoffs—determine whether venture capital financing can successfully open new economic spaces by funding early-stage ventures in particular sectors and at particular moments. Absent these conditions, it is difficult for individual ventures to effectively transform markets by growing in size and valuation enough to attract more ventures, and venture financing, in ways that create a self-sustaining industrial transformation. Worse, because venture capital uses these criteria not only to identify new ventures, but also to shape their strategies, augmenting venture capital's role when these criteria are absent can be counter-productive. Driving high-growth strategies in low-growth markets; rapidly scaling when the cost of growth outpaces the resulting equity value; or attempting to exit quickly in sectors where valuations recognize low growth and low scalability may hinder the success of individual firms. In markets with these conditions, using public monies to amplify individual venture investments may equally amplify the negative effects and destroy a promising venture.

Venture Capital-Driven Transformations in Clean Technology

Innovation in clean technology poses challenges that may be fundamentally different from those VC-backed startups are best suited to overcome. In developed nations, the types of clean technology innovations being supported by federal backing of VC-backed "Schumpeterian ventures" must penetrate existing markets and displace incumbent energy systems that are characterized by three critical features. First, their scale is enormous and the fixed cost aspects of the installed capital stock make competition economically difficult for emerging ventures and technologies that must compete with the variable cost of continuing operation of existing plants. Second, the value of the existing global energy *supply* system (e.g., power plants, transmission lines, drilling rigs, pipelines, refineries, and coal mines) is estimated to be approximately $12 trillion, with a typical asset turnover time of 30-40 years. The global energy *demand* system, including cars and trucks, planes, buildings, appliances, and industrial equipment, represents an even greater amount, with turnovers ranging from 5-7 years for appliances to 80 years or more for buildings.[27] Third, regulations both structure energy markets at the municipal, state, federal, and international levels as well as subsidize incumbent technologies and institutions. This constrains the emergence not only of new technologies, but also the new business models best able to exploit them. Given these features, how well does a venture capital-driven model of innovation fit with aspirations for a clean technology revolution? To answer, we consider the aforementioned features that will condition the success of these ventures in clean technology.

Clean Technology Market Growth

The belief that there will be a rapid and widespread transformation of existing markets within developed countries attracts venture investors to clean technologies. Interestingly, since World War Two (with the exception of the biomedical fields, and outside the information technologies), such transformational growth has been the exception rather than the rule. Almost by definition, the markets most in need of low-carbon innovations depend on incumbent energy systems that are already large, embedded, and heavily regulated. Additionally, energy demand tracks economic growth. Growth in the global energy market, as in OECD economies, has stagnated during the last decade (0.14% annual growth rate). Of that growth, new wind and solar (PV) technologies contributed just 0.23% and 0.01%, respectively. And while 2008 saw 3% growth, this is far less than the double-digit growth of the "hot" portions of information technology markets.

To make significant inroads in these markets, clean technology ventures must displace entrenched competitors with a relatively undifferentiated product—watts of electricity or joules of power. The long lifecycles of existing energy systems limits the number of customers turning over in a given year; the high capital costs limit the risk-tolerance of those customers; and the shared infrastructure and economies of scale enjoyed by existing systems makes it extremely difficult for new technologies to compete on cost. Simply put, while the markets in which clean technology ventures hope to compete is large on an absolute scale, the *relative* arrival of new customers (or churn of old customers) willing to adopt does not provide opportunities for the rapid growth and diffusion of emerging technologies nor provide exponential revenue growth for the new ventures promoting them.[28]

In short, while the markets for clean technology are extremely large, the churn—the rate at which customers switch from or retire their existing capital stock of energy (supply or demand) and adopt the offerings of new and smaller companies—is small.

Scalability in Clean Technology Markets

To displace incumbent systems on which markets currently depend, emerging clean technologies must be able to scale in terms of both capacity and quality. Even if a new technology does have the potential to scale in this way, the costs of achieving this scale in clean technologies rarely reflect the same ratios of investment to growth as historically seen in the information and biomedical technologies. Energy supply technologies (such as solar, wind, or biofuels) find that investments in R&D, while equivalent to similar investments in information and biomedical technologies, are considerably smaller than the investments needed to scale those technologies. For example, Russ Landon, a managing director at the investment bank Canaccord Adams in Boston, compared clean technology startups to IT start-ups: "the capital requirements for energy start-ups are huge."[29] While $25 million may develop a new biofuel production process, an additional $250 million is needed to create a production plant (and each new plant requires equivalent asset investments).

