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# Venture Capital and the Transformation of Private R&D for Agriculture

Gregory D. Graff, Felipe de Figueiredo Silva, and David Zilberman

## 6.1 Introduction

Innovation in the agricultural and food system has been fundamental in enabling it to feed the world. Developments in mechanical, chemical, and biological technologies have contributed to productivity gains that have more than doubled outputs of agricultural production over the last 50 years while scarcely changing the aggregate quantity of inputs (Alston et al. 2010). Innovations in harvesting, processing, and other postharvest steps have also increased the capacity and efficiency of the food system, helping improve food security and the nutritional quality of diets for a growing global population (FAO 2018).

Innovation in modern agriculture increasingly occurs as a result of formal research and development (R&D) activities, conducted in both the public sector and the private sector. Historically, agricultural R&D has been highly managed. In the mid-19th century, it was led by governments supporting agricultural research stations and research at agricultural colleges and universities. By the mid-20th century, an international agricultural research system, supported and overseen by philanthropic foundations and international organizations, became a major source of new innovations. During

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this same time frame, large corporate agribusiness and food firms increased their R&D with the objective of maximizing the profitability of their core production and marketing activities.

While government investments in agricultural R&D have been declining in real terms in high-income countries over the last several decades, industry investments in agricultural R&D have increased steadily (Fuglie et al. 2012; Pardey et al. 2016). Globally, annual industry expenditures on agricultural R&D in 2009 were in the range of $10 billion (Fuglie et al. 2011) to $16 billion (Pardey et al. 2015). The most recent available global estimate of industry's agricultural R&D was $15.6 billion in 2014 (Fuglie 2016). However, all such estimates primarily consider publicly listed companies that are subject to public disclosure requirements by securities regulators. Such estimates have largely ignored small- and medium-size enterprises (SMEs) because historically, they have contributed very little to industry R&D.

In recent years, however, there has been a surge in the founding and financing of start-up companies seeking to develop and apply new technologies in agriculture and the food system. These companies are privately held and have raised significant amounts of equity-based investment from venture capital (VC) funds and related private sources such as seed, angel, and other private equity investors. According to industry reports, in recent years, up to several billion dollars annually have been invested into such agricultural technology (or "agtech") start-up companies (AgFunder 2015, 2019; CBInsights 2017; Dutia 2014; Finistere Ventures 2019; KPMG 2018). While the phenomenon of start-up companies or new technology-based firms (NTBFs) introducing new technologies to agriculture is itself not new, recent rates appear to be unprecedented in terms of both the number of start-ups and the amount being invested in them.

Yet these various accounts of R&D investment in agriculture draw on a range of different private data sources and industry subsector definitions and thus vary in terms of how prevalent they find agtech start-ups to be and how much VC they find is being invested in the industry. To some extent, this variation is due to the inherent challenges of industry classifications. Established categories tend to reflect the incumbent structure of industry—such as seeds, agricultural chemicals, or agricultural machinery. However, many of the recent agtech start-ups span conventional industry categories. For example, a start-up may have its primary industry classification in software, yet that software may be highly specialized for data management and decision support of on-farm crop production. One perennial question is the extent to which downstream food manufacturing, wholesale, and retail categories should be included and how, especially since the business models of some of today's leading start-ups explicitly seek to shorten or span the entire "farm-to-table" value chain. Variations in accounting of VC investments are also due to the fact that, historically, private investments in agricultural R&D have been quite low in developing countries (Pardey and Beintema

2001; Pardey et al. 2006). Yet recently, robust start-up activity and private investment is being reported in middle- and lower-income countries, especially in the larger emerging economies like India (AgFunder 2018b), China (AgFunder 2018a; Gooch and Gale 2018), and Brazil (Mondin and Tomé 2018; Dias, Jardim, and Sakuda 2019). Data sources and procedures for systematic compilation of small-scale private business activity in such countries are nascent at best. It is not clear why this surge in venture investment in agricultural technology has occurred in middle- and lower-income countries now or what factors account for this apparent upturn, but it appears to be an important part of this global phenomenon and has remained largely unrecorded.

We present evidence in this chapter that until 2006, the amount invested globally in agtech start-ups remained relatively negligible, typically less than $200 million per year, then grew steadily from 2007 to 2009 and then exploded in 2010, exceeding $3 billion annually in recent years. One industry source claims that venture investments in agricultural technology may have been as high as $7 billion in 2018 (AgFunder 2019). At that rate, VC and associated private investors could be allocating up to half as much toward agricultural R&D as are the corporate members of the industry.

These start-ups and their R&D activities can be expected to impact existing agricultural technologies and industry structure. These start-ups are tapping new sources of financing to support R&D for agriculture. Compared to established R&D organizations, in both the public and private sectors, venture-backed start-ups are subject to different incentives and constraints and are connected to different professional networks. This allows them, collectively, to pursue a larger and more diverse range of R&D projects. Some of the R&D conducted by start-ups may be complementary to R&D by established organizations. Some are even spun off from established R&D organizations to build on discoveries made within those organizations in order to transfer or translate those findings into market applications. Other start-ups are contributing new research tools or platform technologies—such as novel sensor systems, artificial intelligence algorithms, or genome editing technologies—that could improve the research productivity of all agricultural R&D organizations, public and private. Yet other start-ups may be directly competing with established public sector or corporate R&D agendas, seeking to “disrupt” current technologies or ways of doing business.

The VC-backed start-up is effectively a mechanism to contain the financial risks of prospecting in the process of R&D, reducing or managing the technical and market uncertainties of innovation. While many start-ups fail in the attempt, some do prevail in bringing their innovation to market. An increase in the rate of successful start-ups may help counter recent trends of increased market concentration in agribusiness, in which fewer larger firms have been accounting for ever greater shares of private sector R&D (Fuglie 2016). VC-backed start-ups bring Schumpeter’s “gale of creative destruction," supplanting some current technologies and companies. Without innovation, market concentration can lead to exploitative monopolies, but with innovation, new competition can erode monopoly power (Zilberman, Lu, and Reardon 2019).

This chapter investigates the increase in the number of new agricultural technology start-ups globally. What are the dynamics of entry and growth of new firms financed by VC? Where is it occurring? To what extent are they concentrated in high-income countries? And what are the main market categories or technologies they are pursuing?

This chapter also explores a range of economic factors and circumstances that might help explain this growth of VC investments in agriculture. A better understanding of the factors causing this investment will help us anticipate whether it is merely a transient phenomenon or whether it constitutes a more enduring shift in the composition and dynamics of agricultural R&D. Other industries, such as software, internet services, and pharmaceuticals, have both enjoyed exponential growth and endured downturns in venture investment, most famously with the bursting of the tech bubble circa 1999–2000. Yet today, those sectors continue to exhibit an innovation ecosystem that is routinely refreshed by new start-ups funded by VC in an ongoing virtuous cycle. The fundamental question is the extent to which the R&D and innovation system of agriculture is being transformed by this influx of equity-based private investments in R&D-intensive start-up companies and whether it will come to operate more like these other high-tech industries in the long run.

To investigate these changes, we compile a global data set of 4,552 companies in agriculture, founded from 1977 to 2017, with 11,998 associated financial transactions, including investments into and exits from these start-ups. The lack of reporting requirements for privately held firms generally makes it difficult to systematically track start-ups and their financing (Cumming and Johan 2017). To overcome this challenge, we draw primarily from the commercial data vendor PitchBook (by Morningstar) and augment its data with additional company and financial transaction records from competing commercial data sources, VentureSource (by Dow Jones) and Crunchbase (founded by TechCrunch). The financial transactions reported include a range of VC, seed, and angel investments; some other private equity deals; and debt financing. They also include transactions by which early investors and founders exit their investments in these start-ups, such as initial public offerings (IPOs), mergers and acquisitions (M&As), and other types of buyouts. While the transactions data do indicate some bankruptcies and closures of the start-up firms, the reporting of these is incomplete, and so we are left to impute a rate of firm closures based on clues in the data. Together, these data allow us to explore the start-up life cycles and exit outcomes over time and across the full range of different technologies being developed (e.g., biotech vs. software), across the full range of subsectors of agriculture (e.g., inputs vs. outputs, or crops vs. livestock), and across the globe.

Our data summaries show exponential growth in the number of start-ups from about 2009 to the present. The largest share of start-ups is in the United States (33 percent), followed by Europe (23 percent), with the remainder (44 percent) elsewhere in the world. Significant numbers are in emerging and developing economies, such as India (5 percent), China (4 percent), and Brazil (2 percent). In terms of technologies being developed, about one-third of the new start-ups involve computer, information technology (IT), and data-related technologies; another third involve biotechnology, breeding, genetics, or animal health; and the final third encompass a wide range of other technologies, applications, and business models, including marketing and sales, financial and business services, and even on-farm production.

