CHAPTER 5

FINANCING "TOUGH TECH" INNOVATION

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Venture capital investment across the world has surged in the past two decades but has been disproportionately directed towards a subset of innovations that can generate returns in a short period of time. More complex technologies that are expensive and time-consuming to de-risk have received relatively less capital in recent years, despite great societal need. This is particularly true for nascent technologies building on new science, but without a well-defined market—so-called "tough tech" ventures.

The government's role—as a customer that reduces market risk and as a financier of early-stage experimentation that reduces technology risk—has been shown to be effective in addressing challenges faced by such start-ups in other contexts.

Moreover, new funding and organizational models at the nexus of research universities, philanthropy, and "patient" private capital have the potential to unlock vibrant, tough tech innovation ecosystems that are urgently needed to solve some of the most pressing problems facing societies today.

Venture capital as a growing source of financing

The most important source of financing available for start-ups engaged in innovation is venture capital (VC),[1] which has seen extremely rapid growth across the world in the last decade. VC investors deployed over US$250 billion into start-ups globally in 2019, compared to less than US$40 billion just ten years before in 2009.[2] Moreover, a substantial share of this growth in global VC over the past decade has come from outside the United States of America (U.S.) and particularly from China. The U.S share of global venture capital deal value fell from three-quarters to half over the same period.

Beyond the rise in the number and value of VC investments, the past decade has also seen the contemporaneous rise in several new types of financial intermediaries entering the venture financing ecosystem. Intermediaries range from crowdfunding platforms and accelerators helping new ventures access early-stage capital,[3] to the growing presence of public market investors making direct investments into late-stage, venture capital-backed start-ups while they are still private.[4]

This unprecedented growth of venture capital is a significant validation of VC's role in financing high-risk ventures and its potential for reducing financing constraints faced by technology entrepreneurs. However, a growing number of observers have begun to note concern about a lack of "big ideas" in terms of the innovations that are being financed by VC today.[5] With the backdrop of lagging productivity growth in many Western societies, less corporate investment in R&D, and important breakthroughs needed to solve societal challenges—such as climate change, food and water security, and human health—understanding the degree to which venture capital can effectively address this gap is extremely important for policymakers.

Breakdown of VC investments from 2010 to 2019

Based on data from Pitchbook on global venture-capital investments, Figure 5.1 examines the sectors which have seen the most rapid growth in venture capital financing in the 2010s. It lists the total dollar value of all deals reported in 2010 and 2019, categorized by the main industry sectors reported in Pitchbook. Figure 5.1 shows the remarkable growth in the value of venture capital deals over this period, rising more than fivefold from 2010 to 2019.

Figure 5.1 also shows that growth was largely driven by increases in investment towards IT software and services, consumer products and services (B2C), business products and services (B2B), and financial services. The figure looks virtually identical if restricted to only U.S. venture capital deals, implying that this is driven by an across-the-board change, rather than due to the composition of deals in countries such as China, which have seen faster growth of VC in recent years.

Due to the ubiquity of software, many innovations classified as IT software, B2C, and B2B cut across traditional industry sectors. For example, Uber disintermediated the taxicab business by more efficiently connecting passengers with drivers, and in less than ten years from founding, Airbnb had more listings than the largest hotel chain in the world, despite owning no assets itself. Hundreds of other such VC-backed start-ups serving consumers and enterprises across a range of industries have been financed in the last decade, bringing immense value to their users in many instances, as well as being adopted or replicated across many countries around the world.

However, Figure 5.1 and Figure 5.2 also show that investments in three sectors have not kept up with the overall growth: healthcare; IT hardware—comprising communications and networking equipment, computer hardware, and semiconductors; and energy, materials, and resources. As shown in Figure 5.2, the share of investments in these sectors fell from over 50% of total spending in 2010 to below 25% in 2019. Energy, materials, and resources and IT hardware combined accounted for less than 5% of capital invested by VCs in 2019.