With clean technologies such as wind, solar, or biofuels, the costs of scaling production, distribution, and installation often runs to ten times the costs of initially developing the technology. Most importantly, those costs grow relatively linearly with the revenue growth of the company. In terms of pools of money, even the largest venture capital funds are relatively small (less than $1 billion per fund and, say, $3.5 billion under management). Even with syndication, opportunities requiring over $500 million are rarely attractive as the potential losses are too great. This is one reason that venture capitalists will not invest in firms intending to manufacture semiconductors or build state-of-the-art data centers—the capital investment is just too great. Similarly, achieving even a fraction of the production volumes needed for additional low-carbon technology capacity requires large-scale construction or reallocation of manufacturing capacity. Because the energy sector is both heavily regulated and central to the provision of other goods and services, new technologies must meet very stringent cost, quality, and reliability expectations before they can enter (let alone scale rapidly) to serve the mass market. Indeed, both purchasing and financing decisions demand performance histories of not only the technologies under consideration, but also the companies supplying those technologies and guaranteeing their performance.

Large and Rapid Value Creation in Clean Technology Markets

The rapidity of change and relatively low costs of scaling-up differentiate the industries usually attracting venture capital. This contrasts with relatively slow change and enormous scale-up costs in most energy markets that make it difficult to envision more than a few clean technology companies generating the growth in revenues and market share, and the corresponding growth in equity value, sufficient to reward venture capital investors. Of course, the current mania associated with clean technology may be sufficient to ensure capital gains for the venture investors able to offer an IPO or positive trade sale for their portfolio firms. Thus far, however, the IPOs have had lackluster results. For example, A123 Batteries, a VC-backed company, went public in September 2009 priced at $13/share, with investors at that price suffering an immediate dilution of $8.37 per share. After the 180-day lock-up period, when insiders were able to sell, the stock dropped. By May 2011, A123 traded at $6 per share. A123 proved to be a marginal investment for the venture capitalists and a bad investment for the public. Similarly, the electric car manufacturer Tesla went public in June 2010 at $17 per share and by December 2011 was valued at $30 per share placing the value for Tesla at roughly 20 times their annual revenues. The multiple can be attributed to either its expected growth in revenue and profits, or mania. Considering existing automotive companies are typically valued at less than a single year's revenues (Ford Motor Company is trading at 33% of revenue while Honda is at 59%), Tesla's valuation appears to be based on the unlikely prospect of it becoming the next Ford or Honda soon. Tesla's IPO raised $226 million, which does not cover the $365 million they owe creditors in DOE-backed loans. They are unprofitable and, indeed, are pinning their growth on an expensive mass-market sedan, similar to the already available Nissan Leaf and Chevrolet Volt, due in 2012.

How long the financial market interest in clean technology will continue is unclear. Pinning the hopes of a clean technology revolution on a few companies dependent upon federal loan guarantees, and pushing them to grow fast and exit early, will not transform the market. This led Robert Metcalfe, a partner at Polaris Venture Partners in Waltham to conclude, "Energy investing is ill-suited to venture capital."[30] Regardless of the social benefits, absent sufficient financial returns, private investors such as pension funds and endowments will be compelled to discontinue advancing money to the venture capitalists, unless their investments are driven by political goals—a dangerous motivation for the pension fund endowment beneficiaries. In the meantime, the social networking firms are achieving enormous multiples within several years of inception. In summary, the market conditions and technological constraints of clean technology typically fall short of meeting the criteria for successful venture capital investing.

Exceptio Probat Regulam in Casibus Non Exceptis

There are, of course, subsectors of clean technology in which conditions of high market growth, scalable ventures, and profitable returns may exist and serve as useful exceptions that help to illustrate a general principle. A number of such opportunities, perhaps not surprisingly, can often be found at the intersection between energy and the information technologies and can include areas such as what is broadly referred to as the "smart grid." In these areas (and those such as advanced lighting and cooling technologies), firms can be established and grow rapidly. Interestingly, these firms require relatively little capital and are able to find rapidly growing niche markets. Such firms can provide sufficient returns to early investors, though the exits may be through trade sales. Importantly, these ventures do not require massive doses of public funding—raising the question of whether public money can productively accelerate private venture investing even under the right conditions. Perhaps the largest of these is smart meter manufacturer Silver Spring Networks, which with the assistance of massive federal grants to utilities for installation, has successfully competed with incumbent firms and grown with the roll out of advanced metering. Nonetheless, its planned IPO has been delayed, giving existing ICT companies (such as Cisco, IBM, Oracle, and Hewlett-Packard) time to enter the market.

