WHAT WORKS SCOTLAND

Working paper

Synthetic controls: a new approach to evaluating interventions

Peter Craig

What Works Scotland aims to improve the way local areas in Scotland use evidence to make decisions about public service development and reform.

We are working with Community Planning Partnerships involved in the design and delivery of public services (Aberdeenshire, Fife, Glasgow and West Dunbartonshire) to:

- learn what is and what isn't working in their local area
- encourage collaborative learning with a range of local authority, business, public sector and community partners
- better understand what effective policy interventions and effective services look like
- promote the use of evidence in planning and service delivery
- help organisations get the skills and knowledge they need to use and interpret evidence
- create case studies for wider sharing and sustainability

A further nine areas are working with us to enhance learning, comparison and sharing. We will also link with international partners to effectively compare how public services are delivered here in Scotland and elsewhere. During the programme, we will scale up and share more widely with all local authority areas across Scotland.

WWS brings together the Universities of Glasgow and Edinburgh, other academics across Scotland, with partners from a range of local authorities and:

- Glasgow Centre for Population Health
- Healthcare Improvement Scotland
- Improvement Service
- Inspiring Scotland
- IRISS (Institution for Research and Innovation in Social Services)
- Joint Improvement Team
- NHS Health Scotland
- NHS Education for Scotland
- SCVO (Scottish Council for Voluntary Organisations)

This Working Paper is one of a series of papers that What Works Scotland is publishing to share evidence, learning and ideas about public service reform.

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Summary

Synthetic control methods are a novel approach to comparative case study research using observational data. Though developed within political science, the methods can potentially be applied to a wide range of evaluation problems in economics, public health, social policy and other disciplines.

In the traditional approach, an area in which a new or redesigned service is being implemented is compared with another 'control' area (in which there is no change) and statistical adjustment used to account for any differences between areas that might bias the comparison. In the new approach, a synthetic control is derived using data on past trends in all potentially comparable areas, providing a more robust basis for identifying the impact of the service change.

Synthetic control methods may be a valuable addition to the range of techniques available for non-randomised evaluations of social, economic and public health interventions. To date there have been few applications in a UK context, and none in Scotland. Published evidence suggests considerable potential to apply synthetic controls to public service innovations at NHS Board, local authority or Community Planning Partnership level, and may widen the range of policy and practice changes that can usefully be evaluated.

1 Introduction

The shift towards evidence-informed policy-making, exemplified by initiatives such as What Works Scotland, requires policy-makers to demonstrate the effectiveness of interventions. Given the practical, political or ethical difficulties of applying experimental approaches to many policy interventions, evaluation methods that use observational data are now a focus of research and policy interest.

Policy makers often want to know the impact of interventions being implemented within defined geographical areas. Comparative case studies have long been used to address such questions. Synthetic control methods are a novel approach to comparative case study research using observational data. Though developed within political science, the methods can potentially be applied to a wide range of evaluation problems in economics, public health, social policy and other disciplines.

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Synthetic control methods may be a valuable addition to the range of techniques available for non-randomised evaluations of social, economic and public health interventions. This working paper explores the potential for applying synthetic control methods to place-based interventions within Scotland, making use of the increasing availability of routinely collected data. If synthetic control methods can be usefully applied, we will have identified an efficient solution to a wide range of pressing evaluation problems.

Section 2 provides a brief summary of the synthetic control method. Section 3 describes the range of applications of the method to date. Section 4 looks in greater detail at some applications that are particularly relevant to evaluating public service reform. Section 5 concludes with some recommendations for the use of synthetic controls in Scotland. The Appendix summarises how the literature search for this working paper was carried out.

2 How do synthetic controls work?

A key requirement for evaluating any intervention (such as a change in policy, or the introduction of a new service) is being able to measure outcomes in both the population affected by the intervention and a comparator or 'control' population which is not exposed to the intervention. Finding suitable controls is a key problem in designing evaluation studies.

In an experimental study, such as a clinical trial, randomisation provides the solution: patients are invited to join the study, and those who agree are randomly assigned to receive

either the standard or the novel treatment. Random assignment ensures that if the numbers of patients entering the study is sufficiently large, the groups receiving each treatment will be very similar, and any difference in outcomes will be attributable to the treatment. Coupled with other safeguards, randomisation is a powerful way of ensuring an unbiased estimate of the treatment effect. Yet for many interventions that researchers and policy-makers wish to understand, it is impractical, unethical or unacceptable to conduct experiments.