This chapter proceeds as follows. We turn next to a quick overview of the economic literature on agricultural R&D and on VC. We then introduce a new data set on agricultural technology start-ups. The full sample of start-ups is used to track overall trends, such as founding rates, the geography of start-ups globally, and start-ups by technology or industry categories. A narrower subset of start-ups that also have data on their investments is used to analyze growth in investments and factors associated with that growth, both at the firm level and at the industry level. The results suggest that recent surges in commodity prices—together with higher amounts of VC being invested overall and signals from successful exits in agriculture—may have led to the rise in VC investments in agriculture. We conclude that VC investments into start-up companies represent an important new source of R&D expenditures with the potential to transform many aspects of private R&D for agriculture.

## 6.2 Literature Review

### 6.2.1 Financing of R&D in Agriculture

There is a robust agricultural economics literature on the institutional and financing aspects of agricultural R&D (Alston et al. 2010; Huffman and Evenson 2006; Pardey, Alston, and Ruttan 2010; Sunding and Zilberman 2001). Relative to other industries, agriculture has long had a high ratio of public sector to private sector R&D. Pardey and Beintema (2001) tracked spending globally over several decades and estimate that in 1995, total global agricultural R&D was $33.2 billion, of which 65 percent ($21.7 billion) was by public sector sources (defined as research conducted by or funded by governments, academics, or nonprofit organizations), while 35 percent ($11.5 billion) was by the private sector (defined as profit-motivated R&D by privately or publicly held companies and state organizations). Five years later, in 2000, global total spending on agricultural R&D was only slightly higher, at $33.7 billion, and the sectoral shares had adjusted slightly, with the share conducted by the public sector down to approximately 60 percent and the share conducted by the private sector up to around 40 percent (Pardey et al. 2006).

Several key trends have been observed in the composition of agricultural R&D globally. The share of global agricultural R&D conducted in middle- and low-income countries is about 45 percent versus 55 percent conducted in high-income countries, which is a much higher share than overall R&D conducted in low- and middle-income countries, which is 22 percent versus 78 percent in high-income countries (Pardey et al. 2015). However, of the agricultural R&D conducted in low- and middle-income countries, very little of it is in the private sector. Historically, private sector R&D in developing countries is very low: in 1995, of the agricultural R&D conducted in developing countries, only 5.5 percent was by the private sector (Pardey and Beintema 2001).

Over the last two decades, agricultural R&D has grown steadily but unevenly. In the United States and other high-income countries, public sector spending is growing only very slowly in nominal terms and has declined in real terms (Pardey et al. 2016). At the same time, public sector spending has surged in middle-income countries, particularly in China (Hu et al. 2011). Private sector R&D has grown steadily in both high-income and middle-income countries. Private expenditures on agricultural R&D in 2009 were on the order of $10 billion (Fuglie et al. 2011) to $16 billion (Pardey et al. 2015), with differences in the estimates depending largely on which industry subsectors of the agricultural and food system are included or how data for unobserved spending by SMEs is estimated (Fuglie 2016). The most recent available global estimate of private sector agricultural R&D was $15.6 billion in 2014 (Fuglie 2016). At the same time, private sector agricultural R&D has become increasingly concentrated in the hands of fewer, larger companies (Fuglie et al. 2011).

Such accounts, however, have been based primarily on R&D spending by publicly listed companies. It has not been feasible nor, frankly, relevant to be concerned about R&D spending by SMEs, including VC-backed companies. While biotechnology start-ups were observed to have contributed significantly to the rise of genetic engineering in agriculture in the 1980s and 1990s (Fuglie et al. 2011; Fuglie 2016; Graff, Rausser, and Small 2003), levels of R&D spending and other financial data on such privately held companies are relatively inaccessible, as they are not subject to the same reporting requirements as publicly traded firms. Moreover, the relative amounts of R&D spending contributed by SMEs have historically been negligible (Fuglie 2016).

### 6.2.2 Venture Capital Investments

Dixit and Pindyck (1994) developed the standard methodology used to assess investment decisions, taking uncertainty and irreversibility into account. They argue that while the net present value approach is meaningful when considering whether to make an investment at a given moment in time, in most realistic situations, investors also have to decide about the timing of their investment and therefore have to take into account the randomness of key variables such as costs. The timing of an investment is thus triggered when the key random variable exceeds a certain threshold, also known as a hurdle rate. A good example of this approach in agriculture is the uncertainty around investing in new irrigation technologies due to agricultural prices and weather uncertainty (Carey and Zilberman 2002). Farmers only adopt new irrigation technologies when prices exceed a certain threshold.

The same basic logic can be applied to VC investments in agricultural technology start-ups. Even though VC investments have been feasible for decades, it was only after 2010 that they increased significantly (see figure 6.4). Several factors may have affected the hurdle rate, such as an increase in the ratio of agricultural prices to nonagricultural commodity prices, the occurrence of large exit events in highly visible start-ups, the emergence of new technological opportunities based on advances in enabling technologies (such as genome sequencing, genome editing, or data capacity of sensors and networks), and changes in (agricultural) labor markets in both high-income and middle-income countries.

In general, it has been shown that the dynamics of VC markets are driven by several measurable factors, including expected investment returns, the overall health of the economy, industry characteristics, and company financial performance variables (Gompers and Lerner 2004). VC funds that invest in agriculture are no different. Fundamentally, they are seeking returns on investment. Investors compare performance across industries, aspiring to identify high expected returns. Large positive swings in agricultural commodity prices would be expected to shift the supply of VC investments toward start-ups in this industry. Changes in commodity prices such as those observed especially between 2007 and 2014 might have played a role in the increase of the supply of VC investments in agriculture, even though Deloof and Vanacker (2018) observe that Belgian start-ups founded during the 2007 crisis had a greater chance of facing bankruptcy. In examining economic determinants of VC funding, Groh and Wallmeroth (2016) and Jeng and Wells (2000) investigate both developed countries and emerging markets. Groh and Wallmeroth (2016) show that the global share of VC investments in emerging markets increased from 2.4 percent in 2000 to 20.8 percent in 2013, indicating that the salient factors for VC investors are increasingly found in emerging markets.

Gompers and Lerner (2004) point out the greater number of rounds and larger amounts of VC investments go into high-tech industries, such as computers and biotechnology, compared to other more traditional industries. Puri and Zarutskie (2012) compare VC- and non-VC-financed firms and find that the key firm characteristic that attracts VC investment is its potential for scale. Even though agriculture, broadly speaking, may be considered a traditional industry with low margins, most VC investments in the sector are targeting the application of high technologies, such as geospatial technologies, digital sensors, robotics, biotechnology, automated vertical farming, alternative protein products, artificial intelligence–driven decision-making tools, and big data for supply chain management (AgFunder 2015; Graff, Berklund, and Rennels 2014; Rausser, Gordon, and Davis 2018). Regulations can influence investments in agricultural technologies as well. For example, regulations imposed by different countries or regions (such as the European Union) on gene editing might lead to big changes in biotech investments, with potential market uptake depending on whether other countries will follow the European or the American regulatory standards for this technology (Rausser, Gordon, and Davis 2018).

### 6.2.3 Venture Capital Exits

There is a growing literature examining exit outcomes as a key factor in the functioning of venture capital markets. Large exit events, including IPOs and M&As of start-ups may foment further investments. There is evidence on the positive effect of the size of IPO exits (Jeng and Wells 2000) and M&A exits (Félix, Pires, and Gulamhussen 2013; Groh and Wallmeroth 2016) on subsequent VC investments in earlier-stage start-ups. In agriculture, the acquisitions of the Climate Corporation by Monsanto in 2013 for $930 million and of Blue River Technology by John Deere in 2017 for $305 million were widely publicized and may have stimulated subsequent investments by VCs in other agricultural technology start-ups.

The literature investigating start-up exits identifies key factors that affect both new company starts and existing companies' survival, such as real interest rates, other macroeconomic variables, company sizes, and industry-specific variables (Holmes, Hunt, and Stone 2010; Giovannetti, Ricchiuti, and Velucchi 2011). Audretsch (1994, 1995) also shows that such variables can in turn determine the exit outcome—finding, for example, that start-up size is related to chance of exit, while industry growth rate is not. Puri and Zarutskie's (2012) comparison of VC-backed and non-VC-backed companies finds evidence that companies with VC investors have a higher likelihood of resulting in an M&A or IPO exit and a lower likelihood of a failed exit, controlling for industry-specific characteristics and year fixed effects. Gompers and Lerner (2004) have extensive discussions on the likelihood of start-ups going public via IPO, and they show that generally better industry conditions, such as those captured in an industry equity index (e.g., biotechnology index), are positively associated with that industry's number of IPOs.

