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Technology-Supported Investment Management

Eduard van Gelderen* and David Ouellet†

INTRODUCTION

How difficult is investing really? At a first glance, one is likely to conclude that it must be very difficult. There is a lot of volatility, many nomenclatures and acronyms are used, and only the best educated people seem to find their way around in the investment industry. And yet, in the long run there is a direct relationship between economic growth and the return in financial markets. Hence, provided the investment horizon is long enough, positive economic growth will translate into positive returns on financial assets. An old Dutch expression talks about "trommelpapier", meaning that you just store your financial assets, and the passing of time will do the rest. Obviously, the reality is less simple. Time horizons and investment objectives differ per type of investor, leading to different risk appetites and investment strategies. A buy opportunity for one investor can be a perfect sell opportunity for another investor; it doesn't necessarily mean they fundamentally disagree nor that they behave irrationally. As said, economic growth and financial returns are inextricably linked long term, but they do not run in parallel in the short and medium terms. Financial markets are forward-looking, and a positive economic outlook translates into positive market trends. If the actual economic growth falls short of that outlook or the outlook was simply too optimistic, markets will correct. In fact, markets could very well correct too much due to an overreaction on being wrong the first time. Fiscal and monetary policies

* Eduard van Gelderen is Chief Investment Officer at PSP Investments.
† David Ouellet is Chief Technology and Data Officer at PSP Investments.

DOI: 10.4324/9781003262039-11

by governments and central banks could decouple the real economy and financial markets too. Over the last two decades, we've witnessed exactly that. Monetary easing, stimulus packages, and quantitative easing have led to a stellar performance in capital markets. The resulting low-risk premiums and high valuations are not necessarily a reflection of the state of the economy going forward. With the impact of COVID-19 still there, the frictions in the supply chain and inflation looming around the corner, not many will argue there is as little risk as the risk premiums suggest. Some market participants argue that the risk premiums are low, because quantitative easing has placed a floor in the market; it's a free put option. Still, the divergence is simply not sustainable. The problem of how to normalize the relationship between the real economy and the financial markets isn't getting easier to solve after all these years of divergence. In fact, it's quite the opposite: it is a very uncomfortable feeling that most of the relationships and theories we've learned in business school and used as guidance in our investment decision-making are simply not working anymore.

Technology has always been part of the investment management world. Yet, we would argue that with the recent developments and innovations, technology has become as important as human capital to deliver the investment performance we're aiming for. Technology has an impact on many aspects of running an investment management organization. It is never an objective by itself; it serves a purpose and supports a strategy. McKinsey's approach provides a helpful competitive framework in this respect as in their view, a company can be truly successful only when it excels in (at least) one of the following three business models: customer intimacy, operational efficiency, or product innovation. Customer intimacy implies that client servicing and client solutions are what drives the business model. Application Programming Interface (API) is a good example of how technology can support this model. Information about the client's portfolio is directly accessible, the client receives advice on its investment portfolio and can trade securities via his/her mobile phone instantly. Operational efficiency means that the company is the lowest cost provider. Technology, such as cloud and open source solutions, is the driver of this model by supporting scale and efficient portfolio management and execution. In contrast to customer intimacy, standardization of the end product is a key feature. Passive investments or index-tracking are typical examples of this business model. Product leadership is all about innovation. The premise is that by launching new products, new demand will be created. This model does not necessarily look at disruptive innovation alone. Incremental innovation is equally important as capital markets change constantly and investment strategies need to adapt to new realities (Lo, 2004). In this case, technology focuses on providing the right data and analytical tools to improve decision-making and to evaluate new investment strategies.

A portfolio management system (PMS) in the broadest sense of the word (not just a record keeping system) is at the core of this model. This chapter will deal with technology from a product leadership perspective.

The aim of this chapter is to describe how to deal with the rapidly changing investment environment and the important role technology and knowledge management are going to play in the next decade. It takes the form of a case study as many examples relate to PSP Investments.[1] The first section will set the stage by providing an overview of the role technology has played over the years. Although relatively new, it will include a view on big data and artificial intelligence (AI) too. Moreover, this section will provide two case studies on how PSP Investments is using new techniques to assess and select private equity managers and to determine emerging risks in the portfolio. The next section will describe knowledge management as an approach to come to better investment decisions and how technology supports this management approach. This section also dives into the current discussions on responsible investments and climate change. Although news items on climate change and carbon emission show up in the media every single day, and new "green transition" initiatives and products are launched frequently, current knowledge of the topic is rather fragile and based on a nascent science. The chapter ends with a summary. The ambition is to convince the reader that technology and human capital are the two interwoven drivers of a successful and agile investment management organization.

