29 November 2018

Financial instability: can Big Data help connect the dots?

Remarks by Luiz Awazu Pereira da Silva and Goetz von Peter,[1] based on a speech delivered at the Ninth European Central Bank Statistics Conference on "20 years of ESCB statistics: what's next?", Frankfurt am Main, 11 July 2018.

Introduction

Financial stability has always been a policy concern, but one that has become more pressing with the Great Financial Crisis (GFC) of 2008–09. Every financial crisis leads to calls for new data to be collected. It is natural for policymakers to focus on filling the data gaps for those aspects of a crisis that were not on their radar before. The GFC thus fuelled a broad-based expansion of financial statistics.[2] A second, much larger wave of data hits the shores as central banks and the financial sector embrace Big Data.[3] Can we hope that the growing availability of data will help policymakers anticipate and manage the next crisis?

In these remarks, we will argue that collecting more data or dots is necessary, but *connecting* the dots is the critical step for understanding the implications for financial stability. It is the lens that matters: it takes purposeful analysis to turn data into useful information.[4] Financial markets are flush with data, yet the bigger picture can slip out of sight. This is where policymakers and market participants fall short time and again: in run-ups to previous crises, simple aggregates would signal problems yet warnings went unheeded. The onset of a crisis then sharpens the focus on critical data for the management and resolution of the crisis. Later, when the financial cycle turns again, innovation and changing structure make financial risks harder to locate using the existing data.

The availability of new data may not prevent future crises altogether, but their judicious use can help policymakers respond to early signals and help to manage the consequences. If Big Data is to help in connecting the dots, the harvest of new data should go hand in hand with enhanced analysis, visualisation and considerable judgment. To make the most of the information at their disposal, policymakers need to gear their institutional knowledge to focus on the build-up and manifestation of risks, and constantly look at new ways to get the data to speak to financial stability.

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2 The G20 data gap recommendations are set out in FSB-IMF, "The financial crisis and information gaps", November 2009. The completion of the first phase and the work plan for the second are described in FSB-IMF, "Sixth Progress Report on the Implementation of the G-20 Data Gaps Initiative", September 2015. See also A Carstens, "Are post-crisis statistical initiatives completed? Taking stock", Remarks at the Ninth Biennial Irving Fisher Committee Conference, 30 August 2018.

3 See D Laney, "3D data management: Controlling data volume, velocity and variety", *META Group Research Note*, no 6, 2001. Big Data refers to the management of large volumes of data of various types and from different sources, https://blogs.gartner.com/doug-laney/files/2012/01/ad949-3D-Data-Management-Controlling-Data-Volume-Velocity-and-Variety.pdf.

4 We use the following terms: a framework provides the lens through which data are analysed in order to extract information. Any framework relies on (possibly wrong) assumptions or theories, with implications for the value of the information obtained.

Information needs for price and financial stability mandates

Many countries have established financial stability committees (FSCs), comprised of representatives of ministries of finance, central banks and regulatory agencies, which coexist with monetary policy committees (MPCs) set up exclusively by the central bank. In some respects, the task of MPCs is more straightforward than that of FSCs. Price stability is more measurable and actionable than financial stability, a complicated concept. MPCs have a clear objective and metrics to guide policymakers towards their goal, embedded in a policy process that relies on well understood data sets on inflation, expectations, output, wages etc. Of course, there are complications such as uncertainty about the natural rate of interest, the debate about the inclusion of asset prices or housing costs, or the appropriate use of granular information from scanner data or online prices.[5] But arguably, the information needs of MPCs are conceptually simpler.

The work of FSCs, by contrast, involves first the task of defining goals and metrics based on an elusive concept: what exactly constitutes financial stability? This step already confronts FSCs with the complex notion of systemic risk.[6] The multi-faceted nature of financial stability requires a broad range of indicators and developments to be monitored. As much as more data are necessary, we will argue that the analytical framework for interpreting the data is paramount: the lens matters as much as the data.