Previous and contemporaneous exit outcomes, even in emerging and developing economies, are found to be directly associated with VC investments. While Groh and Wallmeroth (2016) find evidence that M&As impact

VC funding positively, Jeng and Wells (2000) find that IPOs play a greater role in determining VC investments in the later stages of the start-up life cycle. Investments into technologies that may be related to the agricultural industry are also location specific (Kolympiris and Kalaitzandonakes 2013; Pe'er and Keil 2013; Kolympiris, Kalaitzandonakes, and Miller 2015; Kolympiris, Hoenen, and Kalaitzandonakes 2017). This, combined with observations that overall agricultural R&D activities have shifted toward emerging markets, makes it reasonable to expect that the share of VC investments in agriculture has shifted toward emerging markets as well.

### 6.2.4 Venture Capital and Innovation

Following results by Kortum and Lerner (2000), which suggest that VC dollars may be three times as productive as corporate R&D dollars in generating patents, a number of studies have examined the relationship between VC and innovation. The hypothesis that VC-backed firms are more innovative is consistent with more general observations that VC investors select firms that are more likely to succeed and to do so at scale (Baum and Silverman 2004; Engel and Keilbach 2007; Puri and Zarutskie 2012), but there is also evidence that VC investors encourage companies in which they invest to enhance their knowledge absorption and R&D capacity (Da Rin and Penas 2017). There is evidence that start-ups receiving VC investments file more patent applications both in the short run and more permanently, and moreover, those patent applications are more likely to be granted, an indication of higher-quality innovation (Arqué-Castells 2012).

Within the population of VC-backed start-ups, there may be higher payoffs for those that are more innovative. Nadeau (2011) finds that VC-backed start-ups that exit via the more profitable IPO route are more likely to be engaged in patenting than those that exit via M&A, at least in key sectors such as biotechnology, IT, and internet services. Gaulé (2015) similarly finds that VC-backed start-ups with higher-quality patents are more likely to be successful, exiting via an IPO or a highly valued M&A.

One question that arises is the extent to which private equity or VC investment into start-up companies can be compared to or even proxy for R&D expenditures. Kortum and Lerner (2000) and Metrick (2007) distinguish between R&D financed by corporations and R&D financed by VC. However, publicly traded corporations report R&D expenditures according to established requirements, while small privately held firms do not. Kortum and Lerner (2000) assume that the bulk of venture financing goes to support innovative activities while acknowledging that some VC investments may be made in low-technology start-ups or may be spent on other activities such as marketing. Whether these exceptions are greater in agriculture than in industries that have traditionally received VC investment is an important but ultimately empirical question.

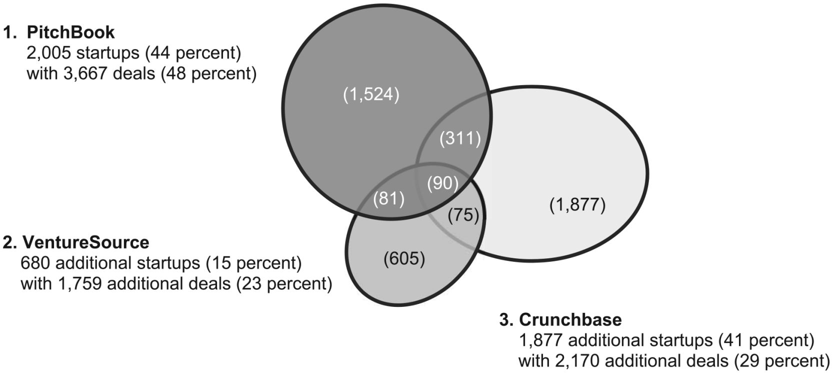



**Fig. 6.1 Venn diagram of data accessed on new start-ups in agriculture and their financial deals by data source**

*Note:* Our primary data source is PitchBook, augmented by additional company and financial deal records from VentureSource and then Crunchbase; data for just 12 percent of total start-ups were found to be available from more than one source.

## 6.3 Data on Venture Capital Investments in Agriculture

The data for this first look at VC investment in agriculture is drawn from several commercial data sources and consists of information on 4,552 start-up companies and 7,596 financing deals. We follow the approach of Hall and Woodward (2010) to compile a data set drawn from a variety of sources in order to overcome the limitations of data reporting and potential biases of any one source. Of the sources we draw on, the industry standard is generally regarded to be PitchBook, a financial database focused on VC and private equity investing, owned by Morningstar. Data from PitchBook are then augmented with data from two other sources: VentureSource and Crunchbase. From each source, two types of data are available, linked in a one-to-many relationship: data on companies and data on financing deals of those companies.

A comparison of company data listings across these three sources was undertaken with an expectation that overlap among data sources would allow for the cross-validation of firms and their deals. However, as figure 6.1 illustrates, we find minimal overlap of company listings across these sources. Our initial sampling, drawn from PitchBook, included 2,005 companies founded in the 40 years from 1977 to 2017, along with 3,667 financial deals for those companies, as designated by PitchBook's "AgTech Vertical" industry category.[1] From VentureSource, by Dow Jones, we drew an additional

1. PitchBook (n.d.) defines an industry vertical or vertical market as "a more specific industry classification" that "identifies companies that offer niche products or fit into multiple industries" or that represents "new fields with promising companies that attract investors." PitchBook describes the agtech vertical as consisting of "companies that provide services, engage

680 companies with 1,759 associated deals—identified by VentureSource's "Agriculture and Forestry" industry category[2]—that were not found in the PitchBook data. From Crunchbase—identified by their "Agriculture and Farming" industry group[3]—we drew an additional 1,885 companies beyond those listed in either PitchBook or VentureSource and 2,170 associated deals for those companies. Just 557 (12 percent) of the total companies were found in more than one data source, and only 90 (2 percent) of the total companies identified were listed in all three sources.[4] This pattern of data availability suggests that any analysis based on one primary data source (e.g., AgFunder 2015, 2019; CBInsights 2017; Finistere Ventures 2019; KPMG 2018) provides only a limited and largely separate sampling of overall venture investments in the industry.

Of the total 4,552 unique companies and 7,596 unique deals, we take about half of the data records on companies and deals in our collection from PitchBook and the other half from VentureSource and Crunchbase (figure 6.1). Of these sources, PitchBook had the most complete data overall, VentureSource was more complete in reporting older companies and deals, and Crunchbase was helpful in identifying a wider range of start-up companies internationally, but unfortunately, it was not able to provide as much coverage of deal information for those firms. Overall, deals data are associated with only 1,584 (35 percent) of the companies in the combined data set. Of the subset of companies with deal data, 1,366 (29 percent of the total) report at least one deal in which the amount is disclosed (others report deals that occurred but do not disclose amounts), and 1,092 (24 percent) report an identified exit deal.

Given these discrepancies in the availability of deal information, the subsequent analysis is undertaken in two parts. First, we summarize major industry trends using the full data set of 4,552 companies. Second, we summarize investments and exits for the 1,348 start-ups with accompanying deals data that disclose amounts, and we analyze those factors that may be associated with the recent growth in those investments. Arguably, given the skewed nature of valuations and investments in VC markets generally,

in scientific research, or develop technology which has the express purpose of enhancing the sustainability of agriculture. This includes wireless sensors to monitor soil, air and animal health; hydroponic and aquaponic systems; remote-controlled irrigation systems; aerial photo technology to analyze field conditions; biotech platforms for crop yields; data-analysis software to augment planting, herd, poultry and livestock management; automation software to manage farm task workflows; and accounting software to track and manage facility and task expenses."

2. VentureSource's "Agriculture and Forestry" industry category is a subset within its larger category of "Industrial Goods and Materials."

3. Crunchbase's "Agriculture and Farming" industry group includes companies in agriculture, agtech, animal feed, aquaculture, equestrian, farming, forestry, horticulture, hydroponics, and livestock.

4. For those 12 percent listed in more than one data source, for each company we use only data from one source, depending on availability, in the following order of preference: (1) PitchBook, (2) VentureSource, (3) Crunchbase. See the numbers of companies and deals in figure 6.1.

