Do Fixed Links Affect Settlement Patterns? A Synthetic Control Approach*

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Abstract: This paper evaluates the extent to which transportation projects affect settlement patterns. We consider fixed link projects because they provide a large and swift change in accessibility. We use the synthetic control method and estimate the impacts on settlement patterns for 11 fixed links projects constructed in the period from 1989 to 2008. The synthetic controls are weighted averages of control municipalities with weights chosen to replicate population trends in the pre-fixed link periods. We find clear impacts on settlement patterns for fixed links connecting islands to urban areas and on islands utilizing natural resources, although there are exceptions. In the other cases, the impacts are negligible.

Key words: Fixed Links; Transportation; Settlement Patterns; Ex-post evaluation; Synthetic Control Method

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1 Introduction

The Norwegian government has invested substantial resources in fixed link projects as a means to improve accessibility to islands and remote areas in the past three decades. The direct impact for road users has reduced travel costs, with a resulting increase in traffic. After this initial impact, further impacts could be induced because of changes in location decisions, commuting pattern or travel behavior. These decisions made by firms and households could have a wide range of regional impacts, such as improved market access, entry of firms, access to a wider range of goods and services, and changes in settlement patterns. Several contributions in the literature evaluate the direct impacts (some examples are Anguera, 2006; Bråthen and Hervik, 1997; Skamris and Flyvbjerg, 1997). A growing literature investigates productivity effects from infrastructure changes (see Melo et al., 2013; Melo et al., 2009 for a meta-analysis of this literature). But, impacts on the population growth on islands with a fixed link are—in contrast—rarely evaluated using an econometric framework.

Impacts on settlement patterns, which are the focus of this paper, are relevant for two reasons. First, settlement patterns can be a separate policy objective. Moreover, impacts on settlements are therefore interesting when evaluating this policy. Second, settlement patterns affect traffic flows and thereby the benefits of a project. This effect is, however, neglected by Norwegian road planners, which implies that population trends and settlement patterns are assumed unaffected by the fixed link. Ironically, this assumption is at odds with the policy objective of supporting regional development. Additionally, this assumption could lead to systematic error in traffic forecasts and thereby an underestimation of the benefits of the project.

Such impact can occur if the fixed link area becomes included in a larger urban area or if the link improves local amenities, or through a better utilization of less footloose resources. We refer to the first idea as *the urban model* explanation, which originates from the works of Alonso (1964), Muth (1969) and Mills (1981). The key idea in this model is readily explained. Due to the fixed amount of land in cities, houses will be built around the city. Since the distance to the city induces commuting costs, housing prices will fall as distance to the city center increases–such that location decisions and housing prices are supported in equilibrium. At the edge of the city, the commuting cost when moving further away from the city equals the decrease in housing prices, both changes at the margin. If a transport project decreases commuting costs, it could therefore increase the size of the functional city. The area at the edge of the city is therefore more attractive, with a resulting increase in settlements (houses). The second idea is the *local amenities* explanation. The mechanism is that travel time changes could enable access to goods and services, such as specialized products or a greater variety of products, which are only found in large markets. This mechanism is analogous to the sharing mechanisms, which is suggested as one of the mechanisms to explain agglomeration economies by Duranton and Puga (2004). This idea is pursued in Glaeser et al. (2001), which finds that high amenity cities have grown faster than low amenity cities. A similar finding from the Swedish context is Haugen and Vilhelmson (2013). The third idea is what we refer to as the *resource* explanation. Inspired by the framework in Krugman (1991), this explains why economic activity tends to be concentrated in areas that initially have some natural advantage in producing the goods. The argument for such effects centers on improvements in market access for final goods (forward linkage) or better access to inputs in the production process (backward linkage).