THE TECHNOLOGIZED INVESTOR[2]

Starting in the early nineties as a financial analyst at an investment bank in Amsterdam, the job was to analyze listed companies and provide buy or sell recommendations. The technology supporting this task was a spreadsheet. Data was gathered from Reuters, annual reports, the stock exchange, and a variety of providers of macro- and sector data. The spreadsheets were set up to be able to follow the year-by-year changes in the corporate's financial data and to make predictions about what would happen to the company and its future share price. Spreadsheets could simply reflect the corporate balance sheet and profit-and-loss account, but more sophisticated analysts made sure that the spreadsheets included relationships between the different financial statements as well as relationships with external factors. For example, the elasticity of product demand to general GDP for durable goods companies or margin developments as a result of developments in commodity prices for energy companies. Ultimately, the goal was to come up with an earning's forecast and relate that forecast to the stock price to assess whether the company was under- or overvalued. The interesting part of the job was that knowledge on business models was built up over time. The feedback loop, in terms of new corporate

financials becoming available every other three or six months, was a learning experience and spreadsheets were modified accordingly.[3] Spreadsheets became more sophisticated as time passed, allowing the user to program its own macros, and statistical packages became available as "add-ins". Parallel to this development, more and better data sources became available, leading to a much higher level of analytical sophistication. In short, technology was on the rise to become an essential part of investment management. Zvi Bodie (1999), one of the greatest thinkers in finance, confirmed this in his article "Investment Management and Technology; Past, Present and Future". He claimed that technological advances had made it possible to put financial theory into practice. But, more importantly, he predicted that investment management would undergo a radical transformation as the result of financial engineering, which he defined as the application of sophisticated mathematical models, computerized information processing, and telecommunications technology. Zvi Bodie was spot on; the investment management sector has seen a lot of new developments since the turn of the century. Data has become a commodity. As a result, the time and efforts spent on finding the right data, cleansing the data, and making it fit for research purposes were reduced significantly, leaving more time for analysis and decision-making. The surge in clean data triggered quant investments, or also called systematic investments, which look to exploit anomalies in the data by applying mathematical models. The significance of having access to clean data became obvious: an anomaly found in dirty data might not be an anomaly at all! Quant investments have gone through different cycles. Exploiting anomalies can lead to appealing uncorrelated[4] returns, but history has also shown that regime changes can bring quant investments in big problems. Perhaps, one of the best examples was the collapse of Long-term Capital Management in 1998 (Lowenstein, 2001). But quant investments never died. Schelling (2021) claims that an investment approach without quants is unthinkable as the human brain is simply not able to follow the sheer growth in data. Experiences such as LTCM only triggered the development of better models and more rigid risk management; a development heavily relying on technology and the surge in better data. An important new quant-driven investment approach is factor investing. It became clear that risk was not the sole driver of investment returns as suggested by the Capital Asset Pricing Model (CAPM), but that a set of several structural factors can do a much better job (Huij & van Gelderen, 2014). The portfolio management systems available nowadays increasingly rely on these factors and do a good job in optimizing and stress testing investment portfolios, especially regarding listed instruments with readily available market prices.[5] One might argue that these systems are making use of simplifying assumptions and therefore do not match reality, but as long as the technology is not replacing human judgment, these systems are of great use.

ADVANCED ANALYTICS ERA

The advanced analytics evolution has been driven by advances in technology. The 1980s and 1990s were the years of statistical analysis (linear and multilinear regression, stochastic process, and Monte Carlo simulation). These analytical techniques were using conventional data, like SEC filings, trading data, macro data, or industry data. After the turn of the century, we witnessed a surge in computing power, cloud computing, and alternative data (satellite picture, web scraping, earning call transcript, Internet of Things with their sensor data or social media sentiment). New technologies such as Machine Learning (with supervised and unsupervised learning), natural language processing (NLP), and even more advanced AI technologies such as deep learning and neural networks became the drivers behind advanced analytics. More recently, quantum computing and synthetic data[6] started to emerge. Although the application of quantum computing is still under review, the gigantic increase in computing power supports the use of AI and will eliminate the need for the use of proxies and other simplifying approaches.

Smart investors continue to use advanced analytics and alternative data sources to become better investors. They want to capture and better understand the dynamics in the capital markets in order to be able to timely adjust portfolios to changing market conditions and to generate excess returns by outsmarting other investors. It's our belief that the increased level of complexity and sophistication will drive a significant gap between smart investors and other investors. This gap is directly linked to the adoption of advanced analytics because the investment environment has become too complex for the human brain to cope with. It is a given that the human brain is powerful and agile, but it also has its limitations. It's not the most powerful processor of data: we get easily lost when the amount of data to deal with starts to pick up. The brain also starts to trick us by trying to impose causality on us while in many cases these causalities are flawed or do not even exist. The literature on behavioral finance has provided many examples of potential biases and flaws in our decision-making. Moreover, we tend to have difficulties to fully understand probabilities. Not so much around the mean or median of a probability distribution but certainly when we move to the tails of a probability distribution. Taleb (2004, 2008) has written extensively about this last topic. Hence, technology helps us to understand the investment environment better, to frame problems, and to make better investment decisions. But is this really true? Did earnings and share price forecasts get any better over time? Most likely not. The problem in the past was that many changes could not be picked up quickly enough by the relatively slow arrival of new data. And due to the limited amount of data, analytical methods did not provide statistically significant outcomes. Technological progress and more data tackles