To evaluate impact in area-based interventions, the simplest approach is to choose a control area similar to the area where the intervention is being introduced, and compare outcomes in the two areas. The key difficulty is finding a control area sufficiently similar to allow outcome differences to be attributed to the intervention. Statistical methods of adjustment for differences between the areas are limited by the availability of data, and often cannot fully account for all the relevant differences. One way of overcoming this limitation is to use the 'difference-in-differences' method, in which change in the intervention area is compared with change over the same period in the control area. This takes account of all differences in the fixed characteristics of the areas, whether or not they are directly observed, and is therefore less limited by data availability. The method cannot, however, take account of area-specific trends, i.e. changes other than those attributable to the intervention that occur in one or other of the areas.

The synthetic control method attempts to overcome this problem by comparing the trend in the outcome of interest in the intervention area with the trend in a synthetic composite area. Suppose we wish to evaluate the impact on fire-related deaths of a new approach to fire and rescue services being implemented in one of Scotland's 32 Community Planning Partnerships (CPPs). The 31 unaffected CPPs would form a 'donor pool'. We would exclude from the donor pool all CPPs in which other changes in fire and rescue services were taking place at the same time as our intervention, and use information on pre-intervention levels in fire-related deaths and predictors of those levels in the remaining areas to derive the synthetic control. The control is the weighted average of all the areas in the donor pool that best mimics the pre-intervention trend in the intervention area. The effect of the intervention is then estimated as the difference between the post-intervention trends in the intervention area and the synthetic control area.

This is known as a data-driven driven approach because it relies (at least partly) on data about past trends and characteristics in the areas in the donor pool, rather than primarily on judgements about which areas are comparable to the intervention area. Since it draws on data from a range of areas, rather than a single comparator, it is less prone than traditional methods to bias due to some unexpected event in the comparator area. It can be extended to cases where the intervention of interest has been introduced in a number of areas, by creating a synthetic control for each intervention area in turn. As the next section shows,

synthetic control methods have been applied to a wide range of interventions and settings, but there are some important limitations on their use.

First, because the method relies on comparisons between a real area and a synthetic control area, standard methods of statistical inference are inappropriate. An alternative approach is to use 'placebo' or 'falsification tests' in which the intervention area is replaced in turn by each of the areas in the donor pool. A synthetic control is derived for each area, and the post-intervention trend compared for each pair of synthetic and real controls, to create a set of placebo effects. The difference in the post intervention trends for the intervention area and its synthetic control can be compared graphically with the differences for all the other pairs, and a P-value can be calculated based on the fraction of placebo effects that are smaller than the estimated intervention effect.

Second, the intervention should be significant at the level of the area in which it is implemented. If it only affects a small proportion of the population, the difference between the intervention area and the synthetic control area will underestimate the true effect. Ideally it should also be sustained long enough to provide a robust estimate of the post-intervention trend.

Third, the effect of the intervention can only be estimated accurately if there were no other events that affect only the intervention area (such as additional service changes that might also reduce fire-related deaths, or changes in systems for measuring deaths).

Fourth, the intervention should affect outcomes only in the intervention area. If it 'contaminates' some or all of the control areas the effect of the intervention may be underestimated.

Fifth, a good fit is needed between the pre-intervention trends in the intervention area and the synthetic control. The longer the pre-intervention period for which data is available, the less likely it is that unobserved area-specific trends will bias the post-intervention comparison.

Finally, for the method to work well, some weighted combination of areas in the donor pool must be similar to the intervention area. If the intervention area is at the extreme end of the range of observed characteristics, it is unlikely that the method will generate accurate predictions. In our example, if fire deaths were higher in the intervention area than in any of the control areas, it would be impossible to mimic precisely the trend in the intervention area with any combination of other areas in the donor pool, though it may still be possible to get an adequately close match. Likewise if the areas are very heterogeneous, it may be necessary to restrict the donor pool to those that are relatively similar in observed characteristics to the intervention area.

Key references

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Abadie, A., et al. (2011). "Synth: An R Package for Synthetic Control Methods in Comparative Case Studies." Journal of Statistical Software 42(13): 1-17.

Dhunguna S., (2011), Identifying and evaluating large scale policy interventions. What Questions Can We Answer? Policy Research Working Paper 5918, World Bank Africa Region, Poverty Reduction and Economic Management Unit.