It is not obvious that improved access through better roads will benefit a specific region. In some cases, the result may be the opposite. Following the pioneering work by Krugman (1991), the UK Standing Advisory Committee on Trunk Road Assessment (SACTRA, 1999) defined the so-called two-way road effect as one where improved transport connections may change the economic balance between two regions. As transport may lead to a concentration of economic activity to the core, the impact may be the opposite of what policy makers originally intended. With improved accessibility, it may become easier to serve a remote area from outside, and increased competition may lead to smaller rural businesses to go bankrupt. Whether this also applies to population levels is less clear, as it may be possible for the population to increase due to urban sprawl and opening new areas for housing without resulting in increased economic activity. Despite being theoretically appealing, the two-way road argument remains to be proven empirically, and Vickerman (2017) has argued that this is not a universal outcome and that a fall in transport costs could overcome the cost disadvantage of peripheral regions.

The main challenge in the ex-post analysis of infrastructure projects is the counterfactual (potential) outcome: What would have been the outcome had the fixed link not been established? By definition, this outcome is never observed and poses one of the most difficult challenges in empirical research. How the researcher manages to address this problem in a world where randomized experiments are not available has become the most crucial element in empirical economics (Angrist and Pischke, 2010). Moreover, for aggregated effects, such as impacts on settlement patterns, there might be no "true" effect to discover, since projects vary in both changes in accessibility and the nature of the communities that get connected. It is therefore important to consider several fixed links, which differs in both changes in travel time and the affected communities.

In our view, the scant existing literature addressing impacts on settlement patterns do not properly address the counterfactual outcome. To the best of our knowledge, only two studies have investigated the impacts on settlement patterns from fixed links: Royle (2007) and Gutiérrez et al. (2015). Royle (2007) considered islands off the coast of Ireland and demonstrated a significant population impact on fixed link islands compared to the unlinked islands. Although an interesting study, the impact attributed to the fixed links could be exaggerated, since the study did not address the fact that the fixed links could be an outcome of strong regional development–rather than a cause. Gutiérrez et al. (2015) studied the effect of connecting two Norwegian islands to the mainland and reported increased population growth for both islands. An objection against this method is that it fails to account for overall changes in population growth in the period.

This paper uses the synthetic control method from Abadie et al. (2010) to address the counterfactual. The basic steps of the method are as follows: (1) Select the treated and potential control units. Treated units are island-municipalities with fixed links, while potential controls are the set of municipalities (hereafter donor pool) that could be used to construct the synthetic control. We limit the donor pools to municipalities with roughly similar population size and no major infrastructure—or other—change in the period. (2) Select the analysis period. We use a 15-year period before the fixed links were constructed and an as long as possible after-period (last available year was 2015). (3) Select the predictors. We use past population growth, population size in the opening year, employment and the share of employment in the two most important industries. (4) Construct the synthetic control. Using the algorithm presented in Abadie et al. (2010), we find the weighting of controls (the synthetic control) that minimizes the difference between the treated and the synthetic control using only pre-fixed link period. The synthetic control is therefore a weighted average of the controls. (5) Using these weights, calculate the synthetic control in the entire analysis period. If we are successful at constructing the synthetic control, the difference between the treated and the synthetic control is the causal effect of the fixed link.

There are several advantages of synthetic control method compared to other methods. First, the method allows for the use of several municipalities as controls—which is an advantage since a single control unit is usually only a poor comparison. This is an advantage compared to using a difference-in-difference approach with only one control group. Second, the selection of controls (weights) follows an automatized ("objective") procedure, which enables an evaluation of the results using statistical methods. Hence, it is more difficult for the researcher to manipulate the results. Third, the method is more transparent than the usual regression approach since the representation of the synthetic control as a weighted average of controls enables a qualitative investigation, for example, by asking the question: Does it make sense that municipality X is used in the construction of the synthetic control? Such questions are difficult to answer (or ask) when validating results from regression models.

Impacts on settlement patterns are estimated using 11 fixed links that improved accessibility for the 15 municipalities in our analysis. Our results show that some of the fixed links have a strong effect on settlement pattern and represent a non-negligible effect. The average effect on the population size amounts to 2 percent after five years and 6 percent after 15 years. The variation, however, is considerable and the effects are between 10 and 30 percent for five municipalities, and for a few projects, the effect is even negative. A placebo study used to evaluate the statistical significance shows that the most clear-cut impacts are the cases that fit the urban model explanation. For the cases where the amenity or the resource explanation applies, the impacts are lower and more uncertain. For the remainder of the links, the impacts are negligible or even negative.