that problem, but the world, including the functioning of capital markets, is constantly changing too. Better still, one could argue that the speed of change has gone up. Hence, many earnings predictions continue to be off, and buy and sell recommendations remain rather unreliable. So, does this mean we're wasting our money on technology? Well, forecasts might still be problematic, but the insights we've gained through technology are significant. We are in a much better position to construct portfolios in line with our objectives. We can use simulations and stress testing to figure out how a portfolio can behave over time and in specific situations. We can back-test new investment strategies and investment ideas. We can create proxies to better differentiate between market and idiosyncratic risks. We can break down investments in specific factors to gain a better understanding of performance drivers. In short, technology has provided us with the tools to have a much better grip on risk[7] and therefore our investment decisions. Put it differently, it helps us to avoid making bad mistakes. Charles Ellis's seminal book *Winning the Loser's Game* (1998) makes perfect sense in this context: as an investor you can win only by exploiting the mistakes of others. By embracing technology, we have become better investors.

CLOUD TECHNOLOGY IS A GAME CHANGER

Another important aspect that we must acknowledge is the fact that the cost of technology has fallen related to storage, operations, and processing power. One of the most important reasons for this is cloud development. Cloud technology has fundamentally changed the way investment management runs its operations nowadays. It is not an exaggeration to say that the public cloud, led by the growth of Google, Microsoft, IBM, and Amazon, is and will be one the biggest game changers in the way technology will impact the investment world. It will also lead to more competition as it allows smaller investment firms to compete directly with larger investment firms. The only thing the investor needs is a browser and an internet connection. So, for investment firms, there is no longer a need to purchase expensive computers with lots of storage and memory. Financial analysts can access programs and storage from any location through an internet connection, which means that data is not confined to an individual's hard drive or to an individual's internal network. The cloud provides investment management firms with a lower cost solution as investment management systems like Order Management System (OMS) or Portfolio Management Systems (PMS) are available in the cloud. External hosting of programs and data eliminates the need for expensive servers. Cloud computing moreover helps to avoid the costs of internal server updates, and there is no need to keep up with the pace of software updates, which can seem constant at times. Maintenance, repair and troubleshooting are the

responsibility of the company hosting the systems and therefore reduces IT support costs even more. This development makes it possible to shift a portion of the available technology budget from running the operations to advanced analytics supporting investment activities. In the context of McKinsey's three models, operational efficiency pays for product innovation.

Where newly established investment firms will benefit from the cloud from the start, established investment management companies need to first deal with their legacy systems and IT infrastructure. This implies a transition. In the case of PSP Investments, this involves a structured and deliberate approach to fully eliminate the two main data centers by the end of 2023. During the transition, several PSP Investments' applications already reside in the cloud. The transition of some applications to the cloud will be expensive and time-intensive. The business case supporting the transition was based on four pillars: (1) create more agility to meet the growing demand of investment professionals, (2) to take advantage of the inherent mobility support of cloud-based solutions, (3) to focus the technology department group on creating business value and increased productivity, and (4) to support new use cases for data and analytics.

AI AS A NEW TOOL FOR SMART INVESTORS

At this point, we would like to discuss the role of new technologies such as big data (digitization) and AI. Agrawal et al. (2018) state that the economic significance of AI is that it lowers the price of prediction, which provides more room for human judgment and hence better-informed decision-making. For investors, two important subfields of AI are natural language processing (NLP) and machine learning (ML). In short, NLP means that computers scan documents to look for specific themes, tone of voice/emotions, and drifts in the narrative. The efficiency improvement to scan through multiple documents goes without saying. But the potential benefits go beyond efficiency gains as NLP could lead to better predictions. New technology can detect early indicators we tend to miss by reading documents ourselves. Moreover, with the help of NLP it is possible to cross-validate data and trends without any human intervention. Machine learning is the process whereby computers learn to detect relationships in data and improve as more data points become available without specific instructions. This sounds very much like the financial analyst, who adjusts his/her spreadsheet once new financial data become available. And in essence it is, except that the computer can detect much more complex relationships, and it works with considerably more data. Moreover, the work of the analyst was based on structured data while the computer deals with unstructured data too. The expectation is that ML will lead to many new insights and a better understanding of market dynamics. Every investor is

fully aware of the potential of AI, but it doesn't mean that they are fully on top of it; most investors are still experimenting with these new tools. PSP Investments is not different and has started up several AI experiments to determine where the most value addition of these new technologies can be found and how to manage advanced analytics as an integral part of the investment process. Two of these experiments will be discussed.