To some extent, these ebbs and flows of funding across sectors reflect technology life cycles, the huge wave of application-related innovations made possible by the Internet revolution in the late 1990s, and the subsequent rise of cloud computing in the mid-2000s.

However, the introduction of cloud computing services in the mid-2000s also had another important effect: it dramatically lowered the cost of learning about the ultimate potential of risky web-based start-ups. Specifically, it allowed those start-ups to rent hardware in small increments from providers like Amazon Web Services, use this to quickly gauge customer demand, and postpone expensive investments to scale up until after learning about the size and nature of demand from consumers.[6] This, in turn, led to a disproportionate rise in the number of start-ups that could benefit from such lowered cost of experimentation.

The increase in such start-ups is reflected in the changing shares of industries shown in Figure 5.1 and Figure 5.2, and also in the development of crowdfunding, accelerators, angel groups, and other early-stage investors who finance the lower initial capital needs of such ventures and promote effective learning about product-market fit using frameworks, such as the *lean start-up model*.[7]

While technological advances, such as rapid prototyping and the advent of advanced simulation and prediction tools, have also lowered the cost of learning and experimentation beyond software and web-based start-ups, growing academic research has begun to articulate certain characteristics of start-ups that make them a poor match for the venture capital model of financing innovation. Three particularly salient elements include: 1) the longer timelines required to build such companies, 2) capital intensity associated with de-risking these ventures, and 3) the nature of market and technology risk faced by new ventures.

Start-up characteristics that pose challenges to the VC model of finance

Long timelines

VCs typically raise closed-end funds, implying that VC investors are required to invest the money they raise from limited partners and return the proceeds within a fixed period, usually 10 years. Given that investments are made over the first few years, this implies that VCs are naturally drawn to investments where they can realize a return through an exit—either an acquisition or an IPO—within a short time.

Not all ventures are amenable to this timeline. For example, start-ups that have a physical component to generating cash flows often take longer to build, particularly if the venture needs to build factories to produce new products—as is the case with computer hardware, energy production, energy storage, advanced materials, and robotics. Although VCs have some leeway to extend the fund life a few years, the fixed limit to a fund's life can become a binding constraint for investors.[8] When VCs know that start-ups, such as those noted above, take longer to mature and are less likely to be ready for an exit when the fund's 10-year period ends, it becomes less likely that VCs will invest in such firms.