Discussion

This article has identified a set of structural causes, stemming from economic conditions that explain both the success and limitations of VC-backed firms in creating self-sustaining industrial transformations. These causes suggest venture capital is an ill-suited investment vehicle—let alone policy framework—for fostering a clean technology revolution. Yet, venture capital investing remains active within clean technology. To avoid a Panglossian justification for venture capital in clean technology, and an attendant rationale for billions in federal loan guarantees to these companies, we consider several reasons for continuing venture capital investment.

First, institutional investors (e.g., California's pension fund manager, CalPERS) driven by moral, ethical, and public relations concerns decided to invest in the "socially desirable" clean technology funds. As a result, from 2006 through the first quarter of 2009, there was a rush among U.S. and European venture capitalists to raise clean technology funds, despite the absence of opportunities equivalent to Google, Yahoo!, or Cisco. Because venture capital funds are typically ten-year commitments, such institutional investments will continue to drive investment activity regardless of fit. Moreover, while venture capital fund managers are incented by overall fund performance for funds in the range of $250-$500 million, the management fees alone provide considerable income and can serve as an incentive to launch and manage sector-specific funds regardless of prospects for the fund's ultimate performance.

Second, the significant federal subsidies flowing into VC-backed investments are distorting the capital markets by multiplying a venture capital fund's investments in companies and mitigating their risk. It is also encouraging political, rather than technological or marketing, competition. A 2009 global survey of venture capitalists by Deloitte opined that the increasing investment could be due to "an increase in government/political support for clean technology and VCs are looking more to government participation in both investments and incentives."[31] In the U.S., the primary direct federal subsidy for VC-backed clean technology firms is loan guarantees, often for building manufacturing facilities. For investors, such government loan guarantees are desirable because they do not dilute the entrepreneur's or investors' equity and have no provision for the government to share in the rewards of success. Ira Ehrenpreis of Technology Partners put this very succinctly: "When I add up the dollars we have received from non-dilutive government funds in the first decade: less than $5 million. In the last two or three years, we have received almost a $1 billion across almost a dozen portfolio companies."[32] If the firm fails, the loans will not be repaid; while if the firm succeeds, the government will capture none of the gains.

Additionally, massive government loan guarantees to individual firms confounds market competition, which selects superior entrepreneurs and technologies, with political competition for the allocation of subsidies and guarantees.[33] Today's VCs have entered the political realm by lobbying for government clean technology subsidies and regulations, appointing former politicians such as Albert Gore and Tony Blair as partners and funding political campaigns. For example, venture capitalists actively invested in ethanol-related ventures lobbied the federal government for increased ethanol mandates; to further their investment in a now bankrupt ethanol producer, Altra Inc., KPCB partners testified to the U.S. Congress in favor of the distinctly environmentally unfriendly mandating of greater ethanol usage.[34]

Government willingness to provide large guarantees to specific firms has made Washington a central node in the clean technology ecosystem and venture capitalists have recognized this. Jason Matlof, a partner at Battery Ventures, stated, "There is so much at stake here that there's an enormous need for entrepreneurs to get close with policy makers. There are billions just for R&D. It's a lot of money."[35] In 2010, as the stock market mania for clean technology firms waned, Stephan Dolezalek of VantagePoint Venture Partners summarized the current situation very well: "We learned that we had to be as good as the defense contracting firms at understanding the flow of dollars from government. If government was going to hand out money, we had to figure out how to get our fair share." Such political competition for support might have little impact on the market acceptance of various technologies, but strongly influences access to capital for emerging ventures.[36] The size of government subsidies and loan guarantees ensures that firms not receiving them have little prospect of competing with the recipients of such massive and low-cost government support. Ira Ehrenpreis of the venture capital firm Technology Partners observed, it is this "kind of support that has catalyzed a number of companies to get that next level."[37] Of course, other car and battery startups not as successful politically in garnering enormous risk-free loans may be doomed.

These startups, despite receiving such enormous subsidies, still must compete with established firms in their sector. So Tesla and Fisker compete with existing carmakers such as Ford, General Motors, Honda, Hyundai, Nissan, and Toyota, while A123 competes with established battery makers such as Johnson Controls, Hitachi, Matsushita, Samsung, Sanyo (recently acquired by Matsushita for its battery expertise), Siemens, and Toshiba. Even with the enormous government subsidies, these smaller firms are missing the complementary assets (such as dealership networks and brand equity) that the existing automakers already have.[38] Should they fail, incumbent firms are likely to be able to acquire the assets of these government-funded startups at fire sale prices. As an illustration, Toyota and Matsushita have already invested significant sums in Tesla Motors.

