Institution: University of Oxford		
Unit of Assessment: 1 – Clinical Medicine		
Title of case study: Controlling the COVID-19 pandemic with mobile phone contact tracing		
Period when the underpinning research was undertaken: July 2016 – December 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Professor Christophe Fraser	Senior Group Leader	July 2016 – present
Dr David Bonsall	Postdoctoral Researcher Clinical Lecturer Postdoctoral Researcher	2016 – 2018 2018 – 2020 February 2020 – present
Dr Luca Ferretti	Researcher	Dec 2018 – present
Dr Christopher Wymant	Researcher	July 2016 – present
Dr Robert Hinch	Researcher	August 2016 – present
Period when the claimed impact occurred: March 2020 - December 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Researchers at the University of Oxford demonstrated the utility of mobile phone contact tracing apps to control the COVID-19 pandemic and provided the epidemiological evidence base used by the UK government, governments worldwide, and Google and Apple, to take the decision to develop and deploy these tools. Their research produced fundamental principles, benchmarks, parameters and design that were taken up by governments and developers and have significantly contributed to the uptake and impact of the apps worldwide. In the UK, the NHS COVID-19 Contact Tracing App sent 1,700,000 exposure notifications to break chains of transmission and prevented an estimated 600,000 cases of COVID-19 in the UK between September and December 2020.

2. Underpinning research

The research of Professor Christophe Fraser's group focuses on population dynamics and epidemiology of pathogens, developing mathematical models and tools for public health. Between 2016 and 2020, the Fraser group in Oxford completed the development of a computationally efficient agent-based mathematical model (PopART-IBM) to simulate sexual networks to understand the HIV epidemic in Zambia as part of the Population Effects of Antiretroviral Therapy to Reduce HIV Transmission (PopART) HPTN 071 Trial. They showed how the model calibrates within a Bayesian inference framework to detailed age- and sex-stratified data from multiple sources on HIV prevalence, awareness of HIV status, ART status, and viral suppression and presented future projections of HIV prevalence and incidence for this community in the absence of trial intervention [1].

In January 2020, the Oxford group begun work on the COVID-19 epidemiological data coming out of China. Their paper in Science [2] represents the unique conception of a mobile phone contact tracing app for controlling the epidemic spread of COVID-19. It recommended that a mobile app that identifies infected people and their recent person-to-person contacts using digital technology should form part of an integrated COVID-19 control strategy. They demonstrated the epidemic potential of COVID-19 and, critically, showed the importance of understanding routes of transmission. In [2], they compared protecting the population using isolation coupled with manual human contact tracing versus algorithmic instantaneous contact tracing assisted by a mobile phone app and concluded that a phone app is an effective strategy for control. Aware of the short incubation time for COVID-19, they highlighted importance of quick contact tracing. In the paper, they also were among the first research teams globally to identify substantial transmission of COVID-19 before symptoms, and to quantify the importance of this for contact tracing.

The Oxford group adapted the HIV sexual network simulation developed in [1] for the case of COVID-19 for social networks [3], which drive COVID-19 infection. The Oxford group also showed that a mobile contact tracing app is still effective at low rates of app uptake, reducing deaths and infections. This work was done in collaboration with Google [4].

In May 2020 the UK introduced a Test, Trace, Isolate programme in response to the COVID-19 pandemic, with the Isle of Wight piloting the NHS COVID-19 contact tracing app. The Oxford group observed significant decreases in incidence and R on the Isle of Wight immediately after the launch, showing that the sub-epidemic on the Isle of Wight was controlled significantly more effectively than the sub-epidemics of most other regions. This work was the first evaluation of an intervention containing a contact tracing app demonstrating a reduction in transmission [5].

With collaborators, the Oxford researchers investigated the timing of the infectious period in relation to time of infection and time of symptom onset [6]. Knowledge about the timing of the infectious period is critical for both manual and app-based contact tracing as it determines which contacts need to go into quarantine and for how long.

3. References to the research

University of Oxford authors in bold. Students in italics.