EXPERIMENT 1: NATURAL LANGUAGE PROCESSING

The first one is an NLP experiment within the private market risk group. To monitor the risk profile of a portfolio company and to determine the risk profile of a new investment, portfolio managers and risk analysts read through multiple articles every day. It is a very labor-intensive process, and the people involved tend to focus on different things. Despite regular meetings and touchpoints to discuss specific holdings and issuers, the process can easily miss early indicators of a weakening credit profile. The idea behind the experiment was that the NLP could help us to analyze global news and ultimately enrich market intelligence related to all investments that we own or could own in the future (not just private loans). The question we were trying to answer was related to emerging risks in the total fund rather than seeking to confirm the existing credit risks within the private loan portfolio. We explored many different types of solutions, as the space is still nascent and evolving. We evaluated technologies offered by established firms, consulting firms, and start-ups and invited eight companies from across the world to pitch their solutions. After four months of demos, we agreed on a partnership with a small fintech firm in Europe. They had developed a tool, which scans more than three million websites a day and applies NLP to filter for specific themes. Together, we spent months defining relevant financial and enterprise risks to train their algorithms. Next, we created a list of the top-1,000 largest PSP Investments' holdings and subsidiaries, further customizing the algorithms to focus only on relevant news associated with PSP Investments' geographies, sectors, and assets. Once the algorithms were in place, unique dashboards were created summarizing the emerging risk trends by industry and geography. Subsequently, we started a four-month pilot program to test the tool. The findings were mixed. The tool certainly improved efficiency and greater productivity, but the real game changer we had hoped for was not there: the early warning signs were simply not meaningful enough. To realize that goal, significantly more time and resources would have been required to train the algorithms even more. We therefore made the decision to pause the project. The project is not considered a failure: after all, the efficiency gains are there, and PSP Investments' data scientists are now better equipped to leverage NLP functionalities in other experiments and projects.

EXPERIMENT 2: MACHINE LEARNING

The second experiment is an application of ML to improve our selection process for external managers. In today's increasingly competitive private equity markets, investment managers will need to look beyond existing relationships and find new ways to evaluate funds, besides previous track record. It is well known that, the performance distribution of private equity funds is rather wide and the difference between top-quartile and average performance determines whether the investment is successful or not. After all, research shows that the average performance in private equity falls short of the average performance in public equity. The research question could be formulated as an ML problem: "What Funds will be part of the top quartile funds environment going forward". The project could rely on a growing amount of private market data. At least seven major providers sell large volumes of historical North American and European PE fund performance data. For example, Cobalt has 40 years of historical data on 21,000 funds, representing 55% global and 80% US coverage. Without ML, it is hard to make sense of the available data and leverage it to support decisions. The project was worked on with four data scientists and PSP Investments' private equity team. Important insights were gained by diving in the academic literature on the topic. For instance, Kaplan and Schoar (2005) showed that private equity returns persist strongly across subsequent funds of the same general partner. Between 2005 and 2019, more than 150 research papers were published on the predictability of private equity returns. Predictive factors largely fall within five categories.

(1) Macroeconomics (e.g., investor sentiment, aggregate private equity fund flows)
(2) Market focus (e.g., country of investments)
(3) Fund structure (e.g., change in fund size, LP investors)
(4) Fund strategy (e.g., GP performance track record)
(5) Team composition (e.g., firm culture, team size)

Armed with the research question, the data, team members, and academic insights, we officially started the project. After a few months, we had created a model which was able to have data for the aforementioned five categories and at the time of writing this chapter, our ML model correctly predicts future performance 70% of the time. We trust that we will improve on this percentage over time when more data is added.

LESSONS LEARNED

We came to realize that to fully benefit from ML, we need even more data than we already had available. Moreover, not all available data is useful, because it

is not always clear what the data exactly represents. It emphasizes the role of data scientists: they determine what data is needed to solve specific ML problems. Just having more data as a result of digitization is not the answer; it could very well trigger more confusion than clarity. As said, once we know what data we need, the question is whether we have enough data to use ML successfully. We realized that the substantial amount of required data is not always available for the investment problems we would like to solve; a lesson learned for new experiments.

Any investment firm that has ambitions to improve their data and advanced analytics capabilities will need to focus on the following five elements.

(1) A proper data and advanced analytic strategy; the firm needs to invest significant time in mapping and prioritizing the needs and aspirations of the investment use cases by looking at business impact and technical feasibility;
(2) The technology architecture; the right architecture will help the delivery of what was promised; it must be scalable and support the solutions required by the investment teams;
(3) The data management foundation; cloud based, including internal and external data sources;
(4) An agile delivery operating model; users must be able to tap into data sources and analytical tools to work in a test environment on new ideas;
(5) The right talent or partnership; there is a war of talent in the investment industry and in the data science field.

Organizations will need to modify their remuneration framework to ensure they can attract the right talent that can enable advanced analytics. As importantly, organizations will need to invest to retain and upskill their current talents. As talent will be limited, for more complex or niche advanced analytic use cases, capacity could come from partnering externally in a highly coordinated fashion with internal talent. The behavioral and culture change is critical, often more so than underlying technology, data, and analytics tool changes.