The final concern about such government subsidies is that it can create a dependence upon continuing government support, which in the energy and environmental sector has proven notoriously fickle.[39] Pat Eilers, of the private equity group, Madison Dearborn Partners, put it well: "I [have] spent an equivalent amount of time in Washington, DC trying to work on policy that gives us long-term certainty."[40] The concern about long-term certainty is particularly important, because political changes can dramatically alter government subsidization patterns. This phenomenon can be seen in Europe where governments changed the grid feed-in tariffs that had encouraged massive investment in solar and wind farms in France, Germany, and Spain.[41] The creation of clean technology firms dependent upon continuing government subsidy has a history going back to the alternative energy boom during the 1974 and 1979 Oil Crises, and when government support was withdrawn nearly all of the new firms collapsed.[42]

A second question raised from this consideration is: What other policy models exist for fueling a clean technology revolution? A detailed discussion of these other policy options is not within the province of this article, but we note some of them. For example, one central policy model for spurring innovation has been government investments in basic research, under the assumption that the new knowledge generated within university and national research laboratories will trickle down into industrial and market use.[43] R&D investment is relatively inexpensive, does not determine winners, and the results can provide opportunities for entrepreneurs to launch small firms.

Probably the single best way to encourage the adoption of Clean Technologies would be a much higher tax on carbon fuels. Politically, such a policy seems untenable, as is demonstrated by the vociferous outcry when gasoline taxes increase. With the energy industry having a powerful role in the U.S. political system, significant taxation of fuels seems quite unlikely. Since raising energy usage taxes is nearly impossible, it might be useful to examine other policy responses.

One inexpensive model that has had success in encouraging technological commercialization without creating significant technological bias is the Small Business Innovation Research Program (SBIR), which was mandated by Congress in 1982. The award process is decentralized to each funding agency and within the larger agencies. The award decision is based on the technical merits of the proposals and not directly upon the commercial potential. The dispersion, relative small size, and evaluation upon technical merits limit any politicization of the process.[44] Nearly all, SBIR Program evaluations have been positive. For example, Lerner found that awardees were "significantly more likely to receive VC funding" after the award.[45] However, he also found that the superior performance of SBIR recipients was "confined to firms based in ZIP codes with substantial venture capital activity," and was greater in high-technology industries. David Audretsch et al. show that the SBIR Program stimulated technological innovation, private sector commercialization of the innovations generated through federal R&D, and had positive social benefits.[46] In the case of NIH SBIR awardees, in terms of follow-on venture capital funding, SBIR program completion, and patenting, firms affiliated with academic scientists performed significantly better than other non-linked SBIR firms.[47] A 2008 National Research Council reports similarly positive results from the SBIR Program.[48] SBIRs appear to have been particularly effective in facilitating the movement of research results from academic laboratories to commercialization. The positive results of the SBIR Program suggest that decentralized, diverse, relatively small investments can produce significant benefits in commercializing technology. Given the sheer immensity and diversity of the current energy system, there are likely to be many opportunities for entrepreneurship that VCs cannot fund, but that have economic merit. There have been other programs (such as the SBA Equity and Debenture Programs that were established in the 1990s) that provided leverage for venture capitalists committing significant amounts of their own capital. This SBA Program was quite decentralized, diverse, and those securing its funds made relatively small investments when compared to private venture capital, thereby reducing the distortions that enormous investments or loan guarantees can make. The other advantage of both the SBIR and SBA efforts is that they invest relatively small amounts in a wide range of industries and technologies.[49] It may be possible to fashion a government investment program that learns from the successful SBIR Program or the recent SBA efforts.

A second policy model employs subsidies and price incentives to shape the relative consumption of particular goods and services and to enable the profitable introduction of other competing, but currently more expensive, goods. This model focuses more on shaping the behavior of incumbent firms and the current market structure. This may be particularly appropriate for the segments of the energy market requiring enormous and long-lasting investments. Consider GE's recently described strategy of focusing on what CEO Jeffrey Immelt described as "heavyweight products that take patience and piles of cash to develop, weigh tons and last for years—next-generation jet engines, power turbines, locomotives, nuclear plants, water-treatment systems, medical-imaging equipment, solar panels, and windmills."[50] Indeed, Immelt noted that the cost of a typical solar-panel plant is, at around $70 million, more than twice the total investment in Google in the six years before it went public in 2004. Targeted subsidies and incentives, with proper caution, may be of use in certain of these cases.