The rest of the paper proceeds as follows. The next section presents the synthetic control method. Section 3 describes the fixed links used in the study together with a description of the data. Section 4 presents the estimation results. Finally, Section 5 concludes the paper.

2 The synthetic control method

The synthetic control method from Abadie and Gardeazabal (2003) and later refined in Abadie et al. (2010) provides a statistically based procedure for conducting ex-post studies using aggregated data. The method is a data-driven procedure to construct a synthetic control using a weighted average of control units from a pool of potential controls. The weights are chosen such that the synthetic control resembles population trends for the fixed link municipalities in the period before the link was established (hereafter the pre-fixed link period). Abadie et al. (2010) provide a formal derivation of the synthetic control method, but for completeness, we sketch the main ideas.

Consider a sample of $J + 1$ municipalities, where the first unit ($j = 1$) is one of our fixed link municipalities and the remainder (J) potential control municipalities. These potential controls are the "donor pool" and discussed in more detail in the Section 4.1. The sample includes observation over T time periods, where T_0 denotes the pre-fixed link period, and T_1 the period after the fixed link was opened (hereafter post-fixed link period); hence, T_0+$T_1 = T$. For each link, T_0 comprises the 15-year period before the opening year, and T_1 runs from the opening year up to 2015. As an example, consider the Askøy Bridge where the opening year is 1993. In this case, T_0 runs from 1977 to 1992, and T_1 runs from 1993 to 2015. The synthetic control is constructed by choosing weights $W = (w_2, \dots, w_J)'$, with $0 \leq w_j \leq 1$ for $j = 2, \dots, J$ and $w_2 + \cdots + w_{J+1} = 1$ by selecting values of W such that characteristics of the fixed link municipality are matched to the characteristics of the synthetic control. The difference in pre-fixed link characteristics is given by $X_1 - X_0W$, where X_1 is a $(k \times 1)$ vector of (k) pre-fixed link predictors for the fixed link municipality and comprise population trends and predictors that influence the population trends (the predictors are discussed in more detail in Section 4), and X_0 is a $(k \times J)$ vector for the J potential control municipalities. The weights are found by solving the quadratic minimizing problem subject to the constraints on W:

$$W^* = \arg\min_{W}[X_1 - X_0W]'V[X_1 - X_0W] \tag{1}$$

where V is a $(k \times k)$ matrix determining the relative importance of each predictor. We follow Abadie and Gardeazabal (2003) and select the weights such that the predictors best reproduce the pre-fixed link population trends. Finally, let Y_1 be a $(T \times 1)$ vector for the population in a fixed link municipality and Y_0 be a $(T \times J)$ matrix for population in the municipalities in the donor pool. The synthetic control is found by multiplying the optimal weights W^* by Y_0.

The variable of interest, α (interpreted as the causal effect), is the difference between the population in the fixed link municipality and the synthetic control in the post-fixed link period:

$$\alpha = Y_1 - Y_0 W^*. \tag{2}$$

The validity of the method rests on the assumption that the synthetic control represents the population trend in the post-fixed link period. Hence, the post-fixed link population trends are assumed parallel in the case of no fixed link for either group. For this assumption to be valid, there should be no interventions that affect the population trend for the controls and no other interventions than the fixed link for the treated unit. This parallel trend hypothesis is inherently untestable, but if the match in the pre-fixed link period is satisfactory, it is reasonable to assume that this carries over to the post-fixed link period.

The standard statistical inference is not valid using the synthetic control method since only one unit is affected. As an alternative, the significance of the effects on populations is investigated in a placebo study. In the placebo study, all municipalities in the donor pool are assigned the treatment status, and the results are significant if the effect for the fixed link municipality is larger than the random effect found when assigning the treatment status to municipalities in the donor pool.