From narratives to statistical analysis

Spontaneous confrontation with new data or outcomes poses challenges in any discipline. Scientific discovery occurs not only through systematic evaluation of data – progress is sometimes made through accidents. Yet, as French scientist Louis Pasteur famously said: experimental accidents help only those who can *interpret* what these accidents mean.[7] Transposed to the present context, a wealth of data does not help analysts who do not know what to look for.

There has been much progress in financial stability analysis over time going from anecdotes to statistics. The broad narratives found in classical works on the history of financial crises, such as Bagehot, Kindleberger and Minsky, have been complemented by analysis grounded in statistics.[8] One example is the effort to identify early warning indicators (EWIs), a class of variables that have statistical power in predicting financial crises. Rose and Spiegel (2012) were sceptical about EWIs, as their statistical approach largely failed to predict the incidence of the 2008 crisis across countries from regressors they associated with commonly cited causes.[9] Yet, one robust predictor of banking crises several years ahead is the credit-to-GDP gap, the deviation of the credit-to-GDP from a long-run trend (based on a one-sided HP filter);

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5 In the euro area, housing costs currently enter the HICP through actual rentals and minor repairs, but the HICP does not include other housing-related consumption expenditures. See ECB, "Assessing the impact of housing costs on HICP inflation", *ECB Economic Bulletin*, Issue 8/2016.

6 In addition to defining what aspect of financial stability is considered important, a fully articulated financial stability objective has to address several other issues, from creditor protection to fiscal aspects, that can give rise to complicated trade-offs; see D Archer, "A coming crisis of legitimacy?", *Sveriges Riksbank Economic Review*, no 3, 2016, pp 86–95.

7 «Souvenez-vous que dans les champs de l'observation le hasard ne favorise que les esprits préparés.», speech delivered at Douai on 7 December 1854 on the occasion of his formal inauguration of the faculty of Letters of Douai and the Faculty of Sciences of Lille.

8 W Bagehot, *Lombard Street – A Description of the Money Market*, New York Scribner, Armstrong & Co, 1873; C Kindleberger *Manias, panics, and crashes: a history of financial crises*, Palgrave Macmillan, 1978; and H Minsky, *Can "It" Happen Again? Essays on Instability and Finance*, M E Sharpe, 1982.

9 A Rose and M Spiegel, "Cross-country causes and consequences of the 2008 crisis: Early warning", *Japan and the World Economy*, vol 24, no 1, 2012, pp 1–16.

debt-service-ratios, cross-border debt and property price gaps also perform well.[10] As our understanding of financial crises evolves, so does our ability to identify what data series serve as EWIs.

However, it is far easier to single out drivers of a financial crisis with the benefit of hindsight – ex post it is clearer which indicators were signalling the build-up of those risk that eventually materialised. *Ex ante* identification is more useful and challenging: where will vulnerabilities show up next? What type of vulnerability is slowly undermining the stability of the system? The signs need not appear in the information available at the time. Think of how the mispricing of risk (its under-estimation) in a run-up conceals growing imbalances. In their regular early warning exercise, the FSB and IMF thus draw on a wide range of market data, analytical work and expert opinion.

The point is that it takes purposeful analysis to turn data into effective warnings. Having data is relevant and important, but it is the analytical lens that maps data into indicators that predict financial crises or otherwise help to monitor financial stability. As much as collecting dots is necessary, *connecting* the dots is of critical importance. This perspective makes clear that the analytical framework, the lens through which developments are assessed, can itself be a source of risk: misguided theory and false beliefs lead the analysis astray.

A brief history of false beliefs

The history of financial crises is also one of false beliefs. The Latin American debt crisis of 1982 proved wrong all those who believed that "countries don't go bankrupt", and who disregarded the prior surge in short-term foreign lending.[11] In the Asian Financial Crisis of 1997–98, strong growth prospects, low inflation and solid government finances led many investors to shrug off the mounting external debt accumulated by the five crisis countries. Statistics on cross-border foreign-currency lending in short maturities, available at the time, should have given pause for thought.[12] And in the run-up to the GFC, observers counted on financial innovation (such as securitisation) to enhance stability, and diversification benefits seemed very real. There was no shortage of false beliefs at the time but, as it turned out, the real shortage was one of US dollars when markets froze.[13]