TECHNOLOGY-ENABLED KNOWLEDGE MANAGEMENT

The previous section talked about the continued rise and use of technology in investment management. This section will talk about knowledge management. The two sections are directly linked, when we work on the basis of the following hierarchy between data, information, and knowledge. Data reflects measurements of the world, but by itself it doesn't mean much. As described in the previous section, the sources of data for investment management were limited and relatively simple. And yet, the management of data has always

been a challenge because not much attention was paid to data management (i.e., defining, cleansing, structuring, and storage). The challenge was not accounting data but management data. The first is backward looking and used for formal reporting while the latter is any type of data informing the investment decision. Nowadays, the amount of management data is growing exponentially due to the process of digitization. Moreover, measurements of the world are no longer just numbers but can take different formats (sound, voices, pictures, videos, etc.). The role of the data scientist cannot be emphasized enough in this environment. In order to give data more meaning, it's augmented and placed in context; it's what we call information. Information is only more valuable than data when it mitigates uncertainty around specific topics. A random speech (data) doesn't mean much, until we learn it is the chair of the Federal Reserve speaking (information). Or, in the context of digitization, satellite pictures of parking lots are meaningful only when these parking lots are used by visitors to a specific shopping mall. Technology platforms play a crucial role in terms of augmentation and placing data in the right context. Portfolio management systems aggregate data and dice and slice portfolios to provide different perspectives. Yet, that information is still static. It is what we do with that information that matters, which brings us to knowledge management.

UNDERSTANDING KNOWLEDGE

Before we go into more detail of knowledge management, some aspects of knowledge and the role of technology need to be addressed first. First of all, what is the definition of knowledge? Epistemology deals with the theory of knowledge and tries to provide answers on questions such as the definition of knowledge, the sources and structure of knowledge, and the transferability and limits of knowledge. For a long time, the definition of knowledge as "justified true belief" was widely accepted. Beliefs can emanate from psychological factors such as desires and prejudices, as well as from perception (our five senses), introspection (our mental state), memory, reason, and testimony; these are considered true. These beliefs need to be strong and should make sense to fit the definition to be justified. Yet, although this would fit the definition of knowledge, these beliefs are not considered knowledge at all times. After all, a justification based on unreliable and faulty methods cannot lead to knowledge. This suggests that reliability is a necessary fourth condition: the justification for the true beliefs must be infallible and there should be no overriding or defeating truths denying one's belief. In science, knowledge is created by testing ideas in a controlled test environment with probabilification as the driver for justification. Knowledge creation in social sciences faces the problem that most experiments cannot be repeated under similar test

conditions while the lack of data stands in the way of proper probabilification. For that reason, justification was often based on reason and triangulation. But technology is changing this approach rapidly. As Zvi Bodie already predicted (see previous section), sophisticated mathematical models and computerized information processing have led to a much better understanding of how economies, markets, and strategies work. The body of knowledge related to finance is growing rapidly and investment beliefs have become more specific. Still, these investment beliefs are modified over time as well. Koedijk and Slager (2011) state that investment theories have undergone several paradigm shifts since 1970. Investment beliefs change as there are no absolute truths and certainties in investment management: knowledge in finance is dynamic.

The second aspect related to knowledge is the distinction between explicit and tacit knowledge. Explicit knowledge is articulated knowledge, that is, expressed and recorded as words, numbers, codes, mathematical and scientific formulae, and musical notations. Explicit knowledge is relatively easy to communicate, store, and distribute and is the knowledge found in books, on the web, and other visual and oral means. New technologies can help to interpret explicit knowledge better by connecting different knowledge sources. Tacit knowledge on the other hand is unwritten, unspoken, difficult to codify, and hidden. Every individual possesses a vast storehouse of valuable tacit knowledge, based on his or her emotions, experiences, insights, intuition, observations, and internalized information. New technologies such as NLP will help us transform tacit knowledge into explicit knowledge. This is hugely powerful, because once the knowledge is explicit, it can be tested on its validity. As a result, the finance industry will become more fact-based and rely less on heuristics.

The third aspect is that knowledge is context dependent. As Nonaka and Takeuchi (1995: 58) pointed out: "First, knowledge, unlike information, is about beliefs and commitment. Knowledge is a function of particular stance, perspective, or intention. Second, knowledge, unlike information, is about action. It is always knowledge 'to some end'". This statement implies an action: knowledge has got value only when acted upon. And for that very same reason, knowledge is context dependent. To solve certain problems, we need to have the appropriate knowledge.