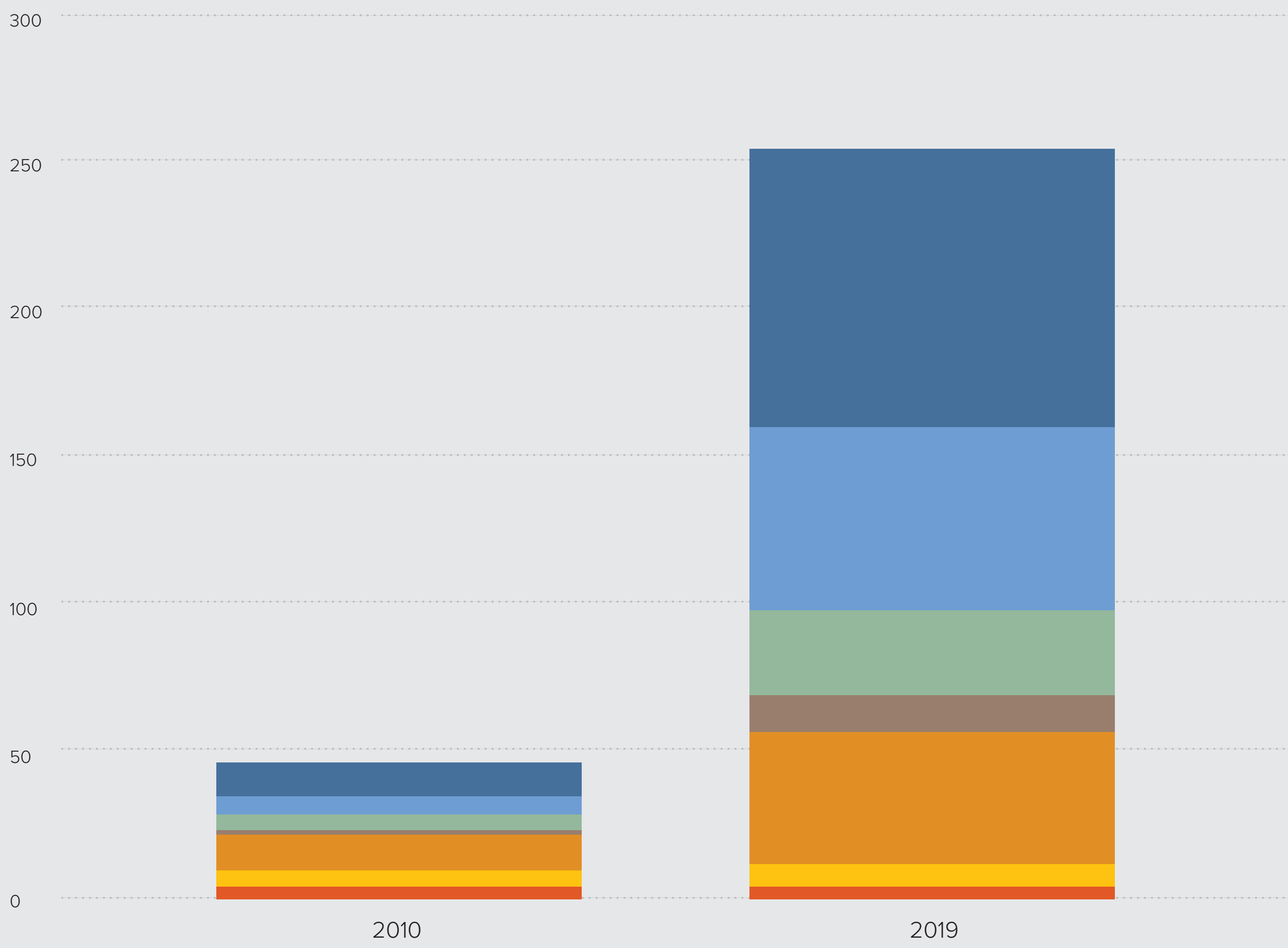
Capital intensity to de-risk ventures

Venture capital investors do not shy away from investing large sums of money, particularly when financing the scale-up of successful ventures. Many B2C social networks and B2B enterprise software firms have raised hundreds of millions, or even billions, of dollars of equity financing from venture capital investors (e.g., Uber raised over US$7 billion in equity financing before its IPO). Indeed, the proliferation of start-up *unicorns*—start-ups raising a large round of venture capital and valuing them above US$1 billion—in recent years is a testament to the ability of hundreds of such firms to raise substantial sums of money from venture capital investors.

However, VCs are particularly sensitive to how much capital it takes to achieve initial milestones in order to de-risk a venture and learn about its ultimate potential.[9] To see why, it is useful to recognize the skewed nature of risk and return in VC: over half of investments that even the most successful VCs make fail entirely, while the majority of return for VC firms is generated by one or two extremely successful investments that are very hard to predict.