3 How have synthetic controls been used so far?

This section is based on a scoping review, carried out to explore the range of applications of the synthetic control method. Unlike a formal systematic review we did not attempt to identify all relevant studies, or to appraise identified studies for methodological quality. Rather we wanted to gain an insight into how the method had been used to date, and its potential applicability to the evaluation of area-based interventions within Scotland. The search method is described in the appendix, and Table 1 lists the studies we identified through the search, plus some we were aware of through earlier work.

The first study to use synthetic control methods was reported in 2003, but it was not until 2010 and the publication of Abadie et al.'s study of the effect of tobacco control programmes on tobacco consumption in California that its use widened. As Table 1 shows, the range of applications is now very wide, from studies of natural disasters and political conflict through to social and economic policy interventions, as is the range of spatial scales, from whole countries down to school districts.

Table 1 Synthetic control studies 2003-15

	National	Sub-national
Natural events	Impact of the Kobe Earthquake on Japan's GDP (Du Pont and Noy, 2012) Effect of catastrophic natural disasters on national economic growth (Cavallo et al., 2013)	Effect of hurricanes on population growth, economic growth and incomes on Hawaiian islands (Coffman and Noi, 2012) Effect of earthquakes on regional economic growth within Italy (Barone and Moccetti, 2014)
Political events	Impact of autocratic transition on GDP growth (Nannicini and Ricciuti, 2010) Effect of armed conflict on bond prices in Colombia (Castaneda and Vargas, 2012) Effects of wars of liberation on economic growth in African countries (Some, 2013) Impact of German reunification on economic growth in West Germany (Abadie et al., 2014) Impact of military involvement on health and military spending and economic growth in Britain and the US (Bove and Elia, 2014) Effects of coups d'etat on defence spending (Bove and Nistico, 2014) Effect of 'colour revolutions' on democratisation and control of corruption (Kennedy, 2014) Effects of resource income on democratisation (Liou and Musgrave, 2014)	Economic impact (GDP and share prices) of terrorist conflict in the Basque country Abadie and Gardeazabal, 2003) Effect of a terrorist killing on house prices in Amsterdam (Gautier et al., 2009) Effect of political uncertainty on provincial GDP growth in Fujian (Yu and Wang, 2013) Effect of the 'Troubles' on GDP in Northern Ireland (Dorsett, 2013)
Economic/social policy	Effect of inflation-targeting polices on inflation rates in emerging economies (Lee, 2011) Impact of trade openness on economic growth in transition economies (Nannicini and Billmeier, 2011) Effect on US inward direct investment of the UK's decision not to adopt the Euro (Sanso-Navarro, 2011) Effect of Nigeria's National Empowerment and Economic Development Strategy on economic growth (Dhunguna, 2011)	Effect of merit-based scholarships on educational outcomes in Arizona (Upton, 2005) Effect of grade retention on educational attainment in the French-speaking community of Belgium (Belot and Vandenberghe, 2009) Impact of US State-level tobacco control programmes on tobacco consumption (Abadie et al., 2010) Effect of a methamphetamine precursor law on methamphetamine use and harm in

	National	Sub-national
	Effect of Kyoto Protocol on CO2 emissions in Australia, Canada, France, Germany, Great Britain, Italy and Japan (Almer and Winkler, 2012) Effect of remaining outside a trade agreement (GAFTA) on Algeria's trade with member countries (Hosny, 2012) Effect of Japanese monetary policy on dollar-yen exchange rates (Inoue, 2012). Impact of economic liberalisation on GDP (Billmeier and Nannicini, 2013) Effect of judicial appointments commissions on gender equity in Commonwealth countries (Iyer, 2013) Effect of capital controls on capital inflow in Brazil (Jinjarak et al., 2013) Effects of efficiency improvements and changing economic structure on energy intensity in Latin American countries (Jimenez and Mercado, 2014) Effect of same sex marriage laws on different sex marriage in the Netherlands (Trandafir, 2014) Effect of expansion of childcare provision on women's labour force participation in Mexico (Calderon, 2014)	California (Nonnemaker et al., 2011) Impact of nutritional labelling on food purchases (Kiesel and Villas Boas, 2013) Impact of mandatory entrance exams of college enrolment in US states (Klasik, 2013) Effect of property taxes on house prices in Shanghai and Chongqing (Zheng and Zhang, 2013) Impact of corporate tax cuts on foreign direct investment in Russian regions (Baccini et al., 2014) Impact of universal state-funded pre-school on private provision in US states (Bassok et al., 2014) Effect of school nutrition policies on diet and overweight in US school districts (Bauhoff, 2014) Effect of state-level immigration laws on Arizona's population composition and housing markets (Bohn et al., 2014) Effect of mandatory financial education on credit behaviour of young adults (Brown et al., 2014) Impact of reducing numbers of traffic police on traffic fatalities and injuries (De Angelo and Hansen, 2014) Impact of a state-level health reform on self-employment (Heim and Lurie, 2014) Effect of supermajority vote requirements on tax burden in California (Lee, 2014) Effect of New York's ban on use of handheld phones while driving on traffic fatalities (Sampaio, 2014) Effect of establishment of nuclear power stations on local per capita incomes in Japan (Ando, 2015) Effect of shale oil and gas production on regional economies in Arkansas, North Dakota and Pennsylvania (Munasib and Rickman, 2015).