KNOWLEDGE MANAGEMENT WITHIN THE ASSET MANAGEMENT INDUSTRY

Now that we have a better understanding of what knowledge means, we can dive into the interaction between knowledge management and technology. Knowledge management is far from a new management discipline. Already for three to four decades the concept of knowledge management is discussed

and improved, triggered by the move from a production-based economy to a knowledge-based economy. Monk and van Gelderen (2016) looked into the status of knowledge management in the investment management industry to conclude that knowledge management was considered of high importance. But at the same time, many investment managers didn't know how to implement such knowledge approach. This was a remarkable finding, given that the investment management industry is a knowledge-intensive industry. Less focus on data and technology in the past is certainly part of the reason. For many years, the C-suite of investment management firms did not include the position of a Chief Technology Officer. The responsibility for data and technology was oftentimes in the hands of someone reporting to the Chief Operating Officer, leading to tactical rather than strategic decisions. Moreover, the budgets allocated to data and technology were oftentimes too low to fully follow technological developments. This led very quickly to the reliance on legacy systems for running the business. The survey in the same study also asked the question who should be responsible for knowledge management. The answers were quite diverse. Of the respondents, 37% stated it should be the Chief Investment Officer as the knowledge activities were primarily investments related. The Chief Executive Officer was mentioned 26% of the time as knowledge management was seen as a competitive edge and of strategic value. The Chief Information and Technology Officer was mentioned in only 11% of responses mainly by respondents who considered knowledge management as an IT project. Perhaps, most remarkable was that 20% of the respondents mentioned that knowledge management was not a C-suite responsibility at all but a line responsibility. We don't support this last view. Given that in this chapter we follow a product innovation strategy aimed at investment activities, we feel that it is a joint responsibility between the Chief Investment Officer and the Chief Data and Information Officer.

KNOWLEDGE MANAGEMENT APPROACH

According to O'Leary (2002a, 2002b), knowledge management is the organizational efforts designed to:

(1) capture knowledge;
(2) convert personal knowledge to group-available knowledge;
(3) create knowledge assets and opportunities for knowledge creation;
(4) introduce measurement systems to understand and follow the added value knowledge delivers.

The very first step is to determine where the knowledge on specific topics sits within and outside the organization. This could be a rather straightforward or challenging activity, depending on the size and complexity of the organization.

The real challenge is to identify the tacit knowledge. Especially, since people with important tacit knowledge might consider this knowledge theirs and are not willing to share it. This is also true with regard to external partners. Very siloed organizations will realize that there is a lot of duplication too. An effective knowledge management system will include a directory with the specific skill set and knowledge areas per employee. A lot of these problems encountered in step 1 are solved when it is emphasized by the C-suite that all knowledge belongs to the company rather than the individual. This is a different way of saying that personal knowledge needs to be converted into group knowledge. Once knowledge is documented, this is not a hard task at all: all documents should be placed on a shared drive and therefore accessible to all employees. Again, the tacit knowledge is harder to share. Yet, a traditional way in many cultures of passing experience on to the next generation is by telling stories. With all the communication technology available, it is very easy to organize learning sessions. Hence, a lot of tacit knowledge will become explicit, simply by talking and debating specific activities.[8] Knowledge assets are oftentimes informal teams with participation from different parts of the firm and external partners. What these participants have in common is experience in a specific field. An obvious example is a sector team with participants from different asset classes. They can share their specific knowledge and views on developments in the sector, compare pricing differences, and determine where the best investment opportunities lie. The external partner could well be a specialist in the field and should therefore be included.[9] New knowledge is created when the participants start to make other investment decisions that differ from the ones they might make in the absence of knowledge assets. The most challenging problem is to measure the value add of knowledge management. Questionnaires are the easiest way to measure the value add. Research methodologies in social science will provide good insights, but advanced analytics will push these insights to the next level. For example, NLP could come of use once we start to link investment recommendations to investment performance. This will lead to a new and more detailed performance attribution approach. Moreover, it provides an opportunity to assess the investment skills of the investment managers. Currently, the performance attribution leaves too much room for interpretation and flawed beliefs on the investment manager's skill set.

TECHNOLOGY-SUPPORTED KNOWLEDGE MANAGEMENT

All organizations with a focus on knowledge management have created a corporate culture in which knowledge sharing is a "must" at all levels of the organization. It's embedded in personal development plans, career path, and compensation. Investment decisions are written up extensively, including assumptions and expectations. At regular intervals, these investment decisions

are reviewed and lessons learned are shared with all stakeholders. From a technology perspective, there is no single technology market for knowledge management. Even Gartner, a public company specializing in technology research and consulting company doesn't produce a Magic Quadrant for knowledge management as there are too many solutions supporting knowledge management activities. Knowledge management can be broken up in different activities, each of which can be supported by different technologies to generate, capture, and distribute knowledge; there is no single all-inclusive knowledge management technology. At PSP Investments, we have been leveraging different processes and technologies. For instance, we have launched a Capital Markets' Research Management System to centralize, organize, store, track, and distribute research produced internally, and, to a lesser extent, externally. In terms of requirements, we defined four major categories.