A third policy is to use the enormous purchasing power of the federal government, and particularly the Defense Department, not to develop technologies but rather to procure them and, in the process, drive the maturation of emerging industries. For example, during the early days of the electronics industry, modest government defense contracts to small technology-intensive firms enabled them to establish operations to prove their technology and stabilize production processes. This last policy option has considerable promise as the clean technology innovations required under current market conditions will likely already be in the later stages of deployment, where "much of the most important cost-reducing innovation work typically occurs."[51] Indeed, the most likely source of innovations providing these cost reductions will emerge from complementary innovations in the supply chain that enables improved production, service, and performance of existing technologies. Hence, and counter-intuitively, a production and consumption-driven policy, rather than one focusing on wholly new technologies and companies, must be part of any progress in clean technology.

Conclusion

The promise and success of venture capital in fueling Schumpeterian creative destruction is undeniable in the information and biomedical technologies. However, generalization from these cases without understanding the boundary conditions in which venture capital investing has traditionally helped open new economic spaces and brought about industrial transformations can be misleading. Because industries differ in terms of their market conditions, maturity, and technological trajectories, not every industry meets the criteria for, and responds to, venture capital investing.

Given the political economic changes expected to result from global warming and the possibility that peak oil has been reached, there are ample opportunities for innovation and entrepreneurship in clean technology. Many clean technology businesses can and should grow using self-financing and investments from friends and family—the Danish wind turbine industry is a classic case of such growth.[52] In Denmark, there was no need for venture capital. The technology was developed in use, as both performance and reliability advanced together. There is every reason to believe that the desire to decrease carbon emissions will offer many such opportunities. Large existing multinationals such as General Electric, Siemens, Alstom, Hitachi, and Toshiba in energy and Toyota, Daimler, Nissan, General Motors, and others in transportation are leveraging their competences to produce clean technology solutions. In addition, existing small and medium-sized firms, which have strong technical abilities in various machinery industries and in components and subcomponents of larger energy solutions, will respond to the real business opportunities.

Governments have an important role to play in assisting entrepreneurship in clean technology. However, the government might be better served by removing subsidies to existing energy technologies and unnecessary regulatory barriers locking-in existing technologies. Enormous loan guarantees to VC-backed firms (and for that matter to nuclear power plant construction) will not transform established markets and may even hinder the process of change. Better to invest—through open technology platforms and enabling policies—in collective action that prepares nascent markets to grow and transform. Massive government capital investments that dwarf anything private sector investor would invest in single firms or technologies will alter the competitive ecosystem—and not for the better. Such policies necessarily create non-market incentives to increase investment in lobbying for large government loans or grants diverting firms from private sector customers and market-based learning to focus upon the government as the customer.

Notes

1. From regulation to active involvement, including the overthrow of foreign governments, politics is omnipresent for sustaining our energy system.
2. R.K. Lester, "America's Energy Innovation Problem," MIT-IPC-Energy Innovation Working Paper 09-007, 2009.