3 Case studies

3.1 Overview of the fixed links

This paper considers the impact on settlement patterns from 11 fixed links on 15 municipalities. Since the late 1980s, approximately 30 fixed links were constructed in Norway, all of which connected islands to the mainland and thereby replaced ferry connections. Unfortunately, not all projects lend oneself to an investigation on settlement pattern because of the limitation in available data below the unit of the municipality. Several projects connect an island to the mainland, but the island does not always represent a municipality. Data at the municipality level are therefore not suitable, since there might be a difference in population trends.

The links considered in this paper have been extensively analyzed in other papers and reports. We therefore only present a few key facts regarding these links and refer the interested reader to Leknes and Dybvik (1996), Bråthen and Hervik (1997), Lian and Rønnevik (2010b) and Hagen et al. (2014) for a more thorough description of the projects.

Figure 1 shows the location of the fixed links, all situated in Norway. As is seen from the map, all the fixed links are situated along the Norwegian coastline. One link is in the eastern part of Norway (The Hvaler Bridge); one in the north (Nappstraumen); four in the southwest (The Askøy Bridge, the Triangle Connection, Finnfast, and Rennfast); and four in the northwest (The Eiksund Connection, The Atlantic Road, Krifast and Hitra-Frøya).

Table 1 displays some key facts for the fixed links such as opening year, traffic growth during the first whole year, affected municipalities, population in the opening year, closest larger labor market with equal travel time, and travel time changes resulting from the fixed link. It is evident from column three that the links provided a substantial improvement in accessibility since the average traffic growth the first year after opening was more than 70 percent. Column 4 shows which municipalities obtained a fixed link to the mainland. In two cases, more than a single municipality is affected. Later in the paper, we therefore present details regarding impacts on the specific municipalities rather than the fixed link itself.

The next column displays population in the opening year and shows that the affected municipalities represent small communities. Only three of the fixed links (the Triangle Connection, Krifast, and the Eiksund Connection) provided a fixed link for communities with a population above ten thousand, while the remainder links gave a fixed link to areas with populations varying from three to eight thousand. The two last columns display the nearest larger municipality, the current travel time and the change in travel time due to the fixed link. We return to this aspect in the discussion below, but for now, we state that a fixed link is expected to have a larger impact on regional development if it reduces travel time to a larger city.

3.2 Selection of potential controls (donor pools)

We select the donor pools (the set of possible control municipalities) using a two-stage procedure for each fixed link municipality. In the first stage, the donor pool is limited to municipalities of similar population size, which we operationalize as a difference of 30 percent. The motivation is to avoid the interpolation of municipalities very different from the fixed link municipality. Such interpolation could lead to interpolation bias, as discussed in Abadie et al. (2015).

[1] Moreover, limiting the donor pool by the population size reflects an assumption of dependency between population growth and population size. As an example, there is a correlation of 0.65 between population size in Norwegian municipalities (in logarithm) and population growth in the period from 2005 to 2015. In the second stage, we screen the donor pools for municipalities with infrastructure changes or other major regional impacts in the period of analysis.

Regional differences in population growth or regional specific shocks could also lead to bias. This issue could arise if the structural process determining population growth is region specific rather than size specific. To account for this possibility, we provide a robustness analysis where the donor pool includes only municipalities in the same county.

3.3 Predictors used to construct the synthetic controls

The pre-fixed link characteristics used in our analysis are population growth fifteen years before the fixed link opened, population in the opening year, employment by place of work, and employment shares in the two most important industries. The choice of these predictors implies that we seek to construct a synthetic control with the equal growth rate in pre-fixed link period, of equal size and with the same important industries. The predictor for workers by place of work is selected to ensure that the synthetic control exhibits similar commuting patterns.

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[1] As an example, consider the case where a medium sized municipality is represented as a weighted average of the smallest and largest municipality in the entire country.