In all those episodes, available statistics pointed to growing risks to financial stability. The problem was not a lack of data, but the failure to interpret them correctly and take corrective action.[14] The title of

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10 See C Borio, "The Great Financial Crisis: setting priorities for new statistics", *Journal of Banking Regulation,* vol 14, no 3–4, July 2013; M Drehmann and M Juselius, "Evaluating early warning indicators of banking crises: satisfying policy requirements", *International Journal of Forecasting*, vol 30, no 3, 2016, pp 759–80; and I Aldasoro, C Borio and M Drehmann, "Early warning indicators of banking crises: expanding the family", *BIS Quarterly Review*, March 2018.

11 The episode is described further in a speech honouring A Lamfalussy: see J Caruana, "International financial crises: new understandings, new data", National Bank of Belgium, Brussels, February 2017.

12 On the usefulness of BIS international banking statistics for identifying vulnerabilities in real time, see S Avdjiev, B Berger and H S Shin, "Gauging procyclicality and financial vulnerability in Asia through the BIS banking and financial statistics", *BIS Working Papers*, no 735.

13 H S Shin describes the role of US dollar assets held by foreign, notably European, banks in the run-up to the GFC, in H S Shin, "Global banking glut and loan risk premium", *IMF Economic Review*, vol 60, no 2, 2012, pp 155–92. The process by which foreign banks' cross-currency funding led to the global dollar shortage is documented in P McGuire and G von Peter, "The dollar shortage in global banking and the international policy response", *International Finance* vol 15, no 2, 2012, pp 155–78.

14 See C Borio, op cit.

Reinhart and Rogoff's book sums it up: "This time is different".[15] Market participants can always find a story or interpretation of conflicting evidence that favours an ongoing boom. Even when solid analysis identifies critical developments and authorities issue specific warnings, actors may be not be receptive, preferring to stick to their own narrative. Sometimes, market participants simply delude themselves; quite often, however, the future is inherently unknowable and a self-interested take on incoming data is as good as any other interpretation.

This behaviour follows a recognisable historical pattern. Booms are typically fuelled by optimistic expectations, or "euphoria", in the words of Kindleberger. Every new dawn promises endless possibilities, and the allure of a bright future serves to justify stretched asset valuations and ample financing. The economics literature is not conclusive on whether speculative activity should be regarded as irrational or rational.[16] The past century saw several periods of transformative change to support this pattern: countries emerging from financial repression; transition economies catching up with the West; financial liberalisation and the globalisation of finance; and rapid technological change heralding a new industrial revolution.

The belief that "this time is different" has often led actors to disregard the red flags in financial statistics; yet, the recurrence of costly crises shows that fundamental aspects of financial instability remain constant, even as appearances change with technology and innovation.[17] To heed these warnings we must not forget the lessons from previous crises as we dive into a data-rich environment.

Information requirements over the cycle

It takes the right lens to see relevant developments in statistics. Sometimes rough aggregates suffice to alert observers that imbalances are building, even if institutional details differ from one cycle to the next. Once a crisis breaks out, however, more granular data are needed for taking decisions. What constitutes useful information to policymakers therefore changes over the financial cycle.

In the run-up phase, BIS experience with aggregate data taught us some lessons on what lens to choose for better focus. As mentioned, simple credit-to-GDP gaps provide useful information about the risk of banking distress several years ahead.[18] When looking for financial vulnerabilities, gross stocks are more informative than net flows.[19] Another lesson is that financial strains are best measured in consolidated, rather than residence-based, statistics, because the fault lines run along balance sheets that transcend

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15 C Reinhart and K Rogoff, *This time is different – eight centuries of financial folly*, Princeton University Press, 2009. See also C Borio, "Change and constancy in the financial system: implications for financial distress and policy", *BIS Working Papers*, no 237, October 2007.