3. There are a number of federal programs investing in the commercialization of nascent clean energy technologies in addition to the DOE Loan Guarantee Program. For example, ARPA-E has a similar focus on "breakthrough technologies promising genuine transformation in the ways we generate, store, distribute and utilize energy . . . [that will] make today's technologies obsolete and create large commercial markets" (Congressional Testimony of Dr. Arun Majumdar, Director, Advanced Research Projects Agency—Energy, March 31, 2011). Funding for ARPA-E totaled $400 million, which, while significant, is a fraction of the $8 billion allocated through loan guarantees. In fact, ARPA-E may be more effective because it is decentralized and seeds more independent efforts.
4. While this article examines only the logic of loan guarantees to entrepreneurial start-ups, we recognize that even larger loan guarantees are going to established firms seeking to build nuclear power plants—an already well-established, though environmentally risky, technology. In fact, the enabling legislation for the alternative energy loan guarantee program supported by Republicans and Democrats has budgeted far greater sums for loan guarantees for nuclear power than for the other clean technologies combined. The largest loan guarantee thus far has been the $8 billion guarantee to investor-owned Georgia Power Company to build a nuclear power plant. In this case, for building nuclear power plants there can be no argument at all that this is supporting a new untried technology. Such guarantees are, quite simply, the only way a nuclear power plant project can receive the necessary funding as investors are simply unwilling to advance capital to what they perceive as being a risky technology—a perception that the accident at Fukushima is likely to only reinforce. The massive allocation of loan guarantees to nuclear power plant construction violates the principles of the program, suffers from the same criticisms of enormous federal loan guarantees, and suggests other factors beyond the purview of this article to explain the efforts of recent administrations to resurrect moribund U.S. nuclear power plant construction.
5. Such an alignment of interests in the success of those individual VC-backed firms that receive federal largesse is exacerbated by the intermingling of policy makers and venture capitalists. These investments are being guided by former venture capitalists now working closely with or for the DOE. For example, Jonathan Silver, previously a venture capitalist and the Managing General Partner of Core Capital Partners, an early-stage venture capital firm, serves as the Executive Director of the Department of Energy Loan Guarantee Program, overseeing more than $50 billion in loan guarantee authority to advance nuclear, clean coal, and advanced renewable and energy efficiency technologies. Venture capitalists also serve on various advisory panels guiding federal government investment policy.
6. R. Premus, *Venture Capital and Innovation*, Study prepared for the Joint Economic Committee of the U.S. Congress (Washington, D.C.: U.S. Government Printing Office, 1986); Federal Reserve System, *Financing Small Business*, A Report to the Committees on Banking and Currency and the Select Committees on Small Business, United States Congress, April 11, 1958.
7. J.A. Schumpeter, The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle (Cambridge, MA: Harvard University Press, 1934), p. 66.
8. K. Hockerts and R. Wüstenhagen, "Greening Goliaths versus Emerging Davids—Theorizing about the Role of Incumbents and New Entrants in Sustainable Entrepreneurship," *Journal of Business Venturing*, 25/5 (September 2010): 481-492.
9. Tyebjee and Bruno, for example, estimated that venture capitalists devote approximately 160 hours to due diligence before making an investment decision, investigating the technology, the potential market, the entrepreneurs, and their business plan. T.T. Tyebjee, and A.V. Bruno, "A Model of Venture Capitalist Investment Activity," *Management Science*, 30/9 (September 1984): 1051-1066. For further research on the venture capital process, see R. Florida and M. Kenney, "Venture Capital and High Technology Entrepreneurship," *Journal of Business Venturing*, 3/4 (Fall 1988): 301-319; P.A. Gompers and J. Lerner, *The Money of Invention* (Cambridge, MA: Harvard Business School Press, 2001); S.N. Kaplan and P. Strömberg, "Characteristics, Contracts, and Actions: Evidence from Venture Capitalist Analyses," *Journal of Finance*, 59/5 (October 2004): 2177-2210; H. Sapienza, S. Manigart, and W. Vermeir, "Venture Capitalist Governance and Value Added in Four Countries," *Journal of Business Venturing*, 11/6 (November 1996): 439-469; A.L. Zacharias and G.D. Meyer, "The Potential of Actuarial Decision Models: Can They Improve the Venture Capital Investment Decision?" *Journal of Business Venturing*, 15/4 (July 2000): 323-346; R. Zider, "How Venture Capital Works," *Harvard Business Review*, 76/6 (November/December 1998): 131-139.
10. U. von Burg and M. Kenney, "There at the Beginning: Venture Capital and the Creation of the Local Area Networking Industry," *Research Policy*, 29/9 (2000): 1135-1155.