The two most important industries are intended to capture industry specific shocks that could affect employment and thereby migration. They are selected as the industries expected to be most affected by an improvement in accessibility. Krugman and Venables (1995) develop the concept of forward - and backward linkages, which supports this approach. Forward linkages are improvements in market access for final products, an effect identified as the home market effect in Krugman (1980)—whereas backward linkages are effects arising from improvements in access to labor or inputs. The most important industries therefore exclude public services and other services where there is no clear relationship between providing the good (service) and changes in transport cost due to the fixed link. As an example, consider a hairdresser located on an island where a fixed link is established. There are no apparent reasons to expect large changes in the demand for haircuts (an example of forward linkage) or improved access to hair products or scissors (an example of backward linkage) after a fixed link is established. In contrast, there are reasons to expect impacts for industries with considerable transport costs or perishable transport such as fish processing (forward linkage). In industries that rely on specialized inputs, for example highly skilled labor, a fixed link could lead to backward linkage benefits. An example is engineering skills in the maritime industry (relevant for the municipalities affected by the Eiksund Connection and the Triangle Connection). Unfortunately, data on the necessary level before 2000 are not readily available, and employment shares are therefore not included as predictors for the fixed links completed before 2000.

Compared to other contributions using the synthetic control method, such as Abadie et al. (2010) and Munasib and Rickman (2015), the analysis draws on a small set of predictors. This choice is made because, in practice, only a few predictors are given significant weight. To construct the most relevant control group, we therefore choose the one we regard as most important.

3.4 Data and period of analysis

A 15-year pre-fixed link period and the period up to 2015 are used for all the fixed link municipalities. Hence, the post-fixed link period varies according to the opening year. When considering the length of the pre-fixed link period, there are conflicting objectives. First, using a long pre-intervention period increases the probability of discovering unobserved factors, and Abadie et al. (2015) therefore recommend a long pre-fixed link period. The premise is that a long period is required to identify unobserved factors, which changes only infrequently or gradually. However, a long pre-fixed link period places a significant burden on the researcher to validate that there are no shocks to the municipalities in the donor pool. To balance these considerations, we choose a pre-intervention period of 15 years. Since some projects date to the 1990s, we need population data back to the 1970s to construct and evaluate the synthetic controls.

The analysis draws on annual population and employment data from Statistics Norway. Population data on the municipality level are readily available from Statistics Norway (2016). The most important industries are the share of employment by place of work in municipalities using the SIC2002 level two data from Statistics Norway. The industries identified as most important are displayed in Table 6 in the Appendix.

4 Results

4.1 Population growth before and after the construction of the fixed links

Table 2 displays the population growth in the periods 5 and 15 years before and after the fixed links were established for all municipalities and the difference between these rates. The population growth in the pre-fixed link was weak and, on average, only one percent. In half of the municipalities, the population declined. This pattern changes considerably in the post-fixed link period, where the populations grew on average by 4 percent and fell only for the municipality Fitjar. By comparing the before-after growth rates, we see that the population growth was three percent higher in the post-fixed link period, compared to the pre-fixed link period.

A period of 5 years is, however, short regarding settlement changes since effects on population occur with considerable lags. For example, individuals normally consider changing their place of residence a few times over an entire lifetime—and less than five percent of the Norwegian population moved between municipalities in 2015, according to Statistics Norway. To account for this inertia, we also consider population changes 15 years after opening. Note that links constructed after 2001 are excluded. The average growth in the post-fixed link period is substantially higher than that in the pre-fixed link period (13 percent in the post-fixed link period and only 4 percent in the pre-fixed link period).

The reason for the change in population growth rate could also be unrelated to the fixed link. An example is changes in the overall population growth rate for the country. Another is industry specific shocks, which could change the growth rate for a particular area. For example, if there is a substantial increase in the demand for fish this could lead to higher employment and thereby population (through migration) in an area with a considerable fishery related activity, such as Frøya. In this case, the population change could have been caused by the price of fish instead of the impact from the fixed link. The synthetic control method is designed to address these two issues.