16 The case of the former is made by R Shiller, *Irrational exuberance*, Princeton Press, 2000; and C Kindleberger, *Manias, panics, and crashes: a history of financial crises*, 1978. The literature on "rational bubbles", by contrast, allows for rational speculation, eg O Blanchard and M Watson, in P Wachtel (ed), *Bubbles, rational expectations and financial markets*, Lexington Books, 1982.

17 C Reinhart and K Rogoff entitled their 2009 book on the history of financial crises "This time is different". See also C Borio, "Change and constancy in the financial system: implications for financial distress and policy", *BIS Working Papers*, no 237, October 2007.

18 See C Borio, op cit, and M Drehmann and M Juselius, op cit. Using imperfect data available as of 2002, the first paper in this line of research underlines the importance of choosing the right lens: C Borio and P Lowe, "Asset prices, financial and monetary stability: exploring the nexus", *BIS Working Papers*, no 114, July 2002.

19 See the BIS global liquidity indicators, www.bis.org/statistics/gli.htm, and N Tarashev, S Avdjiev and B Cohen, "International capital flows and financial vulnerabilities in emerging market economies: analysis and data gaps", Note submitted to the G20 International Financial Architecture Working Group, August 2016.

borders.[20] The common theme is that balance sheet aggregates display procyclicality, reflecting the risk-taking of financial intermediaries.[21] Such aggregates, as rough as they are, hold useful information on emerging risks to financial stability, and there is certainly a case for expanding the breadth and timeliness of monitoring.

In the crisis phase, however, crisis management and resolution require much more granular and timely supervisory data. On the verge of the Lehman bankruptcy in September 2008, the major banks were *unable* to measure their consolidated exposures to the collapsing investment bank. The uncertainty surrounding exposures to failing banks and toxic assets induced market panic and complicated the policy response. In sharp contrast to 10 years ago, the interconnections between G-SIBs are now known to supervisors.[22] And a growing share of OTC derivatives and repo trades are centrally cleared and reported to trade repositories. The financial sector's ability to report such data, in and of itself, improves risk management and market discipline – even if the authorities were to do nothing more than collecting the data.

The promise of Big Data: opportunities and challenges

Does the multi-faceted nature of financial stability require that central banks embrace Big Data to "look at everything"? The Big Data revolution reflects a confluence of several technological advances leading to a proliferation of data – Gartner's classic 3V definition emphasises three dimensions: data volume, velocity and variety.[23] The focus then was on the task of managing large, complex, and often unstructured data, received at high frequency or streamed in real time. It is telling that two more V's, veracity and value, emerged later on – likely with the experience of poor data quality and the challenge of extracting valuable information from vast amounts of data.

Central banks around the world are in the process of enhancing their usage of Big Data.[24] Some operate systems that generate such data, eg payment and settlement systems, or receive granular data in their supervisory capacity from banks' regulatory filings and reporting of large exposures. The Eurosystem collects daily money market transactions data, which helps to monitor the impact of the ECB's asset purchase programme on market functioning.[25] Many Big Data projects are about credit registries, the use of administrative sources or trade repositories. Given the strong interest in the community, central banks cooperate through the Irving Fisher Committee (IFC) by monitoring Big Data developments and value added over "traditional" statistics, and by reporting on their experience with pilot projects.[26]

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[20] See McGuire and von Peter (2012), op cit; and S Avdjiev, R McCauley and H S Shin, "Breaking free of the triple coincidence in international finance", *Economic Policy*, vol 31, no 87, July 2016.

[21] However, careful analysis also reveals remaining data gaps. For instance, non-banks outside the United States owe trillions of dollars through the use of FX swaps and forwards, see C Borio, R McCauley and P McGuire, "FX swaps and forwards: missing global debt?", *BIS Quarterly Review*, September 2017. And non-financial corporations from emerging market economies have increased their external borrowing significantly through the offshore issuance of debt securities, see S Avdjiev, M Chui and H S Shin, "Non-financial corporations from emerging market economies and capital flows", *BIS Quarterly Review*, December 2014.

[22] Most global systemically important banks (G-SIBs) report their bilateral risk exposures to, and funding dependencies on, their largest individual counterparties to the International Data Hub hosted by the BIS.

