Section A

Institution: Durham University

Unit of Assessment: Department of Mathematical Sciences

Title of case study: Digital Banking – Building Atom Bank's Digital Twin

Period when the underpinning research was undertaken: 2007 – 2019

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	**Role(s) (e.g. job** title): **(All Mathematical Sciences)**	**Period(s) employed by submitting HEI:**
Camila Caiado	Associate Professor	2011 – present
Nathan Huntley	Research Associate	2012 – 2018
Ignacio Vilaplana-Sanchez	Research Associate and PhD student	2018 – present
Michael Goldstein	Professor	1990 – present
David Wooff	Professor	1990 – 2015

Period when the claimed impact occurred: 2014 – 2021

Is this case study continued from a case study submitted in 2014? N

Section B

1. Summary of the impact

Durham University worked in collaboration with Atom Bank to develop an end-to-end banking model based on mathematical and statistical methods developed at Durham. The model provides the business with a strategic understanding of the relationships between the bank's key components including customers and products and supports major business decisions such as financial planning, resourcing, product pricing and funding. The impacts of this on Atom Bank include improved management of short term liquidity requirements, improved capital deployment and operational risk reduction. Direct savings to the bank are estimated at [redacted] or more annually since 2018 and these savings are passed on to the bank's customers.

2. Underpinning research

Mathematical models, implemented as high-dimensional computer simulators, are often used to study complex systems. In general terms, a bank is a complex system with multiple interacting components driven by statistical and financial models that are used to predict future market behaviour and optimise scenarios. Banking models need to be constructed so that they can interact with each other seamlessly and so that they can be easily used to predict behaviours (financial market, customer interactions), optimise strategies (investments, funding capture, pricing) and manage risk (operational, risk appetite). Based on the Bayes Linear methodology and uncertainty quantification framework **[R1-R3]**, Atom and Durham University developed a number of critical components necessary for financial operations and decision support solutions used by stakeholders across the business to understand the impact of their choices on the overall business leading to a new interactive and innovative approach to banking.

Durham research on complex simulations, statistical modelling, and optimisation **[R2-R4],** was used to mathematically model and optimise the relationship between investments, customer

behaviour, market behaviour, and their constraints and impacts. It resulted in a “simulator” of the bank, or the “Atom Digital Twin”. Advanced uncertainty analysis constructed a statistical model including an optimisation tool and user interfaces for decision support in line with the work in **R1** and **R3**. In particular, a Bayes Linear approach **[R1]** was used to construct emulators of some of the sub-models of the financial and operational master models of the bank, and history matching was used to identify areas of the models’ input spaces (formed by a number of variables the bank can normally control such as prices and staffing).

One of the tools delivered is a funding optimiser that identifies the potential price combinations that can be set in order to minimise future cost; for example, if there were 4 fixed-term mortgage products with different maturity lengths that have their prices updated weekly within certain constrained price ranges. As in **R1-R3**, we started by building a Bayes Linear emulator of one of the mortgage pricing models. The objective is to find combinations of prices that minimise costs (and maximise long-term profit where possible) over a period of 5 years; with prices varying weekly for each product. In this context, it is necessary to identify suitable time series solutions (length 260 for each product) that are feasible individually but also as a group to ensure capital requirements can be met each week. In **R5**, the process of sensitivity analysis for stochastic dynamical systems and how to investigate the impact of different inputs over time was discussed. Since optimising for 1,040 inputs simultaneously in a reasonable amount of time wasn’t feasible, the same approach was used as in **R5,** to identify the periods in time where price variations were most likely to cause large changes to the output or drive the models into infeasibility. This approach was very effective in reducing the input space and narrowing down price ranges for each product but also to allow the decision makers to see alternative pricing profiles that could lead to a similar (if not the same) outcome that they were used to.

At a given point in time, the bank has the responsibility to retain the correct amount to be paid to customers as their mortgages come to an end, but also has to hold certain amounts of cash to ensure business continuity. However, holding on to money without investing it is costly, so they need to balance out investments and regulatory demands to minimise cost. First, they need to understand how much business to expect if they are to set a specific price for a given product, subject to potential competitor behaviour and other external factors, to derive a price elasticity model of demand for each product. Given a certain demand level, estimated using agent-based modelling principles in **R4**, a retention profile has to be derived and the minimum cash requirements updated. In **R4**, the research looked at how customers behave with respect to peer pressure, innovation, product loyalty and memory. For a new bank, loyalty doesn’t yet exist and memory needs to be built as part of the retention process. The Durham research looked at the trade-offs between parameters such as for innovation and memory for different customer groups at Atom to estimate retention rates. These values have then been subsequently updated based on real data as products matured.