FIGURE 5.1

Venture capital investment globally, by sector



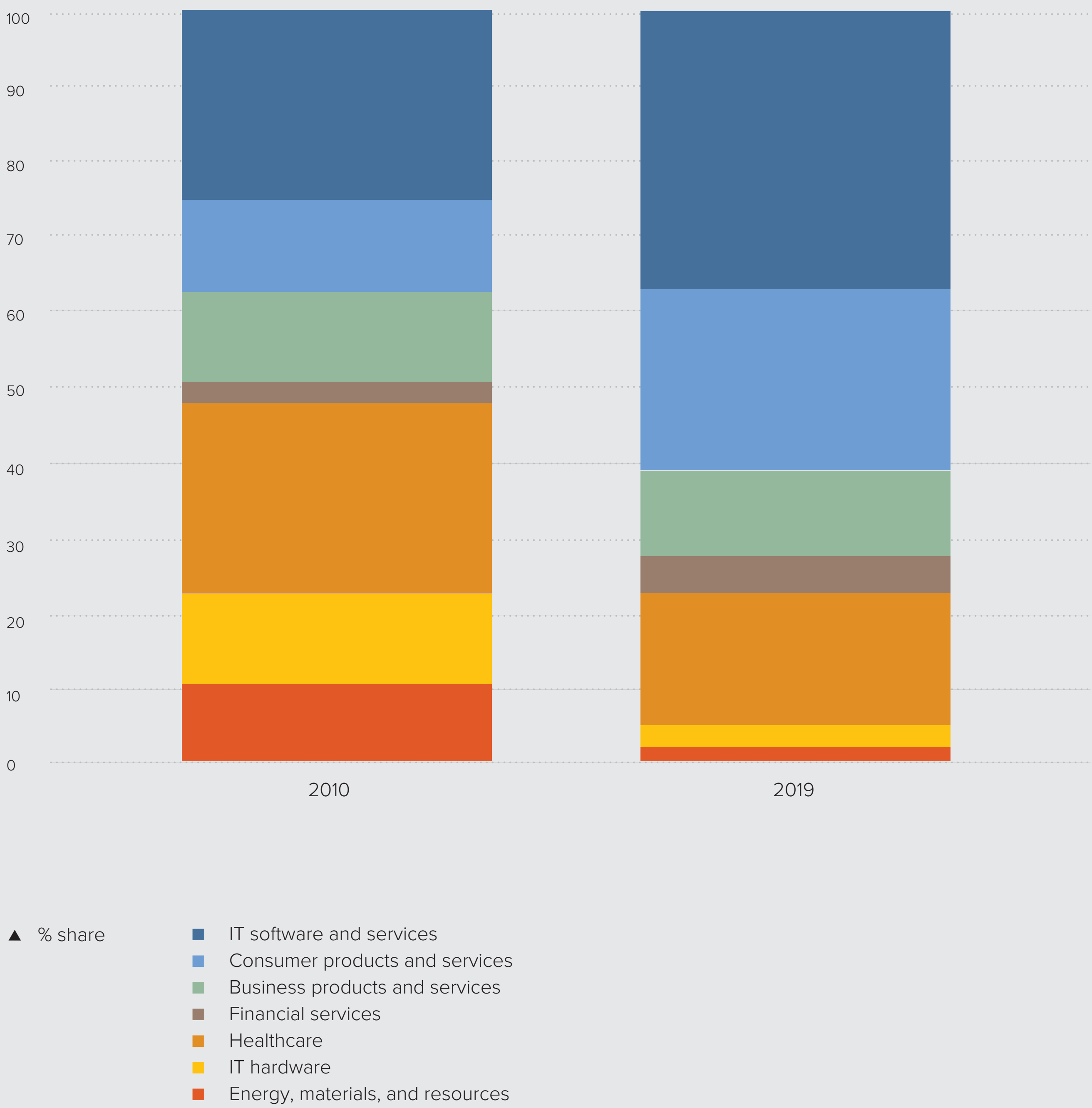
▲ US$ billion

- IT software and services
- Consumer products and services
- Business products and services
- Financial services
- Healthcare
- IT hardware
- Energy, materials, and resources

Source: Pitchbook, accessed February 20, 2020.

FIGURE 5.2

Share of global venture capital investment, by sector



Source: Pitchbook, accessed February 20, 2020.

VCs, therefore, invest in stages, where each stage or round of financing by the VC can be thought of as an experiment that generates information about whether or not a start-up can achieve its promised potential. Staged financing is tied to milestones and effectively gives VCs *real options*—they can choose to invest further in the next round of financing when start-ups achieve milestones, or they can choose to abandon follow-on financing if they do not feel the start-up is showing sufficient promise.