[23] See D Laney (2001), op cit.

[24] See D Bholat, "Big data and central banks", *Bank of England Quarterly Bulletin*, Q1, 2015, pp 86–93; and Central Banking Publications, "Big Data in Central Banks", *Central Banking Focus Report*, 2017.

[25] B Cœuré, "Policy analysis with big data", Speech at the Banque de France, 24 November 2017.

[26] See IFC, "Big Data", *IFC Bulletin*, no 44, September 2017. The use of cloud computing, and the international sharing of granular data between central banks and supervisory agencies are typically limited by data confidentiality. Successful sharing

An indiscriminate adoption of Big Data runs the risk of collecting – without connecting – too many dots. As early as 1971, Herbert Simon recognised the overload problem in modern organisations: "a wealth of information creates a poverty of attention", which may, in turn, lead to poor decision-making.[27] In Big Data analytics, reducing dimensionality is a technical necessity. But Simon's point is more general: an intelligent system should condense many inputs into few outputs to save on recipients' scarce attention. This perspective makes clear that the advent of Big Data is not just an IT issue, but one of analytical capacity.

Central banks appear to choose their new data sources selectively. They routinely stream financial markets data from Reuters or Bloomberg Terminals to monitor trends; this naturally extends to extracting expectations from asset prices or to nowcasting (a portmanteau of now and forecasting), to estimate current GDP by using timelier inputs, mixing frequencies and data types.[28] Another area of interest to central banks is the use of scanner data or online prices for measuring inflation and its persistence.[29]

Big Data has much potential in the realm of financial stability. There has perhaps been less work on nowcasting indicators of financial (in)stability.[30] But there is a strong case for enhancing financial stability analysis with the use of multiple data sources, such as bank balance sheets merged with asset price information or data from trade repositories or credit registries. This would help to extend existing work on systemically important institutions, with their reported large exposures and funding providers, towards a broader range of stress scenarios with potential for contagion. A growing number of central banks access data at trade repositories to bring derivatives markets within their view. By contrast, few go as far as harvesting social network data.[31]

Proceeding selectively is probably wise, since extracting meaningful information requires analysis and judgment. Even basic cleaning and aggregation requires institutional knowledge and analytical choices.[32] Big Data benefits from a range of analytics, such as machine learning techniques for selecting variables and refining prediction models in ways that penalise complexity – which can be helpful for developing

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arrangements include the establishment of supervisory colleges, the European Single Supervisory Mechanism and the International Data Hub hosted by the BIS.

27 See H Simon, "Designing organizations for an information-rich world", in M Greenberger (ed), *Computers, communications, and the public interest*, Johns Hopkins Press, 1971, quoted in A Haldane, "Why institutions matter (more than ever)", speech at the School of Oriental and African Studies, London, 4 September 2013.

28 The New York Fed Staff Nowcast, for instance, tracks quarterly US real growth on the basis of the news releases commonly followed by Wall Street. See B Bok, D Caratelli, A Tambalotti and A Sbordone, "Macroeconomic nowcasting and forecasting with big data", *Annual Review of Economics*, vol 10, 2018, pp 615–43.

29 An early application to Argentina, the United States (and newly, Venezuela) is described in A Cavallo and R Rigobon, "The billion prices project: using online prices for measurement and research", *Journal of Economic Perspectives*, vol 30, no 2, 2016.

30 Examples include M Oet, D Gramlich and P Sarlin, "Evaluating measures of adverse financial conditions", *Journal of Financial Stability*, vol 27, 2016, pp 234–49; and B Vašíček, D Žigraiová M Hoeberichts R Vermeulen, K Šmídková and J de Haan, "Leading indicators of financial stress: New evidence", *Journal of Financial Stability*, vol 28, 2017, pp 240–57. A recent paper uses textual analysis on unstructured text-based sources to identify the extent of consensus in financial market narratives, see R Nyman, S Kapadia, D Tuckett, D Gregory, P Ormerod and R Smith, "News and narratives in financial systems: exploiting big data for systemic risk assessment", *Bank of England Staff Working Paper*, no 704, 2018.