11. Florida and Kenney, op. cit.; Gompers and Lerner, op. cit; M. Gorman and W.A. Sahlman, "What Do Venture Capitalists Do?" *Journal of Business Venturing* 4/4 (July 1989): 231-248. Additionally, as seasoned advisors for early stage ventures, VCs are savvy regarding the raising of subsequent funds that their portfolio firms will require to continue growing. As Gompers and Lerner show, veteran VCs have experienced a number of stock market cycles and can advise their firms regarding propitious opportunities to make a public offering. Gompers and Lerner, op. cit. VCs also are constantly scouting for potential acquirers of their portfolio firms and so assist with this alternative exit strategy.
12. Hockerts and Wüstenhagen, op. cit.
13. While most of the greatest venture capital successes have been in the information and communication technology and biomedical fields, VCs will invest in other sectors ripe for significant change. The well-known delivery firm, Federal Express, received VC funding, as have a number of airlines such as Southwest Airlines and the now defunct People Express. The San Francisco microbrewery Gordon Biersch received VC financing, as did Mrs. Fields' Cookies. All of these investments led to IPOs; however, VCs have not remained continuing sources of capital for driving innovation in the airline package delivery, airlines, microbreweries, or cookie producers. Entrepreneurship is possible in these and many other industries, but generally there are few transformative opportunities. Put simply, VCs are not biased against particular sectors; rather, they invest in firms that have potential to generate significant returns on their investments.
14. Z.J. Acs and D.B. Audretsch, "Innovation in Large and Small Firms: An Empirical Analysis," *American Economic Review*, 78/4 (1September 988): 678-690.
15. J. Lerner, *Boulevard of Broken Dreams* (Princeton, NJ: Princeton University Press, 2009).
16. P. Freiberger and M. Swaine, *Fire in the Valley: The Making of the Personal Computer* (Berkeley, CA: Osborne/McGraw-Hill, 1984).
17. Apple Computer Inc., U.S. Securities and Exchange Commission Filing S1/A, Cupertino, CA, 1980.
18. Google Inc., U.S. Securities and Exchange Commission Filing S1/A, Mountain View, CA, 2004.
19. B. Barnes and C.C. Miller, "Disney Buys Playdom in $763 Million Deal, Becoming Hollywood Leader in Social Games," *New York Times*, July 27, 2010, <www.nytimes.com/2010/07/28/technology/28disney.html?src=busln>, accessed January 18, 2011.
20. E. Von Hippel, *The Sources of Innovation* (New York, NY: Oxford University Press, 1988); E. Von Hippel, "Innovation by User Communities: Learning from Open-Source Software," *Sloan Management Review* 42/4 (Summer 2001): 82-86.
21. For a discussion of this unfolding in the early internet business, see M. Kenney, "The Growth and Development of the internet in the United States," in B. Kogut, ed., *The Global internet Economy* (Cambridge, MA: MIT Press, 2003), pp. 69-108. The growth of the internet market is particularly interesting because it grew in two ways: First, when the market did tip, the number of users grew rapidly. This was important because of the sheer number of potential customers. However, this growth in users was only the base. The second more powerful growth was in the number of uses of the internet. This is better understood by the growth in the number of internet hosts, the number of hours that these users are online, and the seemingly endless variety of new uses that have been invented.
22. In most other markets, such change occurs infrequently. For example, automation sparked radical growth and re-organization of the cigarette market in the late 1880s, but remarkably little has changed in this industry during the past century. The U.S. steel industry experienced significant transformations in the 1850s with the introduction of the Bessemer steel process and again in the 1980s with the rapid diffusion of mini-mills, but otherwise has been quite stable. A.D. Chandler, *The Visible Hand: The Managerial Revolution in American Business* (Cambridge, MA: Harvard University Press, 1977).
23. W.J. Baumol, *The Microtheory of Innovative Entrepreneurship* (Princeton, NJ: Princeton University Press, 2010); P.L. Cantelon, *The History of MCI: 1968-1988, The Early Years* (Washington, D.C.: MCI Communications Corporation, 1993).
24. Christine Frey and John Cook, "How Amazon.com Survived, Thrived and Turned a Profit," January 28, 2004, <seattlepi.nwsource.com/business/158315_amazon28.html>.
25. National Venture Capital Association, *2010 Yearbook* (Washington, D.C.: National Venture Capital Association, 2010).
26. P. Gompers, A. Kovner, J. Lerner, and D. Scharfstein, "Venture Capital Investment Cycles: The Impact of Public Markets," *Journal of Financial Economics*, 87/1 (January 2008): 1-23.
27. J. Helwege and N. Liang, "Initial Public Offerings in Hot and Cold Markets," *Journal of Financial and Quantitative Analysis*, 39/3 (September 2004): 541-569.