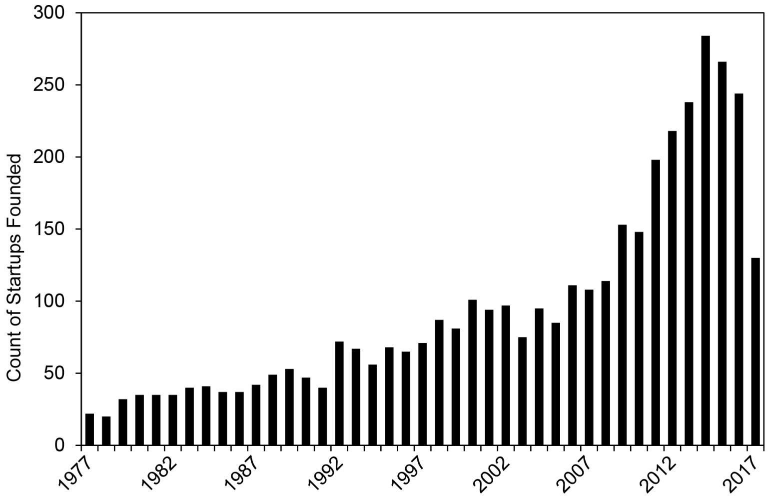



**Fig. 6.2 VC-funded start-ups in agriculture by founding year, 1977–2017**
N = 3,891 companies for which founding year is reported or proxied by first deal date

together with a propensity to report information on larger, more significant investments and exits (Hall and Woodward 2010), it stands to reason that the 29 percent of companies with disclosed deals represents a greater share of the overall financing activity in the industry. It is important to emphasize that despite efforts to be inclusive, this data set is still necessarily an under-representation of overall activity in the industry. Yet it provides a broad, representative sampling of private investment activity across agriculture globally.

### 6.3.1 Full Combined Data Set of Start-Up Companies in Agriculture: Global Summary Statistics

For many of the 4,552 companies in the combined sample, the founding date is available. For those companies with the founding date missing but for which deal information is available, we use the date of the first deal as a proxy for the founding year. Figure 6.2 plots the number of start-ups by founding year.

Qualitatively, there appear to have been three phases of growth in agricultural start-ups. First, from 1977 to 1991, we see steady, slow growth, with between 20 and 50 start-ups globally each year (however, this time period precedes the full data coverage for some of the countries and/or data sources on which this data set draws). In the second phase, from 1992 to 2008, the growth rate appears to have increased, yet it also appears to be more volatile—characteristic of the wider tech sector during this period—

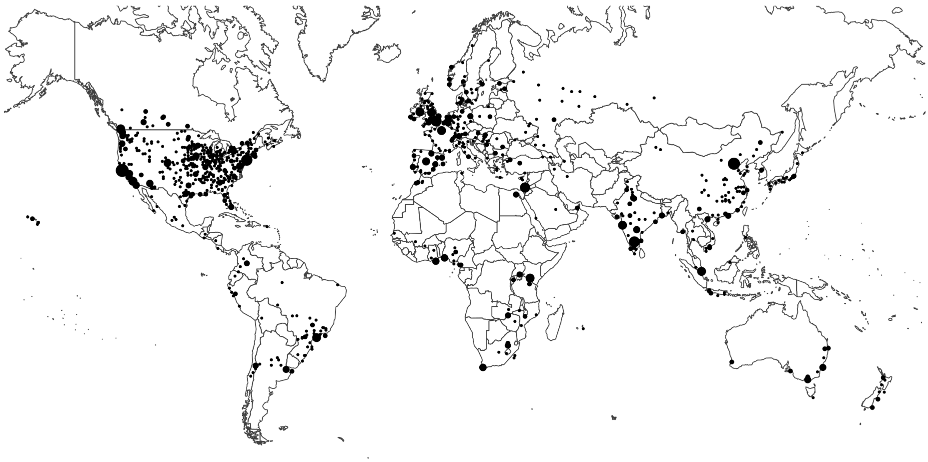
with a downturn for several years following the bursting of the tech bubble in 2000. Third, starting in 2009—a year after grain prices reached a peak associated with the expansion of the US biofuel mandate (Wright 2009)—growth in start-ups experienced a sharp increase that, arguably, continues until the end of the time frame of this analysis despite the right-hand truncation seen here.[5]

The overall sample of 4,552 companies also includes data on physical address, which allows us to analyze the geographical distribution of entrepreneurship in agriculture globally. We find 1,483 start-ups in the United States, which accounts for about 33 percent of the global sample (figure 6.3). Within the United States, by far the most are in the state of California (348), with other leading states including Colorado, New York, Texas, Massachusetts, and Illinois. Of the US start-ups, 320 were located across the 11 midwestern states that encompass the highly fertile Corn Belt region. The European Union has 1,063 start-ups, accounting for about 23 percent of the global total, led by the United Kingdom (with 261), France (173), and Spain (102). Canada is home to 228 start-ups (5 percent of the global total). Among the emerging markets, India stands out with 210 start-ups, followed by China (172). South American countries have 144 start-ups in the sample, led by Brazil (88). Agricultural start-ups are also found in Africa, with the most in South Africa (41), followed by Kenya (31) and Nigeria (27). The pattern of VC-funded start-ups follows the growth pattern of VC in developing countries identified by Groh and Wallmeroth (2016). This global distribution of start-ups appears to track somewhat more closely with the pattern of public sector agricultural R&D, with a significant share in emerging and developing economies (Pardey et al. 2016), compared to the pattern of private sector agricultural R&D, which is more heavily concentrated in high-income countries (Fuglie 2016).

The categorization of start-up companies by industry—or of innovations by technology field—has long been a fraught exercise. Of the three data sources, each provides several data fields describing the company, its market activities, and the technologies it is developing. However, the descriptions of companies are very heterogeneous, even within the same data field from the same source. Even standardized industry category variables, which are more consistently reported within each data source, are not readily comparable across the three data sources. We therefore construct a common categorization for the start-ups in the combined sample, drawing on the full range of these descriptive data fields across all three sources based on

5. The apparent decline in start-ups after 2014 is, arguably, due to truncation in the data. New companies generally get reported to these data sources upon their first formal equity-based investment, which can occur up to several years following the founding of the company. Industry reports such as AgFunder (2019) show steady continued growth in start-up activity through 2018.

A. Global Density Mapping, by City and/or Postal Code



B. Global Share, by Country and Region

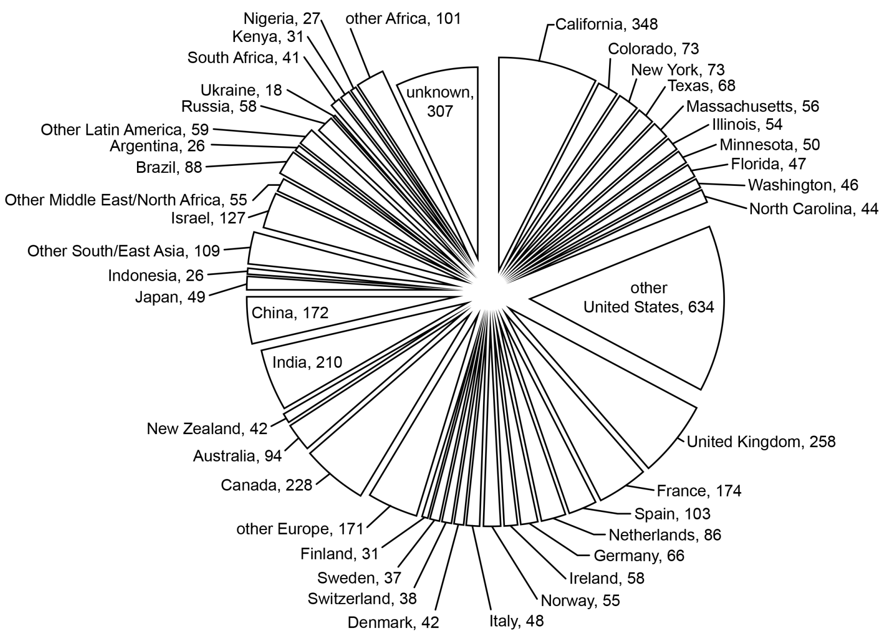



**Fig. 6.3 The global scope of new VC-funded start-ups in agriculture, 1977–2018**

*Note:* (a) Global density mapping by city and/or postal code and (b) global share by country and region

**Table 6.1** **Industry and technology categories characterizing venture-funded start-ups in agriculture**

| Category* | Number of start-ups with activities described by each category |
|---|---|
| Agricultural input technologies and services | 2,482 |
| Software, data, and information technologies | 942 |
| Electronic devices, sensors, and systems (electronic hardware) | 430 |
| Genetics, breeding, biotech, and health | 918 |
| Chemicals | 230 |
| Machinery and equipment (mechanical hardware) | 302 |
| Agricultural input distributions and sales | 678 |
| Agricultural production and farming | 467 |
| Agricultural output marketing, processing, and manufacturing | 730 |
| Consumer products and services | 105 |
| Business and financial services | 539 |
| Online services and content | 471 |
| Unspecified | 1,165 |

N = 4,552 firms, of which 1,226 (27 percent) are identified with two or more categories

industry observations (see Graff, Berklund, and Rennels 2014; Dutia 2014; and AgFunder 2019), as detailed in the appendix.