31 See Central Banking Publications (2017), op cit; and IFC Report, "Central banks and trade repositories derivatives data", 2018 Survey, conducted by the Irving Fisher Committee on Central Bank Statistics, October 2018.

32 Consider a structured bank supervisory data set as an example. Such data can be highly granular; the analyst must navigate not only data quality pitfalls, but deal with conceptual issues. One may have a prior on what constitutes a reasonable maturity profile, or a sense of the appropriate currency mix of bank assets and liabilities, on- and off-balance sheet. Such priors are harder to formulate at the position level (eg euro-denominated overnight repo with a non-bank counterparty), let alone at the transactions level. And these are structured data – extracting actionable information from text, audio and video is more difficult.

early warning systems.[33] Some useful methods have a pedigree in statistics and econometrics, such as classification and regression trees, dynamic factor models or elastic net regularisation.[34] When it comes to relational data, network analysis also has much to offer in the way of characterising, reducing and visualising large data sets. Visualisation methods, in particular, should play a key role in conveying information within a data-rich environment. All these methods are bound to become more prominent as analysts expand the range of variables being considered as predictors of financial crises.[35]

Employing such methods is promising, but automation can only go so far – using Big Data also requires considerable judgment. Creating a compelling network graph, for instance, requires informed choices to define the variables, the node and link attributes and the layout that govern its appearance. Similarly, devising a reliable regression model requires people who understand the methods and think critically about sample size, data quality, accuracy and biases. A Big Data study found that firms often remain stuck in the "expert phase": they employ some skilled professionals but have not begun to train everyone else.[36]

The same challenge may await central banks embracing Big Data. While analytics help to distil data into information, assessing its relevance for financial stability requires input from theory and experience. How do we judge an early warning signal, for instance, from a predictor that performed well in the past but is causally unrelated or hard to understand?[37] Should policymakers act on predictions from a complex model that they see as a black box, and how do they communicate such decisions to the public?

Beyond their own use of Big Data, central banks are taking an interest in how its use in the corporate world affects competition, concentration and procyclicality. "Big tech" companies naturally have a comparative advantage vis-à-vis traditional financial intermediaries in exploiting advances in computing power and data storage. Their customer-centred business models require them to make greater use of large and diverse data sets (eg from online payment and social media behaviour) to gain a competitive edge. For example, some Chinese lenders are experimenting with Big Data and machine learning to screen online borrowers and improve credit scoring.[38] Does the extensive usage of this new technology in business models raise concentration, or could it increase the procyclicality of financial systems?

In sum, the sheer scope of Big Data requires that central banks invest substantially in analysis and judgment, hence time and effort, to understand its use and realise its promise. This brings us back to the importance of having the right lens. A lens is a tool that should allow us to look at *many* things while keeping the focus, akin to a powerful telescope. Input from theory and experience are valuable for defining the right lens. But the rapid pace of change in the financial system requires continuous adaptation of data collection and analytical frameworks. There is a growing awareness that the international dimension is essential, following the experience of the euro area debt crisis and subprime losses of European banks in the GFC. The post-crisis shift to bond markets and non-bank intermediaries forces policymakers and supervisors to think beyond banking, and regard CCPs and other key non-banks as potentially systemic.

33 For a recent application, see M Holopainen and P Sarlin, "Toward robust early-warning models: a horse race, ensembles and model uncertainty", *Quantitative Finance*, vol 17, no 12, 2017, pp 1933–63.

34 See H Varian, "Big Data: new tricks for econometrics", *Journal of Economic Perspectives*, vol 28, no 2, Spring 2014, pp 3–28.

35 Ongoing work in this area includes J Fouliard, M Howell and H Rey, "Answering the Queen: online machine learning and financial crises", forthcoming. While their current work uses a small set of regressors, the way the forecasting model learns holds promise for Big Data applications.