28. J.P. Holdren, "The Energy Innovation Imperative: Addressing Oil Dependence, Climate Change, and Other 21st Century Energy Challenges," *Innovations: Technology, Governance, Globalization*. 1/2 (Spring 2006): 3-23.
29. It is this arrival of new customers that makes it possible for clean technologies and clean technology firms to be more successful in rapidly growing developing nations that have far less fixed investments. Not surprisingly, rapidly growing China has received significant clean technology VC investment, aiding to the development of a number of firms.
30. S. Kirsner, "Innovation Economy," March 14, 2010, <www.boston.com/business/technology/articles/2010/03/14/venture_backing_may_be_scarce_for_clean_tech/>.
31. Kirsner, op. cit.
32. Deloitte, "Global Trends in Venture Capital: 2009 Global Report," <www.deloitte.com/dtt/cda/doc/content/us_tmt_2009vcreport_060809.pdf>, accessed January 18, 2011, p. 8.
33. Y. Cohen, "The Lessons Veteran Investors Have Learned," Greentechmedia.com, October 8, 2010, <www.greentechmedia.com/articles/read/the-lessons-veteran-investors-have-learned/>, accessed January 18, 2011.
34. Massive loan guarantees also create arbitrage opportunities for the VCs. The loans make it far easier for the recipient firm to make an initial public stock offering, after which the VCs can exit the investment with their capital gains. For the VC investors, the ultimate fate of the firm is unimportant, as the losses fall upon later investors and the government. This micro-level tilting of the market in favor of specific competitors and mitigating the risk for specific entrepreneurs and their backers is a public investment policy of choosing the potential winners prior to any competitive tests winnowing ineffective technologies, inferior business models, or bad management. For the startup and its venture backers, this places a premium on effective government relations, not technology and market development.
35. Testimony of John Denniston, Partner Kleiner Perkins Caufield & Byers, Before the Senate Energy and Natural Resources Committee, March 7, 2007.
36. T. Mullaney, "Lobbyists Are First Winners in Obama's Clean technology Push," *Bloomberg News*, accessed March 25, 2009.
37. In a recent report, the Center for Public Integrity noted the rise in venture capital lobbying, advising us to "watch the venture capitalists that have money riding on new technology try to gain advantage in a game that so far has been deftly controlled by the old machine," In addition to lobbying, witness also the rising role of venture capitalists moving into positions within the Department of Energy and advising on the department's investment strategies. M. Lavelle and M.B. Pell, "The Climate Lobby from Soup to Nuts," The Center for Public Integrity, December 27, 2009, <www.publicintegrity.org/investigations/global_climate_change_lobby/articles/entry/1884/>, accessed November 29, 2011.
38. Cohen, op. cit.
39. On complementary assets, see D.J. Teece, G. Pisano, and A. Shuen, "Dynamic Capabilities and Strategic Management," *Strategic Management Journal*, 18/7 (August 1997): 509-533.
40. M. Kenney, "Venture Capital Investment in the Greentech Industries: A Provocative Essay," in R. Wüstenhagen and R. Wuebker, eds., *Handbook of Research on Energy Entrepreneurship* (Cheltenham, UK: Edward Elgar Publishing, 2010).
41. Cohen, op. cit.
42. T. Macalister, "Uncertainty Over Spanish Economy Hits Green Energy Firms' Ambitions to Float," *Guardian*, May 13, 2010, <www.guardian.co.uk/business/2010/may/13/renewables-float-spain-economic-uncertainty>, accessed January 18, 2011; Euractiv.com, "Germany, France Cut Support for Solar Power," January 21, 2010, <www.euractiv.com/en/energy/germany-france-cut-support-solar-power/article-189131>, accessed January 18, 2011.
43. Kenney, op. cit.
44. V. Bush, *Science, The Endless Frontier: A Report to the President* (Washington, D.C.: U.S. Government Printing Office, 1945).
45. Josh Lerner, "The Government as Venture Capitalist: The Long-Run Impact of the SBIR Program," *The Journal of Business*, 72/3 (July 1999): 285-318.
46. Lerner, op. cit., p. 315.
47. D.B. Audretsch, A.N. Link, J.T. Scott, "Public/Private Technology Partnerships: Evaluating SBIR-Supported Research," *Research Policy*, 31/1 (January 2002): 145-158.
48. A.A. Toole and D. Czarnitzki, "Biomedical Academic Entrepreneurship through the SBIR Program," *Journal of Economic Behavior & Organization*, 63/4 (August 2007): 716-738.
49. National Research Council, C. Wessner, ed., *An Assessment of the SBIR Program* (Washington, D. C.: National Academies Press, 2008).

50. On the SBA Programs, see K. Temkin, B. Theodos, with K. Gentsch, *The Debenture Small Business Investment Company Program: A Comparative Analysis of Investment Patterns with Private Venture Capital Equity* (Washington, D.C.: The Urban Institute, 2008). Also, B.A. Kinn and A.M. Zaff, "VCs Tap New Funding Source: The SBIC Equity Leverage Program and the Reasons for Its Growing Popularity," *Venture Capital Journal*, 41/7 (July 2001).
51. S. Lohr, "G.E. Goes with What It Knows: Making Stuff," December 4, 2010, <www.nytimes.com/2010/12/05/business/05ge.html>.
52. Lester, op. cit., p. 35.
53. R. Garud, and P. Karnøe, "Bricolage Versus Breakthrough: Distributed and Embedded Agency in Technology Entrepreneurship," *Research Policy*, 32/2 (February 2003): 277-300.

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