It is important to note that the categories we develop are not exclusive. By their very nature, start-ups often span more than one industry or technology. Of the 4,552 start-ups in the data set, 1,226 (27 percent) span more than one category in table 6.1. Of these, 1,048 start-ups are classified in two categories, 161 in three, and 15 in four. For example, we have a start-up that is developing sensors with specialized data management tools to conduct high-throughput phenotyping to decipher crop genetics. Such a firm would be labeled with three of these categories: (1) electronic devices, sensors, and systems; (2) software, data, and information technologies; and (3) genetics, breeding, biotech, and health. While such an approach does result in multi-counting of firms by categories, it is not an uncommon practice.[6]

Table 6.1 displays the number of start-ups described by each of the categories we developed. Just over half of the start-ups in the data set are involved in some form of agricultural input technology or service, which in turn encompasses a number of different technology-based subcategories. Of these, the two largest are software and data (which describes 942 start-ups) and biotech, genetics, or health (which describes 918 start-ups). Companies identified by one or both of these categories attracted more than 60 percent of the venture investments made in the industry in 2016.

6. For example, under the International Patent Classification (IPC) system, multiple patent classifications can be assigned to a single patent.

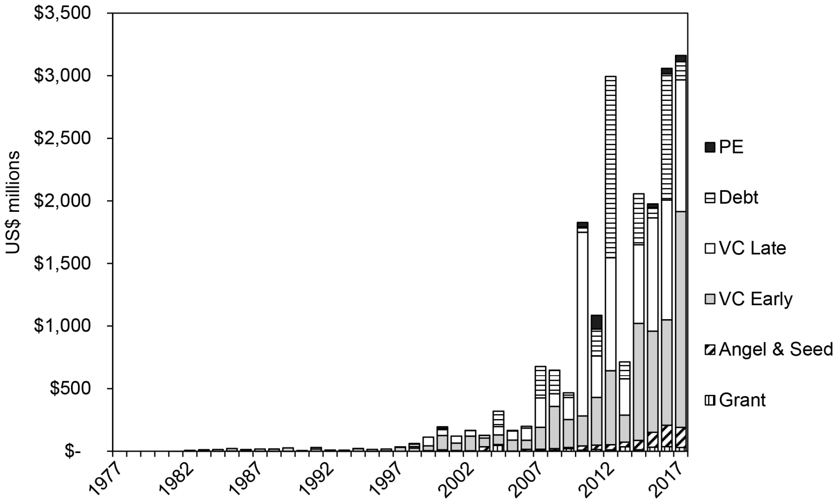



**Fig. 6.4 Investments into VC-funded start-ups in agriculture by type of investment, 1977–2017**

*Note:* PE = private equity; VC = venture capital

### 6.3.2 Subsample of Companies with Reported Deals: Investments and Exits

Of the 4,552 companies in the overall data set, only 1,584 (35 percent) are associated with the 7,596 reported deals (which, again, include investments, successful exits, and reported closures or bankruptcies). However, of these reported deals, many do not disclose the amount of the deal. To analyze VC investment trends, we narrow our information down to a subsample of just those 1,367 start-ups (29 percent of the overall sample) that report at least one venture-type money-in investment with a disclosed amount. In other words, all additional money-in investments received by that same start-up are considered in this analysis, including grants, angel, and seed stage investments; early-stage VC, late-stage VC; debt; and any other private equity investments. Companies that did not report deal amounts and companies with only private equity investments or debt financing were dropped from the sample for this part of the analysis. Figure 6.3 displays the total money-in investments by type and year for those firms from 1977 to 2017.

Total money-in investments over the entire period were $22.1 billion. Following the growth in new start-ups overall (see figure 6.2), investments exhibited a sharp increase starting in 2010 and reached an annual maximum of $3.2 billion in 2017 (figure 6.4). We can be confident that this maximum would be exceeded in 2018 were these data not truncated, as industry reports indicate investments in 2018 significantly exceeded those in 2017 (AgFunder 2019). Early- and late-stage VC (totaling $8.1 and $8.4 billion, respectively) represent most of the money raised by these start-ups. Even though absolute amounts increased substantially over time, the composition of investments between early-stage and late-stage VC remained quite stable. Debt financing of these firms totaled $4.2 billion but appears more sporadic, coming in large tranches when it does occur.

The ultimate fates of the 1,584 start-up companies with any associated data on transactions can be roughly divided into three types of outcomes. First, some start-ups go through a successful financial exit. In that transaction, the initial venture investors are able to exit their ownership of otherwise illiquid equity shares and realize a return on their investment. Successful exits include IPOs, M&As by other companies, and other less common buyouts, such as management buyouts or private equity buyouts. Second, the fate of start-ups that are not successful is the closure of the company—with some filing for bankruptcy, some liquidating assets, and some quietly winding down operations until they are effectively defunct. The third fate, if neither of the other two has occurred, is for a start-up to remain in business as a privately held company.

Cumulatively, for the 1,584 start-ups for which we have transaction data, we find that 150 (9.5 percent) exited via IPO, 739 (46.7 percent) exited via M&A, and 159 (10.0 percent) exited via some other buyout. Interestingly, just 49 of the start-ups (3.1 percent) reported closure or bankruptcy, implying that 487 (30.1 percent) are still in business. Not only does this ratio seem unrealistic, but others have identified a strong bias against negative news—including firm closures, small investments, and other indicators of underperformance—in VC data sets such as these (Hall and Woodward 2010). We find that of the 49 start-ups that do report closures, 90 percent of these closed within four years of their last money-in deal. It stands to reason that companies relying on VC need to raise new money every two to four years, and if they stop doing so, it is a strong indication that they have closed. Given that many of the 487 (30.1 percent) start-ups deemed "still in business" had fallen silent, lacking any newly announced deals for more than four years, we estimate that 417 (26.3 percent) face a similar probability of having closed, and thus, just 70 (4.4 percent) of the total sample were likely still in business.

Looking at exits and closures over time (figure 6.7a), we see that they occurred only sporadically prior to the mid-2000s. The number of exits began to grow steadily after 2005 and peaked in 2015. The number of closures (reported and estimated) began to increase about five years later, around 2010. Exit amounts are much more sporadic and took off dramatically in 2008, when over $2.3 billion was realized by investors (figure 6.7b). The maximum year for exit amounts was 2013, at close to $6 billion, mostly due to M&As. While the counts of exits (figure 6.7a) have displayed a smoother year-on-year growth trend, the sporadic nature of the values of exits (figure 6.7b) belies the tendency for exit valuations of start-ups in VC portfolios to be highly skewed, which has been generally observed in venture investing for decades (Gompers and Lerner 2004; Metrick 2007).

## 6.4 Analysis of Factors Associated with Increased Venture Capital Investments in Agriculture

There are a number of possible explanations for the sharp increase in agricultural technology start-ups beginning in 2009 (figure 6.2) and the steep rise in private investments into those companies starting in 2010 (figure 6.4). The simplest hypothesis, following the logic of Dixit and Pindyck (1994), is that prices across the industry pushed potential returns above a critical threshold. Agricultural commodity prices, indeed, increased strongly in 2007 and 2008 and then, after a correction in 2009, surged to even higher levels from 2011 to 2014 (figure 6.5a). While certainly logical, agricultural commodity prices alone do not seem sufficient to explain why VC investments began to flow into agriculture.

A more nuanced hypothesis is that the ratio of commodity prices in agriculture to prices in other sectors of the economy, particularly energy, may have diverted investments toward agriculture. And the timing of those shifts may also have played a role. "Cleantech" investment funds—which had focused primarily on the energy sector, presumably encouraged by high energy prices—may have discovered agriculture when investing in biofuels. Crude oil prices faced a sharp increase in 2007 and 2008, followed by a marked downturn in 2009, and while oil rebounded and remained around \$100/barrel from 2011 to 2014, it fell back to less than \$50/barrel within a year (figure 6.5b). At key points when oil prices dropped, investors in cleantech may have pivoted toward opportunities in agriculture as agricultural commodity prices remained higher. While such conditions seem to have held for only short windows of time (comparing figures 6.5a and 6.5b), the swings in price ratios may have been enough for venture investors to have discovered the agricultural sector. Once found, agriculture continued to be a focus of investor attention.

There is also very likely a supply-side factor, given that overall VC investments in the economy increased steadily during this period. Ewens, Nanda, and Rhodes-Kropf (2018) document an increase in investment volume by existing VC firms as well as an increase in entry by new financial intermediaries after 2006. Figure 6.6 shows that growth in investment in agtech appears to be correlated with total VC investment in the United States (PwC 2019) Thus an additional hypothesis is that a greater supply of VC coupled with lower costs of early-stage investing in this time period pushed VC investing into adjacent industries from its traditional core of software, computer/networking equipment, online businesses, and biotechnology (Ewens, Nanda, and Rhodes-Kropf 2018).