36 See S Shah, A Horne and J Capellá, "Good data won't guarantee good decisions", *Harvard Business Review*, April 2012.

37 A machine-learning approach may identify predictors that are completely unrelated to the economic series being predicted. But in traditional prediction, some potentially related variables can be difficult to understand; one example is the signalling power of a dyadic motif called "unreciprocated 3-loop" for the 2008 collapse of the interbank market in the Netherlands, see T Squartini, I van Lelyveld and D Garlaschelli, "Early-warning signals of topological collapse in interbank networks", *Nature – Scientific Reports*, no 3:3357, 2013.

38 See Institute of International Finance, "A new kind of conglomerate: Bigtech in China", November 2018.

Meanwhile, innovation is taking the financial system into uncharted waters; policymakers must try to imagine the ways in which fintech, algorithmic trading or crypto assets may disrupt the system.

Conclusions

Financial stability is a multi-faceted concept and a moving target in the flow of financial innovation. Perhaps this makes embracing Big Data a necessity. But the promise of Big Data for financial stability hinges on the analytical capabilities and judgment we apply to the wave of new data. One area of great potential is the use of new data and analytics for early warning purposes. Looking only under the lamp post risks ignoring the area where the light does not shine; we could be more creative and look at a broader array of data and methods, in and outside the domain of economics and finance.

It is possible that Big Data will help policymakers use the right framework to identify the mechanisms behind the herd behaviour that fuels systemic risk. It might be possible then to move from macroprudential instruments to nanoprudential tools, addressing individual customer behaviour. For example, suppose we start from the statistical regularity that credit-to-GDP gaps predict future banking crises. The same regularity can probably be observed at the bank level, and further down at the individual loan level, since it is millions of financial transactions that drive the aggregate credit series.[39] But those past transactions are part of an even broader universe of social behaviour; scanning social media for trends in sentiment or intentions to take up credit or invest would convey additional (and timely) information, which may align (or not) with the aggregates we started with. Indeed, Big Tech firms tailor financial services to individual customers. Can this selectivity be adapted for use by supervisors and regulators (suptech and regtech) so that Big Data reduces the probability of financial crises?

The BIS is making a special effort to focus on "Innovation and the Digital Economy". In the light of what was said above, it is important to undertake policy analysis and research on how key innovations, such as machine learning, artificial intelligence, distributed ledger technology, and the increased availability of data, can inform policy and shape the responses of central banks.

When it comes to policy, we need to develop tools to prevent or mitigate financial crises. More work should go into devising and testing macroprudential instruments to tame the financial cycle.[40] In parallel, developing comprehensive macro-financial models to explore policy trade-offs also deserves more attention.[41] We are still missing a robust framework for understanding the endogenous forces fuelling financial crises, which would help to identify potential early warning indicators. Efforts along those lines help sharpen the lens for discerning what matters for financial stability.

Looking forward, attempts to identify crisis risks in real time will inevitably fall short – in spite of best efforts. Where prescience fails, resilience has to make up for it. Thanks to the G20 regulatory reforms, the core financial system is now more resilient than a decade ago. Ultimately, it has to be the combination of enhanced regulation, supervision and information-sharing that helps prepare us for the next financial crisis.

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39 The ECB's collection of granular credit data (AnaCredit) can be used for monitoring at this level, see B Cœuré (2017), op cit.

40 A combined effort of the BIS, IMF and FSB has made several data sets available in this area, see IMF-FSB-BIS, "Elements of effective macroprudential policies – lessons from international experience", joint publication, 31 August 2016, www.bis.org/press/p160831.htm, and sources cited therein. See also E Cerutti, S Claessens and L Laeven, "The use and effectiveness of macroprudential policies: New evidence", *Journal of Financial Stability*, vol 28, 2017, pp 203–24.

41 For instance, a recent example is the paper of P-R Agénor, E Kharroubi, L Gambacorta, G Lombardo and L Pereira da Silva, "The international dimensions of macroprudential policies", *BIS Working Papers*, no 643, June 2017. It is important to incorporate how the financial sector interacts with the real economy; for a recent discussion, see M Gertler and S Gilchrist, "What happened: financial factors in the Great Recession", *Journal of Economic Perspectives*, vol 32, no 3, 2018.