	National	Sub-national
Other	Effect of academic honours on subsequent research productivity and citations (Chan et al., 2014)	

A number of the studies use synthetic controls alongside other methods, such as difference-in-differences. As well as improving the robustness of estimates from the individual studies, this is a useful way of learning about the advantages and drawbacks of the different methods and their applicability in different circumstances. Several studies are classic natural experiments in that they exploit a sudden event such as natural disaster, the introduction of new legislation or a sudden policy change. Since many of the primary studies are retrospective and require data over an extended period they focus on outcomes where routinely collected data is available, such as mortality or economic growth. The range of potential applications of the method is therefore limited by the availability of such data.

4 Case studies

Here we briefly summarise two synthetic control studies to demonstrate how the method may be applied. The first is Abadie and Gardeazabal's (2003) seminal study of the effect of conflict in the Basque country on regional economic growth.

The Basque Country was historically one of the richest regions of Spain, but dropped down the ranking after terrorist activity escalated in the 1970s. As the whole of Spain suffered an economic downturn in the late 1970s, it is possible that the relative decline in prosperity of the Basque country reflected features of its economy that left it vulnerable to the downturn. To distinguish the effects of terrorism from these other influences, Abadie and Gardeazabal created a synthetic Basque Country, using information on pre-1975 predictors of economic growth, such as investment as a proportion of GDP, human capital and economic structure. The trend in GDP in the synthetic Basque country, a weighted composite of Catalonia and Madrid, closely matched the trend in the real Basque Country from 1955 to the early 1970s, but diverged upwards after 1975, with the size of the gap suggesting a 10% loss in GDP as a result of terrorism. To further test whether the effect was attributable to terrorism, Abadie and Gardeazabal created a synthetic Catalonia using the same methods, and again looked for a divergence after 1975. In this case growth in the synthetic control fell below that of the real region after 1975, possibly because the trend in the synthetic control did not take into account the 1992 Barcelona Olympics. As Catalonia was the main contributor to the synthetic Basque Country, this suggests that the post-1975 loss of GDP in the Basque Country may if anything have been under-estimated.

A second case study used a mass layoff of police officers in Oregon, USA, to estimate the effect of traffic policing on fatal road traffic accidents (De Angelo and Hansen, 2014). Following a cut in the Oregon state budget in 2003, a third of the state police force was laid

off, with 70% of the layoffs among traffic police. A wide range of factors other than policing might affect numbers of fatal accident in different states, making standard geographical controls a potentially misleading basis on which to estimate the impact of the Oregon layoff. In addition to applying difference-in-differences methods to compare trends in accidents in Oregon and two neighbouring states (Washington and Idaho), DeAngelo and Hansen derived a synthetic control based on a weighted average of four states (Washington, Idaho, Nevada and West Virginia). The difference-in-difference and synthetic control methods yielded consistent estimates of a 12-14% increase in fatalities per mile travelled, which were more than twice as large as the increase suggested by a comparison of Oregon with all US states. Based on their estimate of the increase in fatalities, and information on the cost of employing a traffic policeman, De Angelo and Hansen calculated that preventing a death cost $309,000, well below conventional estimates of the value of a statistical life.

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5 How might synthetic controls be applied in Scotland?