Finally, it is reasonable to expect that market signals from successful exits may have played a role. The most desired outcomes for VC investors are IPO

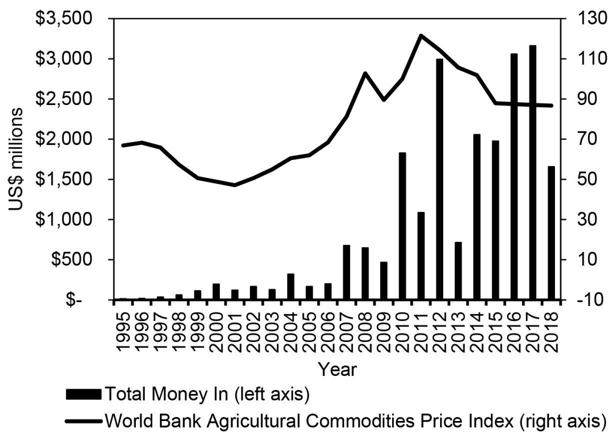



**Fig. 6.5a Investments in agricultural technology start-ups plotted against agricultural commodity prices (base year 2010 = 100)**

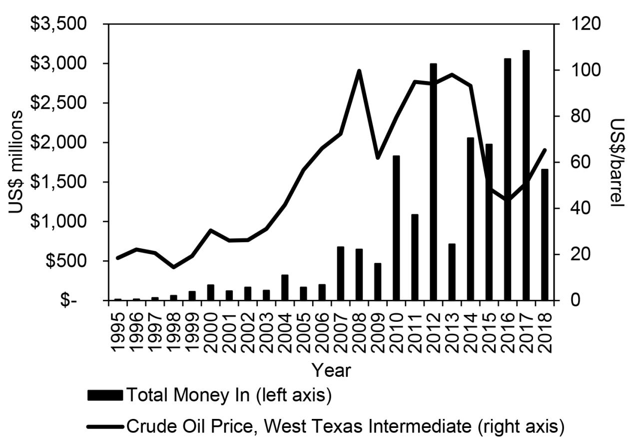



**Fig. 6.5b Investments in agricultural technology start-ups plotted against oil prices (US$/barrel)**

or M&A exits, as these generate the largest payoffs. Other exit outcomes, such as management buyouts or asset acquisitions, might merely return the initial investment via the sale of the start-up's assets. Gompers and Lerner (2004), Jeng and Wells (2000), and a literature spawned by such studies present evidence that successful exits influence subsequent VC investments.

Anecdotally, there were several large exits from agricultural start-ups in the years around the upturn in venture investment—including the $283 mil-

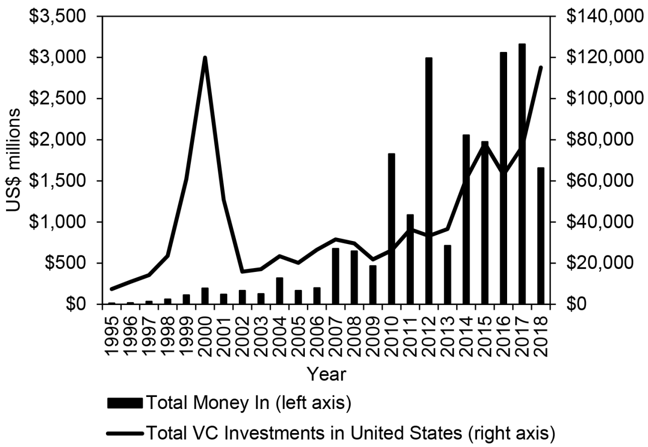



**Fig. 6.6 Investments in agricultural technology start-ups plotted against total annual VC investments in the United States**

lion IPO of Agria in 2007, the €1.9 billion private equity buyout of Arysta LifeScience in 2008, and the $279 million IPO of Digital Globe in 2009. According to the data, a regular rhythm of IPOs and M&As began in 2006, with significant returns first logged in 2008 (figures 6.7a and 6.7b) coinciding with the sharp increase in the numbers of new start-ups (figure 6.2) and investments (figure 6.4). In agriculture, it appears that M&As have generated much larger gross returns for VC investors than IPOs (figure 6.7b). These patterns corroborate the idea that the occurrence of IPOs and M&As signal returns being made on venture investments in agriculture, thus helping attract new investors to the newer start-ups in agriculture.

### 6.4.1 Regression Analysis of Investments at a Firm Level

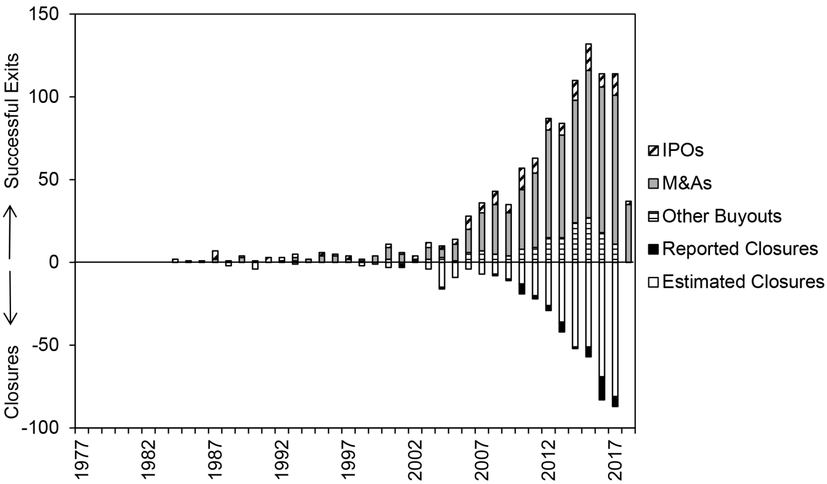
A regression analysis was undertaken to offer a more systematic description of the relationships between VC investments in agricultural start-ups and several of these factors hypothesized to influence decisions by venture capitalists to invest. A simple framework used for analysis at the firm level is described by equation (1):

$$(1) \quad y_{it} = \alpha + \beta_1 P_{1,t-k} + \beta_2 P_{2,t-k} + \beta_3 \mathrm{VC}_t + \delta_1 ee^{m\&a}_{t-k} + \delta_2 ee^{ipo}_{t-k} + X_i\theta + u_{it},$$

where the dependent variable, $y_{it}$, is the sum of reported amounts of investments received by a start-up $i$ in year $t$. If a start-up did not exist in year $t$, the observation is dropped. If a start-up did exist in year $t$ but simply received no investment, the observation is kept, and $y_{it} = 0$. If a start-up received more than one investment in a given year, then those investments are summed.

Of the independent variables in equation (1), the $P_{1,t-k}$ are agricultural commodity prices, lagged $k$ years, for which World Bank and Food and

A. Counts of successful exits and closures for the 1,584 startups with associated deals data, 1977-2018




B. Amounts realized from successful exits, 1977-2018

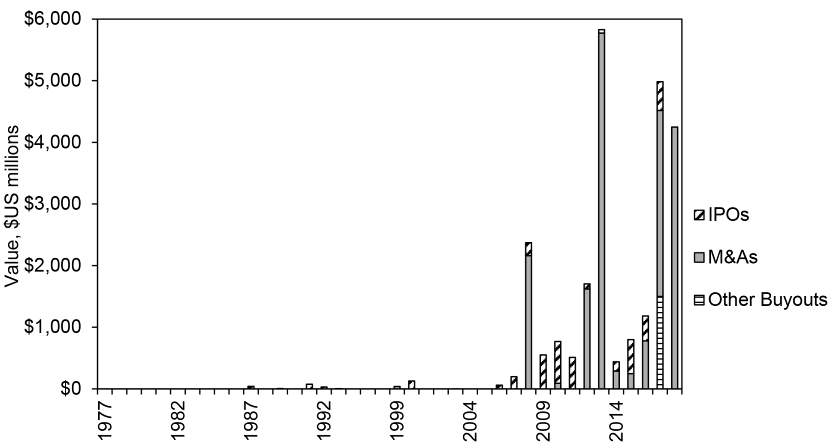



**Fig. 6.7 Exits by VC investors from start-ups in agriculture**

Agriculture Organization (FAO) agricultural commodity price indices as well as nominal soybean prices are considered. We also focus our analysis on possible changes in the relationship with agricultural commodity prices in the period after 2000, when they began to grow and became more volatile, by interacting agricultural prices with a date range dummy variable. The $P_{2t}$ are nominal oil prices. The $VC_t$ are total annual VC investments in the United States according to PricewaterhouseCoopers (PwC). The exit variables $ee_{t-k}^{m\&a}$ and $ee_{t-k}^{ipo}$ measure the annual sum of money raised in IPO and

M&A exits of the agricultural start-ups in the sample $k$ years prior to year $t$. The $X_i$ are control variables. The sample is very heterogenous, including firms in different stages of the start-up life cycle, in different countries, and in different industry categories. Company age is used to control for stage in the start-up life cycle. Dummy variables are added for start-up locations in the United States and Europe. And dummy variables are added for the 12 industry categories described in table 6.1. Finally, $u_{it}$ is the random error term clustered at the firm level.