VCs are naturally drawn to start-ups where early experiments are cheaper since it means their real option to reinvest or abandon at the next round is less expensive. Their real options are also more valuable in sectors where initial experiments generate more information—in other words, where achieving or missing initial milestones helps VCs learn more about the ultimate potential of a venture. This is because more informative experiments help VCs learn faster about firms that might ultimately fail, enabling them to "throw less good money after bad". More informative experiments also show firms achieving their promise earlier in their life, enabling start-ups to raise their next round of financing at much higher valuation step-ups. VCs who fund the initial rounds of financing in these ventures are therefore less diluted—that is, they maintain greater equity ownership—and hence generate a larger return for any given exit value.

A particularly important milestone VCs focus on is the point at which a start-up gets traction with customers, often referred to as achieving "product-market fit". Beyond this milestone, start-ups are focused less on de-risking, or understanding the true potential of the business, and more on scaling the business to achieve their potential. It can be seen from this discussion that start-ups in sectors where it is harder to achieve product-market fit—because initial experiments are more expensive or less informative—are far less appealing to venture capital investors.

The nature of technology and market risk

What leads to variation in the degree to which ventures can be de-risked? Two important drivers are the amount of technology risk and market risk faced by a venture. For example, forecasting the unit costs associated with storing energy at scale using a new battery material can be extremely difficult, even if the technology has been shown to work in a controlled laboratory environment. Since demand is tied to the ability of firms to produce at certain price points, this also implies that technology and market risk can often be intricately tied to each other. In such instances, the costs and timelines associated with the learning and de-risking process can be prohibitively large for VC investors, as they may need to finance a full-scale prototype—potentially costing tens, if not hundreds, of millions of dollars—before learning whether the technology is sufficiently good to disrupt a market.

Beyond technology risk, the risk that there will not be sufficient interest from customers for the product to generate a large return for VCs (market risk) is also substantial in some sectors—particularly sectors that are regulated or have substantial involvement from government because of their importance to the economy. Even when the government is not involved, the end customer in some industries may be a large incumbent with substantial market power, thereby making it hard to command high profit margins when selling to them.

Because of these challenges, VC investors usually back well-understood technologies in sectors with less regulatory risk and focus their efforts and skills around helping portfolio companies achieve product-market fit. Indeed, history suggests that instances where start-ups with substantial technology risk were successfully commercialized by VC also had substantial government involvement that helped with de-risking the technology and/or reducing market risk.[10] For example, while VC was intricately involved in helping to finance the semiconductor revolution, the U.S. government also played a fundamental role as a key early customer that virtually eliminated market risk. Similarly, the large amounts of venture capital finance for biotechnology start-ups is tied to the drug approval and reimbursement system that enables investors to accurately assess the market value of a new drug if it is successful in passing through clinical trials.

"Tough tech"

Start-ups that share one or more of the characteristics that make them a poor fit for VC investment have sometimes been referred to as tough tech—in reference to the fact that these technologies are often tough to commercialize using venture capital. In many instances, they involve breakthroughs in fundamental science or nascent technologies, which leads to long timelines and substantial technology risk. Such ventures have sometimes also been referred to as "deep tech".

It is important to emphasize that not all science-based ventures are bad fits for VC; indeed, some ventures spinning out of university labs raise substantial venture capital, generate high returns for investors, and solve important problems for the world. Nevertheless, many of the innovations required to solve society's most pressing problems do not have solutions that fit the timelines and economic constraints of VC investors. In light of these constraints, and the growing sense that there is also a decline in fundamental innovation coming from large corporations,[11] there are several elements that policymakers and other stakeholders could consider to help support the commercialization of tough tech.