Even though the individual models mentioned have been optimised to run in real-time (<10ms), it is necessary to identify the regions in the input space for which cost is minimized; here the methodology outlined in **R3** and **R5** was used. At the moment, this takes around 90s per planning year reducing severely the time taken by this process which used to take hours and required constant manual intervention; a combination of Bayesian optimisation techniques for space reduction, and Bayes Linear methods were used. Now this is enveloped in a user interface that can be used to stress test price interactions, inform treasury of needed funding capture, investigate marketing strategies, and optimise for the yearly 7-year financial planning round.

3. References to the research

[R1] Goldstein, M., & Wooff, D. (2007). Bayes linear statistics: Theory and methods (Vol. 716). John Wiley & Sons. [https://doi.org/10.1002/pst.328]

[R2] Goldstein, M., & Huntley, N. (2016). Bayes Linear Emulation, History Matching, and Forecasting for Complex Computer Simulators. Handbook of Uncertainty Quantification, 1-24. [DOI 10.1007/978-3-319-11259-6_14-1]

[R3] Caiado, C. C. S., & Goldstein, M. (2015). Bayesian uncertainty analysis for complex physical systems modelled by computer simulators with applications to tipping points. Communications in Nonlinear Science and Numerical Simulation, 26(1-3), 123-136. [http://dx.doi.org/10.1016/j.cnsns.2015.02.006]

[R4] Bentley, R.A., Caiado, C.C.S. & Ormerod, P. (2014). Effects of memory on spatial heterogeneity in neutrally transmitted culture. Evolution and Human Behavior 35(4): 257-263. [https://doi.org/10.1016/j.evolhumbehav.2014.02.001]

[R5] Bissell, J. J., Caiado, C. C. S., Goldstein, M., & Straughan, B. (2014). Compartmental modelling of social dynamics with generalised peer incidence. Mathematical Models and Methods in Applied Sciences, 24(04), 719-750. [http://dx.doi.org/10.1142/S0218202513500656]

The original research contained in: **R1** was supported by a number of EPSRC grants, all of which were highly graded in final review; **R2** was supported by the NERC funded Consortium 'CREDIBLE'; **R3-R5** was supported by the Leverhulme funded Tipping Points project.

4. Details of the impact

Atom is a digital challenger bank based in the City of Durham, which started trading in 2016, offering an innovative and efficient mobile-only app-based personal and business banking experience. One of the reasons Atom chose Durham as its base was to take advantage of the research output of the University. *'It quickly became apparent that the department's specialisation in applying Bayesian techniques to financial and other systems [e.g. **[R3, R4]**] offered the opportunity to create a digital twin of some of the bank's key allocation decisions.'* **[E1].** The collaboration between Atom bank and Durham University resulted in the creation of the Atom Bank Digital Twin using methods [**R1-R5**] developed within the Mathematical Sciences department. This has allowed Atom Bank to re-invent financial planning in financial services enabling it to 1. **Optimise business activity** so that it generates the maximum return from each set of investment decisions and 2. **Understand in full the consequential impacts of any business decision** on each business area. This enables the bank to link its resource planning accurately to product and pricing decisions **[E2].** Atom says that this was *'critical to building a competitive advantage that can be shared between investors and customers'* **[E1]. The total estimated savings, detailed below, are currently** [redacted]

The Atom Bank Digital Twin is a novel decision support suite, which is being used to support major business decisions such as financial planning, resourcing, product pricing and funding. Atom Bank now has the unique opportunity to mathematically model the organisation and manage the business according to the inputs and outputs of that model. The direct impact of the collaboration with Durham University (which originally centred around a Knowledge Transfer Partnership) on Atom's financial performance can be summarised in three categories as taken from **E1**:

Improved management of short-term liquidity requirements [E1]

Banks are required by regulation to hold sufficient liquid assets to cover their forthcoming cash flows. Many aspects of inflows and outflows, such as the quantity of loans being provided to customers, and the savings deposits received by customers, are uncertain. The models

created with Durham research **[R1-5]** have greatly increased the accuracy of Atom's ability to forecast these cash flows and so reduce the overall liquid assets the bank is obliged to hold (which are an overall cost to the business). The main items are:

1. Improved modelling of loan completions allowed the liquidity held against future loan completions to be reduced by approximately [redacted] at all times, leading to around [redacted] reduction on average in liquid assets held, with an annualised cost reduction of around [redacted] This benefit was first fully realised in 2018 and a similar annual benefit remains today.
2. Improved ability to predict the behaviour of savings customers has allowed Atom to reduce the volume of liquid assets needed to ensure that deposit holders can access their funds upon maturity. It is estimated that around [redacted] lower liquid assets were needed in 2018 and 2019, leading to a reduction in cost of liquidity of around [redacted] in each year. In 2020, a different business strategy meant that the modelling reduced the risk of accidental breaches of regulatory limits, which cannot easily be measured in terms of financial value, but is of critical reputational importance.
3. Advanced uncertainty analysis (R) on the above models allowed the business to reduce buffers (designed to minimise the risk of regulatory breaches) on liquidity, leading to another [redacted] of reduced liquidity requirements in 2019. Again, in 2020, this methodology has led to risk reduction rather than financial improvements.

Improved capital deployment [E1]

Banks, particularly fast-growing banks such as Atom, are often constrained by available capital. They are obliged to hold certain levels of capital for each loan sold. Therefore, maximising the efficiency of this limited resource is key to profitability. Working with Durham University has principally provided benefits in the following areas:

1. Quality assurance work carried out on Atom's internal lending models is estimated to have led to at least a [redacted] improvement on margin. This equates to around [redacted] per year on loans originated in 2019.
2. Improved long-term financial planning from the summer of 2017 onwards will have led to a more efficient business plan. This benefit is significantly harder to estimate than any of the others, but financial planning experts quantified this as at least [redacted] improvement on the net interest margin of the entire book, which equates to around [redacted] per year based on Atom's current book.

Operational risk reduction [E1]

Another use of a bank's capital is to be held against risks to implementing the business plan successfully. Collaborating with Durham University meant a number of operational risks were reduced. The highlights were:

1. Quality assurance on regulatory mortgage calculations.
2. Reduction in model risk, i.e. the risk that Atom's internal models give erroneous or misleading forecasts.

[redacted]

Changes in practice at Atom Bank

Embedding the use of the Atom Bank Digital Twin has had a substantial impact on processes and policy within Atom Bank. Atom's data and analytics team has expanded from [redacted] employed in the North East of England to deliver this project and its extensions **[E2]** (gross value added based on North East 2017 figure is [redacted]) and a total of 30 staff have been trained in using the model output as well as in the R language to allow model development and maintenance to continue **[E2]**. By embedding expertise in the open-source

R programming language, the business has been able to avoid costly licensing for commercial data analysis software. Based on quotes provided to Atom, the impact of this is a saving of around [redacted] per year **[E2]**. Atom says that the collaboration '*has also shifted expectations and perceptions amongst the senior team at Atom, many of whom had not had or seen the benefit of deep engagement with university researchers in their previous roles*' **[E1]**. Atom Bank have continued to win industry recognition and have recently been included in the Tech Nation Future Fifty business community **[E5].** They continue to increase the number of products offered and [redacted] **[E6].**

Impact on customers of Atom Bank

Atom bank is a retail business and so every efficiency improvement also has a benefit to customers. '*Reducing the friction between teams, increasing the allocative efficiency of our capital, and responding to the constraints on optimisation that are a necessary part of being a regulated bank all mean that customers get better prices for their savings and lower costs for their lending than we could otherwise afford to offer. Atom continues to be recognised for its excellence in the savings and lending markets' **[E1]*** (as recognised by various media organisations **[E3]**) *'and behind all of these sits an engine that is refined and tuned by the work done with Dr Caiado and colleagues.*' **[E1]**. Atom is Trustpilot's most trusted UK bank and consistently achieves Net Promoter Scores in excess of +75 [**E4**, 2020 annual report, page 15].

In summary Durham University have helped to develop an end-to-end banking model that provides a live and interactive overview of the business with a strategic understanding of the relationships between the bank's key components including customers and products. This is unique within the banking sector and the change in practice has given Atom Bank the opportunity to update both the simulation and the optimisation in real time as the Bank evolves and grows, increasing sustainability and providing rigorous calculations supporting the mortgage lending process that minimise the risk of operational damage or regulatory breaches from calculation error. All these benefits are passed on to the customers as savings.

5. Sources to corroborate the impact

[E1] Letter from Chief Technology Officer and Founder (November 2020)

[E2] KTP Final report (July 2019)

[E3] Atom in the media, for example The Times and The Northern Echo.

[E4] Atom Bank Annual reports (2015/16, 2016/17, 2017/18, 2018/19, 2019/20)

[E5] TechNation Future 50 - https://technation.io/news/future-fifty-cohort-2020/

[E6] Total assets growth from 2015-2019 - https://thebanks.eu/banks/18618