Since data for the independent variables of oil prices and total VC investments were available only after 1995, the sample incorporates investment activity from 1995 to 2017. We build an unbalanced panel that consists of 12,094 observations involving 1,447 start-ups. Most of the firms were founded after 1995, with the frequency of firms entering the data set increasing toward the end of the period, according to the trend illustrated in figure 6.2. We have 2,439 firm-year observations with positive investment values and 9,655 with zero values. Due to this censoring from below, we use a tobit regression model.

We are not attempting to deal here with three important econometric challenges in working with these data. First, we are not dealing with unreported data, at two levels, in the dependent variable: for many start-ups, we observe that investments occurred, but their value is not reported, which therefore gets represented as a zero value; but we also know that there are many more investments that are entirely unreported. Second, we are not dealing with the unbalanced nature of the panel. And third, we are not attempting to deal with the endogeneity or the dynamic nature of these investments. Clearly, the trends we have summarized in the previous section are all largely moving in the same direction, making identification problematic yet beyond the scope of this chapter's objective as a descriptive exercise.

Table 6.2 presents results for the firm-level regression described by equation (1). The estimation results corroborate observations from the summary statistics displayed in figure 6.5a that trends in agricultural commodity prices are positively associated with trends in investments in agtech start-ups. The result that investments are more strongly associated with agricultural commodity prices after 2000 is consistent with the notion that growing commodity prices could have shifted the attention of VC investors toward agricultural markets.[7] Oil prices, in contrast, are negatively related to investments. This may be picking up the trends visible in figure 6.5b—namely, that investments initially remained low as oil prices increased and then later boomed as oil prices fell.[8]

7. Estimation results were found to be robust across various versions of the model that used different prices and lags, not reported here.

8. In addition, we tested the effect of the ratio of agricultural commodity prices to oil prices in regressions not reported here, with a larger ratio indicating a potentially greater return in agriculture compared to energy. We find a strong positive effect of the price ratio on the size of

**Table 6.2** **Firm-level tobit regression of commodity prices, lagged exits, and total VC supply on investments made in existing firms annually over the period 1995−2017**

| Independent variables | Dependent variable: Amount invested in firm *i* in year *t* |
|---|---|
| Ag commodity prices | 0.01170 |
| | (0.02122) |
| Ag commodity prices after 2000 | 0.08949*** |
| | (0.02211) |
| Oil prices | −0.31869*** |
| | (0.08935) |
| Ag IPO amounts, lagged 1 year | 0.01204*** |
| | (0.00443) |
| Ag M&A amounts, lagged 1 year | 0.00179*** |
| | (0.00049) |
| Total VC invested in US | 0.00026*** |
| | (0.00005) |
| Firm age | −0.88796*** |
| | (0.18550) |
| EU dummy | −1.99442 |
| | (1.32819) |
| US dummy | 9.52096*** |
| | (2.35058) |
| Industry category dummies | |
| Constant | −85.62672*** |
| | (18.55865) |
| Observations | 12,094 |

*Note:* Standard errors in parentheses. *** for 1 percent significance, ** for 5 percent, and * for 10 percent. All lagged variables are lagged only one period. IPOs and M&A values for agriculture and total VC for the United States are in US$ million; ag commodity price is the nominal US soy price in US$/metric tons; oil price is West Texas Intermediate (WTI), Cushing, Oklahoma, US$ per barrel, annual, not seasonally adjusted, available at FRED. Dependent variable of annual firm deals value is in US$ million.

The variable of total VC investments reflects the overall health of VC markets and implies a greater availability of VC investments, which is plausibly associated with increased investments in start-ups in agriculture, all else being equal.[9]

Coefficients on the agIPO and agM&A variables indicate that the higher amounts realized in a previous year's exits by agtech start-ups are positively associated with higher investments in agtech start-ups in subsequent

investments when limited to the 2000–2017 window. The coefficient on the price ratio over the entire time frame is, however, not significant.

9. We also separately added an interaction between the total VC investments variable and a 2000–2018 dummy, but the resulting coefficient indicates no stronger relationship during this more limited period.

years.[10] IPOs appear to be more strongly associated than are M&As, but both are statistically significant in this regression. Both types of exits could be interpreted as playing a role in signaling returns and attracting investments into agriculture, in line with previous observations in the literature (Gompers and Lerner 2004; Jeng and Wells 2000).

Additional insights arise from the control variables in equation (1) and table 6.2. It appears that location is an important differentiator. Even though similar numbers of start-ups are found in the United States and Europe (figure 6.3b), the estimated coefficient on the US dummy variable is strongly positive and significant, while the estimated coefficient on the European dummy variable is negative and significant. This corroborates common observations that VC finance is more mature and active in the United States, and generally, US start-ups tend to receive greater VC investments compared to non-US start-ups. The estimated coefficient on the company age variable would be expected to be positive to indicate a positive relationship between age and investments: companies that have been in the market longer and have grown larger tend to receive larger VC investments, which is by design in most VC investment strategies (Gompers and Lerner 2004; Metrick 2007). The negative coefficient on company age likely reflects a high frequency of zero annual investments for older start-ups. This could arise because we still give four years of zero investments after the last reported investment to those companies that we estimate are ultimately closed; perhaps this is too generous, if many of these companies in fact closed sooner (and thus those observations should have been dropped rather than assigned a $y_{it} = 0$). Coefficients on industry category dummies are positive and significant (in order of magnitude) for (1) biotechnology, genetics, and health; (2) chemicals; and (3) software, data, and information technologies, indicating relatively more and/or larger investments are received by companies in these categories.

### 6.4.2 Regression Analysis of Investments at an Industry Level

To explore venture investments made at the level of the industry categories described in table 6.1 (and detailed in the appendix), a similar model is estimated:

$$(2) \quad y_{ct} = \alpha + \beta_1 P_{1,t-k} + \beta_2 P_{2,t-k} + \beta_3 VC_t + \delta_1 ee^{m\&a}_{t-k} + \delta_2 ee^{ipo}_{t-k} + X_c\theta + u_{ct},$$

where the dependent variable now is $y_{ct}$, the annual sum of investments for all start-ups in industry category $c$ during year $t$. There are reasons to believe that factors affecting investment may vary across industry or technology. As already noted, about a quarter of the start-ups in the sample are categorized in more than one industry classification due to the multidisciplinary nature of the technologies being developed or due to integration across markets. We therefore split these start-ups' investment amounts across the relevant

10. Test regressions find that exits in the same year are not significantly related to investments.

**Table 6.3** **Industry-level tobit regression of commodity prices, lagged exits, and total VC supply on investments made in 12 industry categories annually over the period 1995–2017**

| Independent variables | Dependent variable: Amount invested in industry category *c* in year *t* |
|---|---|
| Ag commodity prices | 0.29046 |
| | (0.25682) |
| Ag commodity prices after 2000 | 0.49434** |
| | (0.22219) |
| Oil prices | −2.72660 |
| | (1.73527) |
| Ag IPO amounts, lagged 1 year | 0.18959*** |
| | (0.06578) |
| Ag M&A amounts, lagged 1 year | 0.01305* |
| | (0.00693) |
| Total VC invested in US | 0.00085** |
| | (0.00040) |
| Industry category dummies | |
| Constant | −372.03315*** |
| | (103.07161) |
| Observations | 288 |

*Note:* Standard errors in parentheses. *** for 1 percent significance, ** for 5 percent and * for 10 percent. All lagged variables are lagged only one period. IPO and M&A values for agriculture and total VC for the United States are in US$ million; ag commodity price is the nominal US soy price in US$/metric tons; oil price is West Texas Intermediate (WTI), Cushing, Oklahoma, US$ per barrel, annual, not seasonally adjusted available at FRED. Dependent variable of annual firm deals value is in US$ million.

categories (e.g., if start-up A appears in two categories, we multiply its investments in year *t* by 0.5 and allocate to both categories for year *t*). The independent variables are the same as defined for equation (1).