Synthetic control studies have produced important findings across a wide range of social and economic policy areas, and been applicable at a range of geographical scales, from school districts to whole countries. Yet there are few applications in a UK context, and none in Scotland. Published evidence suggests the method has considerable potential to be applied to public service innovations at NHS Board, local authority or Community Planning Partnership level, and may widen the range of policy and practice changes that can usefully be evaluated. The availability of routinely collected data which can be aggregated at relevant spatial scales will be an important determinant of how widely the method can be applied. Recent developments such as the Scottish Government's Data Sharing and Linkage Framework,[1] the Farr Institute[2] and the Administrative Data Research Centre – Scotland,[3] building on well-established systems for linking hospitalisation and mortality data, should significantly expand available opportunities.

[1] http://www.gov.scot/Topics/Statistics/datalinkageframework
[2] http://www.farrinstitute.org/centre/Scotland/3_About.html
[3] http://adrn.ac.uk/about/research-centre-scotland

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7 Appendix: search methodology

This appendix details the results of the data search conducted by the Evidence Bank for the WWS Approaches to Evaluation workstream. The search was conducted to inform the research question: *How have synthetic controls been used as an evaluative approach for comparative case studies?*

The Evidence Bank was asked to carry out a systematic search of this limited field and log references. The search aimed to identify key primary studies and papers debating the method of synthetic controls.

While the Evidence Bank was not required to extract data or carry out quality appraisal, abstracts were scanned for duplication and relevance.

The search was conducted, logged and reported by Karen Seditas.

8.1 Methodology

This section outlines sources searched, criteria, results yielded, and exclusions made. As anticipated, most papers were found in academic sources, with some grey literature. All data was accessed between 11th and 19th February 2015.

8.2 Academic databases

Academic databases were selected to capture social science fields, including economics and politics. References were logged using Endnote. The following searches were conducted:

	Database	**Search criteria**	**Results and exclusions**	**Total selected**
1	Web of Science	"synthetic control*" 2003-2015 Article, proceedings paper Topics: all topic categories selected to become familiar with potential fields	Search yielded 280 results Excluded experimental science (e.g. chemistry papers)	21
2	Medline	"synthetic control*" In fields: title/abstract 2003-2015 Topics: humanities English language	Search yielded 32 results Excluded experimental science and medicine papers	2
3	Scopus	"synthetic control*" In fields: title/abstract/article/keywords	Search yielded 56 results Excluded experimental science and medicine	34

		2003-2015 Article, conference paper Topics: social sciences, humanities English language	papers	
4	Econlit	"synthetic control*" 2003-2015	Search yielded 52 results Excluded papers already retrieved where recognised, those not relevant to topic	37
			Total articles selected	94
	Total after duplicates removed using Endnote and a final scan of abstracts			**52**

8.3 Grey literature

Since synthetic controls is an emerging field, broad searches for grey literature were conducted using Google and Google Scholar to try to ascertain any particular sources that might yield results. However, no obvious additional key sources were identified. The World Bank and Open DOAR were searched since they were known to the researcher. The term 'synthetic control' was not necessarily included in the title of articles, making searching more labour intensive and less precise.

Google and Google scholar

Search criteria	**Results yielded**	**Description**
Google: "synthetic control"	65,000	On looking through the first five pages: Instructional (e.g. lectures, slides), duplicates of articles already retrieved, forums, too high yield to search individually
Google: "synthetic control comparative case study"	2	1 relevant
Google: "synthetic control" "comparative case study"	1,420	On looking through the first five pages: Instructional (e.g. lectures, slides), duplicates of articles already retrieved, forums, too high yield to search individually
Google scholar: Exact phrase: synthetic control At least one of: social* OR poli* OR ec* OR health*	985	Includes duplicates of articles already retrieved; relevance of articles not always clear from titles or brief outline. The first 5 pages of this google scholar

Without: chem* bio* phys* Fields: anywhere in the article 2003-2015		search were investigated: articles were downloaded and searched for the term 'synthetic control'. Articles without the full term, not relevant to public services, or only citing other sources were excluded. Duplicates were then removed. Retrieved 11 (from 50-60 results)
Google scholar: Exact phrase: synthetic control All of words: synthetic control Fields: title 2003-2015	235	Results dominated by experimental science articles

Other searches

Source	**Search criteria**	**Results and exclusions**	**Total selected**
World Bank http://www.worldbank.org/	"synthetic control" English	14 8 excluded for duplications, outwith date range	6
OpenDOAR http://www.opendoar.org/index.html	"synthetic control"	18,500	
	"synthetic control" AND "comparative case study"	221 results However, when going from page 1 to page 2 of results, the yield reduces to 17. Duplicates of articles already retrieved were excluded.	10