1. Pickles M, Cori A, **Probert W**, **Sauter R**, Fidler S, Ayles H, Bock P, Donnell D, Wilson E, Piwowar-Manning E, Floyd S, Hayes R and **Fraser C** (2020). PopART-IBM, a highly efficient stochastic individual-based simulation model of generalised HIV epidemics developed in the context of the HPTN 071 (PopART) trial, *MedRxiv,* Working paper, DOI: 10.1101/2020.08.24.20181180
2. **Ferretti L, Wymant C, Kendall M, Zhao L, Nurtay A, Abeler-Dörner L, Parker M, Bonsall D** and **Fraser C** (2020). Quantifying SARS-CoV-2 transmission suggests epidemic control with digital contact tracing, *Science* 368 (6491), Journal article, DOI: 10.1126/science.abb6936. 407 citations (WoS, 03-2021)
3. **Hinch R**, **Probert W**, **Nurtay A**, **Kendall M**, **Wymant C**, **Hall M**, **Lythgoe K**, **Bulas Cruz A**, **Zhao L**, **Stewart A**, **Ferretti L**, Montero D, Warren J, Mather N, Abueg M, Wu N, Finkelstein A, **Bonsall D**, **Abeler-Dörner L** and **Fraser C** (2020). OpenABM-Covid19 - an agent-based model for non-pharmaceutical interventions against COVID-19 including contact tracing, *MedRxiv.* Working paper, DOI: 10.1101/2020.09.16.20195925
4. Abueg M, **Hinch R**, Wu N, Liu L, **Probert W**, Wu A, Eastham P, Shafi Y, Rosencrantz M, Dikovsky M, Cheng Z, **Nurtay A**, **Abeler-Dörner L**, **Bonsall D**, McConnell M, O'Banion S and **Fraser C** (2021). Modeling the effect of exposure notification and non-pharmaceutical interventions on COVID-19 transmission in Washington state. *NPJ Digit Med* 4(1):49. Journal article, DOI: 10.1038/s41746-021-00422-7
5. **Kendall M**, *Milsom L*, **Abeler-Dörner L, Wymant C**, **Ferretti L,** Briers M, **Holmes C, Bonsall D, Abeler J** and **Fraser C** (2020). Epidemiological changes on the Isle of Wight after the launch of the NHS Test and Trace programme: a preliminary analysis, *Lancet Digital Health*, 2(12):e658-e666. Journal article, DOI: 10.1016/S2589-7500(20)30241-7
6. **Ferretti L**, Ledda A, **Wymant C**, **Zhao L**, Ledda V, **Abeler-Dörner L**, **Kendall M**, **Nurtay A**, Cheng H-Y, Ng H-H, Lin, **Hinch R**, Masel J, Kilpatrick A and **Fraser C** (2020). The timing of COVID-19 transmission, *MedRxiv.* Working paper, DOI: 10.1101/2020.09.04.20188516

4. Details of the impact

Contact tracing is a key tool for enabling locally specific and relevant control measures, identification of emergence of dangerous clusters, enabling an informed public health response and promoting socially responsible behaviours for individuals. The Oxford research informed decisions by governments and development companies to pursue digital contact tracing for COVID-19 and detailed parameters for deployment to maximise the impact of this public health intervention to prevent infections, break chains of transmission, save lives and reduce the burden on health systems.

Providing an evidence base for governments

UK

Within a week of sharing the preprint of [2] with the UK Government, Oxford researchers embarked on developing a digital contract tracing programme with NHS-X from 7 March 2020. NHS-X CEO confirms that [2] "*provided compelling evidence that digital contact tracing could play an important role in controlling the pandemic*", that it *"played a pivotal role in ministers' decision to pursue digital contact tracing",* and it *"contributed significantly to the government's response to Covid-19".* [A]. Fraser was called as a witness to the House of Commons Select Committee on Science and Technology on 28 April 2020 alongside the NHS-X CEO who confirmed the Oxford research provided the scientific justification for the NHS app stating "W*e very quickly moved when Professor Fraser gave us the epidemiological basis for why it would be a powerful intervention".* [B].