Government subsidies to financing prototypes when de-risking is hard

Governments regularly subsidize the financing of new firms and small to mid-size enterprises (SMEs). In considering the role of subsidies, it is important to recognize that the financial support required for most SMEs—who depend primarily on debt finance—is likely very different from the venture capital required to support start-up innovation. Further, the record of government involvement in trying to promote entrepreneurship and venture capital has been mixed at best.[12] Nevertheless, one setting where start-ups engaged in innovation have been shown to benefit substantially is the U.S. Department of Energy's

SBIR grant program, which has helped start-ups finance the prototyping of new technologies and thereby substantially increase the odds of receiving venture capital.[13] This ties in directly to the friction outlined above—where start-ups in some sectors cannot attract VC due to the difficulty they face in learning about the effectiveness of a new technology in the field as opposed to the lab, and hence have trouble convincing investors they can achieve product-market fit and generate sufficient customer demand.

The role of government as customer

Many successful examples of government involvement in the commercialization of tough tech have been related to the government's (often the military's) role as a customer.[14] A key reason for this may have to do with government contracts substantially reducing market risk through a willingness to pay for early versions of an emerging technology. A large military contract can also help to establish standards and coordinate the direction of technology trajectories. Finally, through their role as customers, governments can even reduce financing constraints via the timing of contract payment. For example, paying part of the contract value in advance can substantially reduce start-ups' dependence on external finance.[15] This important role of the government as customer is often underappreciated when considering the role that policymakers can play in jump-starting innovation.

New organizational and financing models

As seen from the discussion above, the challenge faced by many tough tech ventures is that they need a long period of incubation and de-risking in an environment that does not face the same time and financial hurdles as VCs or corporations. In part, this is because of the stochastic nature of technological breakthroughs, which cannot be controlled in the same way as experiments related to customer demand. Moreover, fundamental breakthroughs may require a tolerance for failure to induce innovators to try unproven paths.[16]

Given that tough tech ventures are often based on new science or technology developed in universities, academic institutions have the potential to play a central role in helping to de-risk technologies prior to start-ups raising risk capital from investors.[17] Another role that universities can play is in helping founders of tough tech ventures, who often have a technical background but less business training, to understand the appropriate customer segments, business models, and financing sources for their new ventures.

Universities, government labs, corporate R&D, VC firms, corporate venture capital firms, and longer-term "patient capital" associated with family offices each bring different incentives, funding models, ability to experiment, and tolerance for failure. Each has different benefits and constraints.[18] Understanding the degree to which these can be adapted to most effectively help commercialize tough tech—perhaps while also harnessing non-dilutive and non-market rate capital from philanthropy for initial experiments—is a promising area of further inquiry.[19]

In considering the role of non-dilutive capital helping to de-risk new technologies, it is worth noting that globally, an estimated US$1.5 trillion of philanthropic capital is managed by hundreds of thousands of foundations.[20] Providing incentives to unlock some of this capital to finance tough tech innovation may provide a unique way to bridge the "valley of death" between advanced R&D projects in universities and start-ups looking to quickly achieve product-market fit.

Notes:

1 Kortum et al., 2000; Gompers et al., 2001.

2 National Venture Capital Association, 2020.

3 Agrawal et al., 2016; Hochberg, 2016.

4 Chernenko et al., 2019.

5 Pontin, 2012.

6 Ewens et al., 2018.

7 Reis, 2011.

8 Ivashina et al., 2019.

9 Kerr et al., 2014.

10 Janeway, 2016; Nicholas, 2019.

11 Arora et al., 2017.

12 Lerner, 2009.

13 Howell, 2017.

14 Janeway, 2016; Nicholas, 2019.

15 Barrot et al., forthcoming.

16 Manso, 2008.

17 Of course, the degree to which universities should be focused on basic vs. applied science, as well as concerns about commercial bias and academic freedom, need to be appropriately balanced as universities consider how best to support the commercialization of such technologies.

18 Lerner et al., 2007; Lerner, 2012.

19 Nanda et al., 2019.

20 McGrath, 2018.

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