(1) Data search and processing
(2) Content creating
(3) Content consumption
(4) Management oversight

By analyzing the different vendors in the markets, we chose Bipsync as our research management systems because of its knowledge-sharing feature. Bipsync has allowed PSP Investments to build a centralized hub to share curated investment research and insights through thematic pages, intelligent searches, and tags capabilities with all users. Bipsync has allowed PSP Investments to better generate, collectively, new investment ideas to be shared (curated view). The other big technology stack that we are leveraging is Microsoft applications. Microsoft has invested significantly in their knowledge management capabilities. Our approach to general knowledge management from a technology perspective is to make the best use of Microsoft 365. After all, this is the system the users were most familiar with. We are therefore leveraging SharePoint, Teams, Exchange, and OneDrive. Moreover, we started to experiment with Microsoft Viva Topics. Microsoft describes Viva Topics as "a knowledge management system that connects, manages, and protects knowledge and expertise from your organization". Viva Topics uses Microsoft Graph, Search, and ML to identify and connect knowledge across Microsoft 365.

THE SEARCH FOR ESG KNOWLEDGE

An interesting activity to discuss in the context of technology-enabled knowledge management is investments in climate change. Many investors started their ESG activities years ago as part of their stewardship role as an investor. Initially, good governance was the name of the game. In later years, the focus

shifted to social and environmental issues too. Earlier on, we emphasized the differences between data, information, and knowledge. If we move to the bottom of the hierarchy, ESG data still primarily consists of qualitative data. Moreover, much of this information is "G" related. More "E" data becomes available, but the data on "S" is still very poor. Thanks to the surge in integrated reporting, these data points are placed in context by issuers to become information. Yet, the information is based on self-reporting and doesn't follow a market standard. ESG knowledge implies that we fully understand the topic and that we can apply this knowledge correctly in our decision-making. And this is exactly where we struggle. Using the definition of knowledge, we firmly belief that ESG is the right thing to do. But is it justified? It is true that more scientific evidence has emerged regarding the benefits of good governance. And is it reliable? Most scientific work is reliable. Still, one of the good governance principles is that the chair and the CEO of a company should not be one and the same person. However, there are many examples of (private) companies with a stellar performance and where the chair is also the CEO of the company. Strictly speaking, this would falsify the theory. The ESG challenge going forward is first and foremost to collect more relevant data points, especially related to the "S" and the "E". For example, we have hardly any workable data on human rights and labor issues. This is also true for "diversity & inclusion", despite the growing attention it receives recently. The second challenge is to transition from this data into true knowledge.

CLIMATE CHANGE IN FOCUS

More recently, climate change has become the ESG focus point. At the time of writing this chapter, COP26 just took place in Glasgow. The reactions in the media are mixed, as there seems to be less willingness by participants than expected to commit to specific climate change targets. From a knowledge perspective, this doesn't come as a huge surprise. We all agree that we should fight climate change, but there is still a lot of uncertainty regarding the right way forward. Yes, we have enough evidence to believe in global warming. Moreover, we have evidence that global warming is directly linked to GHG emissions. But what is the right approach to deal with this problem and what is our knowledge on the topic? Let's follow O'Leary approach and determine what an investment management firm can do to get more grip on its climate change knowledge.[10] The very first step is to make sure that we know who has specific knowledge on the topic. The responsible investment team or ESG team comes directly to mind, but there are multiple other sources too. The investment team focusing on real assets, whether infrastructure, natural resources, or real estate, must have encountered transactions dealing with green assets and/or the transition of brown into green assets.

An obvious investment area in this respect is renewable energy. Studying the investment cases must lead to insights on how renewable energy contributes to a lower carbon footprint. Venture capital could be another source if the investment team invests in new technologies to capture carbon emission and/or make assets more carbon efficient. The listed equities investment team is yet another source: equity analysts should have a good view on how listed companies deal with ESG issues, including climate change. And last, but not least, a thematic research team could assess available external research. For example, the International Energy Agency and other scientific institutions provide valuable insights. This quick and dirty inventory will already lead to an impressive collection of internal knowledge sources. However, the problem is that all these sources have their own specific views and approaches and do not necessarily work together. The available knowledge needs to be organized, which is part of O'Leary's step 2. The different data sets and documents available need to be combined into one centralized depository. This requires a dedicated technology approach as many sources aren't using the same text format, and data/information is often not standardized and/or irrelevant in another context. To a large extent, it is about data cleansing and interpreting documents to assess its external validity. Advanced analytics can help enormously to do the job. Once this is done, step 3 comes into play: the formation of a knowledge asset, being an intra-disciplinary team with a common focus. The purpose is to complement each other, fill knowledge gaps, and to create new knowledge. Step 1 already provided insights who in the organization has relevant knowledge on the topic and therefore should be considered part of the knowledge asset. External sources should be considered too. Especially, when specialized external managers have been selected[11] to form strategic relationships on the topic. External sources could also include universities and memberships of institutions such as the World Economic Forum. The collective knowledge on climate change will grow and new knowledge is created, simply by having discussions and combining different perspectives. Technology plays an important role as data scientists help to select the appropriate new data sets to test new hypotheses and assumptions. Moreover, the knowledge should be embedded in the different systems. For example, ESG data needs to be linked to specific holdings and combined with performance data to be able to assess specific ESG strategies. Moreover, by including only carbon emission data in the portfolio management system, we learn what the impact of our investment decisions is on the portfolio's carbon footprint. And in order to test the impact of climate change scenarios on the total portfolio, we need the right functionalities in our systems. This is all easier said than done; the biggest challenge related to climate change is that it is still a nascent discipline. There are a lot of known unknowns and even unknown unknowns. For example, there is no agreement on the right methodology to