This role of the Oxford research in the decision to pursue digital contact tracing is described by the Government Office for Science, who stated

> *"Prof Christophe Fraser was present from the outset and played the central role in providing evidence that mobile contact tracing – using an app – could play a powerful role in controlling the pandemic. His work, subsequently published in Science [2], played a decisive role in both convincing us that this was an important direction to pursue and also illuminating the directions that might be taken to implement the approach. Prof Fraser was scrupulous in helping us to understand strengths and limitations."* [C]

The Oxford team produced two reports for the UK Government [D, E] assessing options in detail, which led to the UK pilot of the mobile contact tracing app on the Isle of Wight in May 2020 as part of a pilot of the Test and Trace system, which was successful in reducing transmission and controlling the epidemic [5]. Based on their research including [2], the Oxford researchers laid out in May 2020 five epidemiological and public health requirements that any COVID-19 tracing app should satisfy [F]. These are

1. Sensitively and specifically quarantine infectious individuals
2. Higher user uptake and adherence
3. Rapid notification
4. Integration with local health policy
5. Ability to evaluate effectiveness transparently

The NHX-C CEO described that these requirements *"summarised succinctly the guiding principles of the app's development*" [A], citing [2] and [D,E,F].

The Government Office for Science letter confirms *"Prof Fraser and his team […], actively contributed to all aspects of the app development"* and in describing [D, E] notes the "*major contributions to the setting of the parameters of the app and modelling of design alternatives. They also participated in extensive work on validation including preparation for multiple searching independent checks of their work."* [C]

The NHS Test and Trace Product Director gave the following example of how the research has impacted the app design:

> *"Their initial modelling work, in particular the assessment of the distribution over index case infectiousness, is used within the NHS COVID-19 app, and also referenced in recommendations around the world. Inclusion of this distribution within the app's risk scoring helped to reduce the number of false notifications by over 30%."* [G]

Following the Isle of Wight pilot, the UK app moved to the Google/Apple platform. The Oxford group established a partnership with Google to develop the platform. Oxford's five principles were used by the Google/Apple Exposure Notification API developers as requirements for their app to meet before launch.

Globally

The Google/Apple API drives the UK NHS COVID-19 contact tracing app and many other apps worldwide. In Europe in particular, countries have embraced the decentralised model provided by Google/Apple including UK, Germany, Italy, Austria, Switzerland and Ireland. The API is integrated into the operating system of Apple and Android phones and a risk scoring algorithm is used to decide how to sum up exposure times to arrive at an overall risk score which will lead to an exposure notification to the user if one or more of the contacts later test positive for COVID-19. The UK NHS app uses its own risk scoring algorithm which is based on research by the Fraser group and the Alan Turing Institute.

In a letter, the Vice President of Engineering at Google commented on impact on the press:

> *"The initial absence of evidence made health authorities reluctant to invest in the technology and users hesitant to adopt it. When the press misinterpreted findings to question the feasibility of digital contact tracing, Professor Fraser's team proactively clarified the misunderstanding; changing the narrative in the mainstream press."* [H]

Describing the impact of [4] on approaches by governments and health authorities, Google wrote:

> *"It's difficult to overstate how impactful this evidence base has been in enabling governments make informed decisions around adopting Exposure Notifications technology. The joint publication's focus on low levels of app adoption and the added impact to traditional contact tracing was also instrumental in convincing uptake of the technology by many public health authorities, as part of collaboration with different third party entities, and even with uptake by the public."* [H]

On the topic of global impact, the Government Office for Science said:

> *"the app as it currently exists would not exist without the scientific work of Prof Fraser. Furthermore, the work of Prof Fraser informed the efforts of numerous other countries (including France, Norway, Ireland, Israel) each of which took different directions but nevertheless relied upon scientific and modelling direction established by Prof Fraser. I will be unequivocal: this is the finest example of true scientific impact that I have encountered in my career. It combines excellent scientific work, advocacy, engagement, ethics and selfless work in extremely difficult conditions and under great pressure. It has undoubtedly saved lives and had substantial economic impact."* [C]

Impact on Google and Apple

Google describe the impact of the Oxford research on their decision to pursue digital contact tracing:

> *"Prior to this pandemic, there was little known about effectiveness of digital contact tracing technologies and factors key to their success. The Fraser group's initial publication in Science [2] and report to the NHS provided scientifically credible and immensely valuable information in this area."* [H]