We build a balanced panel of 12 industry categories over 24 years from 1995 to 2018 to estimate a fixed effects model also using a tobit regression model. Table 6.3 presents estimation results for investments aggregated by industry category. At this level of aggregation, coefficients on the independent variables are naturally greater than in the firm-level analysis. Agricultural commodity prices, at least after 2000, exhibit a significant positive coefficient. Oil prices are again negatively related to investments in agricultural start-ups. Coefficients on the agIPO and agM&A variables are again positive and significant, with the magnitude of the IPO coefficient again larger than the M&A coefficient. The variable for total annual VC investments is positively and significantly related to VC investments in agriculture.

At the industry level of aggregation, not all of the control variables used in the firm-level analysis—such as age or location—are meaningful. Fixed effects for industry categories are jointly statistically significant. A few of these have larger values, including (in order) (1) online services and content; (2) software, data, and information technologies; (3) marketing, processing, and distribution; and (4) agricultural input distribution and sales, indicating that relatively more frequent and/or larger aggregate investments are received in these categories.

## 6.5 Summary and Conclusions

The VC-backed start-up is a mechanism to contain the financial risks of prospecting and thereby manage the technical and market uncertainties of innovation. The population of start-ups developing innovations for agriculture has increased substantially over the last decade in not only high-income countries but also emerging and developing countries. Venture investments in such start-ups have grown as well—almost half as much as the estimated amounts of global corporate agriculture R&D expenditures. This first look has introduced extensive representative data on start-up companies related to agriculture and their financial transactions, and it has explored several factors that are likely to be related to the observed increase in private venture investment in agricultural R&D.

Simple tests of several hypotheses suggest that agricultural commodity prices and successful exits have been closely associated with increased VC investments in agriculture. Especially the run-up in agricultural commodity prices after 2000 appears correlated with investment levels. Both IPO and M&A exit amounts realized by agricultural start-ups are associated with subsequent investments at both the firm and industry levels. IPOs appear to have a stronger relationship with new investments than do M&As, even though a much larger share of the returns realized from exits come from M&As. Investments in agricultural start-ups are to some extent technology specific, favoring biotech, online businesses, software, commodity processing, and agricultural input dealers. There is also evidence that start-ups in the United States receive more venture investments than start-ups in other countries, all else being equal.

This analysis sheds light on an important new source of R&D expenditure that has the potential to transform many aspects of private R&D for agriculture, altering the risk profile of innovations being pursued, the networks of highly skilled human capital being accessed, and the market power of companies introducing innovations throughout the agricultural value chain. Much is needed in the way of further economic analysis of these trends to improve on current models and explore the factors potentially driving such investments (e.g., public sector research, other sources of technological opportunity, increased labor costs, or shifts in consumer demand) and the determinants and impacts of different types of exits (with IPOs creating independent competitors but M&As putting new technologies under the control of industry incumbents). Venture capital has discovered agriculture, but it has only begun to impact agriculture.

## Appendix

### *Characterization of Agricultural Start-Up Firms by Industry and Technology*

In the data obtained from commercial vendors, either start-up companies self-report or the commercial data vendor composes a business description, usually a short paragraph, and assigns an industry code or segment categorization. These vary, however, across vendors. In order to ascertain more uniformly the industry or technology in which start-ups are engaged, we queried and filtered the company description and industry categorization fields to assign start-ups to 12 categories, as summarized in table 6.1. These categories are relied on to introduce field-specific controls in our estimations (tables 6.2 and 6.3). The following notes describe in greater detail the types of businesses that are included in each of the categories:

Business and financial services

1. Real estate, land brokerages
2. Human resource management, labor contracting, training and education services
3. Financial services, investment
4. Insurance, risk management
5. Industry associations and advocacy
6. Economic development and regional development organizations
7. Business-to-business (B2B) services or marketplaces (in combination with the online category)
8. Publishing, catalogs, information for industry clients (may be in combination with the online category)
9. Consulting and advisory services
10. Contract research services

Online services and content

1. Online, website, web, or portal; often platform
2. B2B or business-to-consumer (B2C); almost always in combination with another appropriate category
3. Apps or mobile; often in combination with the software, data, and information technologies category

Genetics, breeding, biotech, and health

1. Companies described as biotech
2. Companies that mention genetics

3. Breeding
4. Biological control
5. Biopesticides
6. Biofertilizers, compost, biochar, other biologically derived soil amendments
7. Microbial/microbiome
8. Animal health, including vaccines (but *not* feed additives)
9. Animal reproduction, such as sexing, artificial insemination (AI)

Chemicals

1. Agricultural chemical manufacturing
2. Any of the chemical "-cides" (pesticides, insecticides, herbicides, fungicides, etc.), if not explicitly biological (i.e., *not* biopesticides or *not if* explicitly described as a protein or peptide, which are instead included in the "genetics, breeding, biotech, and health" category)
3. Mention of a specific class of chemical compound that characterizes the company's products
4. Inert materials with beneficial properties as soil additives, fillers, growth media, weed blockers, mulches, and so on
5. Nanomaterials

   Note: The use of this category indicates R&D or manufacturing, not merely distribution or "provider" of chemical products.

Electronic devices, sensors, and systems (electronic hardware)

1. Use of the words *device* or *sensor*, smart or automated systems, measurement or monitoring in electronics context
2. Hardware (as opposed to software)
3. Robots, drones, unmanned or autonomous vehicles (UAVs)
4. Lighting or LED systems for contained or indoor agriculture
5. Control systems

   Note: This category includes technologies/products that would be in electrical engineering, not mechanical, civil, or hydrological engineering (these are under the "machinery and equipment [mechanical hardware]" category).

Software, data, and information technologies

1. Software or app
2. Data
3. Analytics
4. Artificial intelligence or machine learning
5. Blockchain or distributed ledger

Machinery and equipment (mechanical hardware)

1. Manufacture of farm machinery or equipment
2. Development or sales of vertical or indoor agricultural equipment and infrastructure (not control systems or automation, which are

included under the "electronic devices, sensors, and systems [electronic hardware]" category)

Note: This category does not include the distribution, import, or sales of farm machinery and equipment; these are under the "agricultural input distribution and sales" category.

Agricultural input distribution and sales

1. Distribution, sales, retail, wholesale, supply, provision (but *not* manufacturing) of a range of agricultural inputs, including
   a. seeds, plant starts
   b. agricultural chemicals, pesticides, fertilizers
   c. biological amendments, inputs
   d. animal feed, feed additives, supplements
   e. animal health, veterinary products and supplies
   f. young live animals (chicks, fish fry, etc.)
   g. farm supplies, aquaculture supplies
   h. machinery and equipment (for farms, ranches, aquaculture, fishing, timber operations)
   i. parts and services
2. Small minority include agricultural services, such as contract harvesting, piecework, agronomic consulting services, monitoring, and management
3. Does not include provision of or contracting of agricultural labor; human resource services are all under the "business and financial services" category
4. When the input is animal feed (1.d above), this category is often used in combination with the agricultural outputs marketing, processing, and manufacturing category if the company also manufactures or produces the animal feed, which often involves grain or oilseed milling

Agricultural production and farming

1. Actual operation of a farm or other agricultural production operation such as a ranch or fish hatchery
2. Cultivation
3. Production
4. Often includes the phrase *provision of agricultural services*
5. Often mentions actual commodities produced
6. In combination with the agricultural outputs marketing, processing, and manufacturing category if the company is a vertically integrated agribusiness (e.g., in livestock, oil palm)
7. In combination with the agricultural outputs marketing, processing, and manufacturing category if vertically integrated fresh market (e.g., fruit, vegetable, produce)
8. In combination with the "agricultural output marketing, processing,

and manufacturing" category *and* with the "consumer products or services" category if it includes the phrases *community-supported agriculture* (CSA), *farm to table*, *locally produced*, and so on

Agricultural output marketing, processing, and manufacturing

1. Postharvest marketing, distribution, export/import, brokering
2. Transportation, logistics
3. Processing, milling
   a. animal slaughter, meat processing, meat packing
   b. grain milling, feed manufacturing
   c. oilseed pressing, processing
   d. cotton ginning
   e. sawmills
   f. ethanol plants
4. Other fermentation, extraction, separation, purification for ingredient manufacturing; animal feed additives (amino acids, micronutrients, etc.)
5. Food manufacturing; food brand or category for broad market (i.e., national or commodity-wide)
6. Wineries, breweries, distilleries
7. Farmers' markets, local food marketing

Consumer products and services

1. Explicit mention of the consumer, home, or household
2. Retail
3. A specific final product, often branded
4. Direct marketing or distribution to final consumer (not to stores, restaurants, or other food services)
5. Consumer connected to production/distribution (e.g., community agriculture, farm to table, farm share schemes)
6. Mention of garden, gardening supplies, garden equipment, indoor gardening systems, if clearly intended for home (not for horticulture or greenhouse industry)

Unspecified

1. Unable to determine: combined industry/technology descriptions are too general or missing altogether

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