measure a carbon footprint. Moreover, sustainability ratings of different suppliers tend to rank companies in complete opposite orders (see Johnson & Swanepoel, 2021), and international policies on climate around the world are not aligned. It could well be the reason why COP26 might not have been as impactful as hoped for, as it relies on O'Leary's step 4. This last step deals with measuring the impact of the knowledge. However, the body of knowledge related to climate change is currently much less sophisticated than the body of knowledge related to other investment themes. Knowledge management related to climate change seems to be between step 3 and step 4; we're still in the process of completing the full body of knowledge and learning to apply what we know on climate change in the best way possible.

SUMMARY

We started the introduction to this chapter with the question on how difficult investing really is. Globalization, free capital flows, and the surge in information technology and computing power have made the world of investing more transparent but also more complex. The efficient market hypothesis makes even more sense now than when it was introduced several decades ago due to the quicker price discovery processes but at the same time more challenging because of the increased complexity. Irrespective of the right answer, the conclusion of this chapter is that in the current day, investing cannot take place without relying on data and technology. We choose to discuss technology as an enabler of the investment process, but technology is equally important for client servicing and investment operations. We touched on the increasing amount of available data, especially due to digitization. But, the abundance of data also triggers the question what to do with it. We can easily claim "more is less" if the data is useless for the decisions we need to make. Data scientists bring in the human judgment in this respect. New technologies such as AI are potential game changers as it will allow us to analyze more data and in a different way than before. The expectation is that these new technologies, or advanced analytics, will provide us with new insights to improve our investment process. Yet, the jury is still out: we do see papers and articles expressing successful implementations, but we don't read about the many failed attempts. In the second section of this chapter, we argued that knowledge management is crucial for investment managers to be successful. It touches on the idea that successful investment strategies and investment decisions should be not only fact based but also tested for validity. A different way of saying the same thing is that we should strive for the highest academic rigor. Given the complexity of today's investment world, we cannot rely on narratives and gut feeling anymore. Building up collective knowledge, instead of relying on the sum of the individual knowledge, is crucial to create

new knowledge. This chapter talked about ESG activities specifically because of the nascent nature of these activities. Much of the data is still based on self-reporting, measurement methodologies differ greatly, and national ESG policies have not been synchronized yet. The discussion on the closing statement at COP26 is telling in that respect. So, what does this all mean for a skillful investment manager? In line with Monk and van Gelderen (2016), we would typify a skillful investment manager by the ability to act on changing market conditions by creating new superior knowledge and abandoning obsolete knowledge. The true impact of skills on investment performance, it turns out, is largely dependent on an organization's ability to foster enduring and valuable knowledge and to adjust investment strategies accordingly. To do so, technology should be fully embraced; it's the only way forward to maximize the value add of human decision-making.

NOTES

1 PSP Investments is responsible for the investments of the post-2000 liabilities of the Canadian government's pension plans. All information related to PSP Investments in this chapter is presented solely to support the narrative of the two authors and is not an official positioning of PSP Investments.
2 This title is borrowed from the book by Ashby Monk and Dane Rook (2020), which provides an excellent overview of how technology is shaping the investment world.
3 As Rebonato (2007) points out, this very low-frequency data makes it almost impossible for analysts to determine the true trend in the company's earnings.
4 Here, the assumption is that the anomalies are not correlated with general market movements.
5 One area of further development is related to private assets and the integration of public and private assets in a portfolio management system. Given that the price discovery process and asset pricing models for private assets are very different from public assets, the integration of both is not a trivial task.
6 Data generated by computer simulation as an alternative to real-world data.
7 We use risk in case the outcome is unknown, but the probability distribution governing that outcome is known. In case of uncertainty, both the outcome and the governing probability distribution are unknown.
8 Obviously, this requires a safe environment and corporate culture in which people feel free to speak up and make mistakes.
9 See Monk and van Gelderen (2019) on the role of strategic partnerships.
10 This part is, to a large extent, based on the experience within PSP Investments. The use of technology plays an important role in all steps described.
11 In this respect, PSP Investments works closely with TPG and Brookfield to invest specifically in opportunities related to climate change. These opportunities are asset and benchmark agnostic and therefore fall outside of the mainstream asset mandates.

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