Google also describe specific examples of how the underpinning research influenced the app design, including the requirement set out in [F] for rapid notification:

> *"At Google and Apple, these results directly influenced API design decisions; they demonstrated user-reported symptoms were an important facilitator of timely notifications, leading us to support self-reported symptoms in the API. Findings also informed quantifiable benchmarks for system efficacy (e.g., the number of days by which contacts must be notified), which enabled strategic investment of time and resources (e.g., effort to help health authorities automate distribution of codes verifying a positive test)."* [H]

Health impact of NHS COVID-19 Contact Tracing App

Between launch on 24 September 2020 and 31 December 2020, NHS COVID-19 app was downloaded to over 21,000,000 phones, and used regularly by approximately 16,500,000 users in England and Wales, which is 49% of the eligible population with compatible phones, and 28% of the total population. During these three months, the app sent 1,700,000 exposure notifications to break chains of transmission and in an analysis by the Fraser group with collaborators [I], they estimated **600,000 cases had been prevented**. The success of the app during 2020 was made public by the Government in February 2021 [J].

The NHS Test and Trace Product Director explains that

> *"The app has an estimated (lower bound) secondary attack rate of approximately 6%, which compares favourably to traditional contact tracing, yet has the advantage of being privacy preserving and extremely fast. The app has therefore been crucial in breaking chains of transmission and protecting users and their communities."* and goes on to confirm that the University of Oxford's *"contributions to its development have helped prevent many cases of COVID-19, and ultimately deaths."* [G]

Predicting infection rates for healthcare planning and provision

The COVID-19 social network open source simulation OpenABM-Covid-19 [3] was the main tool used by NHS England and NHS Wales to predict COVID-19 infection rates and therefore plan key resources e.g. staffing, hospital beds, equipment, medications. The AI technology specialist company Faculty use Oxford'sOpenABM-Covid-19 as the underpinning simulation for their contact with NHS-England to provide data visualisations dashboard information for key central government decision-makers with a deeper level of information about the current and future coronavirus situation to help inform the response [K]. Similarly, the company Armakuni provide data visualisations for NHS-Wales. OpenABM-Covid-19 [3] has also been used by Singapore and France to predict infection rates and therefore plan key resources e.g. staffing, hospital beds, equipment, medications.

5. Sources to corroborate the impact

A. Letter from Chief Executive Officer of NHS-X, January 2021

B. Transcript from House of Commons Science and Technology Select Committee, 28 April 2020.

C. Letter from Chief Scientific Adviser for National Security, Government Office for Science, December 2020

D. Hinch R *et al.* Effective Configurations of a Digital Contact Tracing App: A report to NHSX. First published 16 April 2020, updated 10 August 2020. https://github.com/BDI-pathogens/covid-19_instant_tracing/blob/master/Report%20-%20Effective%20Configurations%20of%20a%20Digital%20Contact%20Tracing%20App.pdf

E. Report from the Oxford Pathogen Dynamics Group, Digital Contact Tracing advice and simulations, Update at 25 May 2020. https://github.com/BDI-pathogens/covid-19_instant_tracing/blob/master/Oxford%20BDI%20DCT%20update%2025%20May%202020.pdf

F. Oxford Pathogen Dynamics Group, Epidemiological requirements for app-based contact tracing of COVID-19, 7 May 2020. https://github.com/BDI-pathogens/covid-19_instant_tracing/blob/master/Epidemiological requirements for app-based contact tracing of COVID-19.pdf

G. Letter from NHS Test and Trace Product Director, February 2021

H. Letter from Google Vice President of Engineering, Exposure Notifications Lead, January 2021

I. Report: Wymant C, Ferretti L *et al*. The epidemiological impact of the NHS COVID-19 App, 9 February 2021. https://github.com/BDI-pathogens/covid-19_instant_tracing/blob/master/Epidemiological_Impact_of_the_NHS_COVID_19_App_Public_Release_V1.pdf

J. UK Government announcement of impact of COVID-19 App https://www.gov.uk/government/news/nhs-covid-19-app-alerts-17-million-contacts-to-stop-spread-of-covid-19

K. Faculty company website citing use of Oxford work to underpin products https://faculty.ai/blog/faculty-and-the-nhs-the-facts/