4.2 The synthetic control municipalities

Before turning to the estimated impacts, we review the representation of the synthetic controls and how well they match their fixed link counterparts. Table 3 displays the weights of each synthetic control for all the fixed links municipalities, which are the resulting weights after solving the minimizing problem in equation (1). For some of the municipalities, such as Ulstein, only a few municipalities constitute the synthetic control., whereas for municipalities such as Kristiansund, the synthetic control comprises several municipalities. The number of controls partly reflects the number of similar municipalities in the donor pool. Hence, only a few share the characteristics of a municipality such as Ulstein, while many municipalities share the pre-fixed link population trend and population size for municipalities such as Kristiansund. This is no surprise since Ulstein represents a specialized labor market within the maritime industry. Moreover, a potential concern arises when the controls are located in a different part of the country because they could be affected by regional specific structural processes. As mentioned in Section 3, we address this issue by providing a robustness check using only within county controls.

As stated in Section 3, the validity of the controls rests on the assumption that they are not exposed to any substantial shocks. However, a problem could arise when the control units are located close to the treated unit, which is the problem of spatial autocorrelation. For example, if the fixed link causes individuals in a nearby municipality to move to the fixed link area and the same municipality is used a control unit, the effect on the settlement impact will be upward biased. To the best of our knowledge, no shocks affected the control municipalities reported in Table 3 in the relevant period; they are also not located very near the fixed link municipality.

Table 4 displays the value of the predictors, both the observed and the corresponding synthetic controls and the percentage difference error—of which the latter can be used to assess the quality of the matching. Panel A displays the population 15 years before opening together with population size in the opening year. The match is reasonable for all municipalities and exceeds only an error of 5 percent for Frøya, but now the error is less than 10 percent. Such a small difference is unlikely to be of practical relevance.

Panel B in Table 4 displays the matched employment in the opening year. The matched employment displays larger deviations, however with no systematic error. For Askøy, Frøya, Hareid and Hvaler, the employment for the synthetic controls is up 17 percent too large, whereas for Ulstein and

Stord, the employment is up to 48 percent too small. The synthetic controls are therefore only partially able to match the size of the labor market.

Panel C in Table 4 displays the matched employment shares, and except for Stord, they are satisfactory for all the fixed links for which data are available. Note that in this case, the differences displayed are the differences in the employment shares

4.3 Results using the synthetic control method

Table 5 displays the percentage population impact using the synthetic control method. Remember that the impact for each fixed link municipality is the difference between actual population and the synthetic counterpart, as defined in (2). The second column in the table displays the impact five years after opening, while the second displays the impact 15 years after. The average population impact is 1 percent five years after opening, but for eight of the links, the effect is negative, and the large effects found for Rennesøy and Finnøy mainly explain the result. When calculating the effect 15 years after, which excludes the links after 2001, the average population effect increases to 6 percent. The impact is still largest for Rennesøy, while the effect appears to be negative for Kristiansund, Osterøy, Stord, and in particular, for Bømlo.[2] A similar unexplained negative effect for Bømlo is also found in Lian and Rønnevik (2010a). Below we provide a study to evaluate whether the results are significant or merely due to a random error between the fixed link municipality and its' synthetic counterpart. In addition, note that the results when using synthetic controls differ substantially from the difference-in-difference results. For Hvaler and Rennesøy, the population effects are much higher and conversely much lower for Hitra, Frøya, and Bømlo. Since the synthetic control takes the counterfactual problem more serious than a simple comparison with the past growth, this result shows that simple difference-in-difference results could be

[2] We have tested whether a longer pre-fixed link period changes that result, but the result is almost unchanged. We have also examined a wide range of variables such as education, average age, property prices, unemployment, and employment, but these cannot explain the puzzle. Hence, we cannot explain this large negative effect, and the explanation is probably another structural shock rather than the fixed link.

substantially biased.

A graphical illustration is provided in Figure 2, with the results for each fixed link municipality shown in a separate graph. All the graphs include the following: A solid line is the observed population in the period 15 years before the fixed link and runs to 2015, a dashed line represents the synthetic control for each fixed link municipality, a vertical dashed line indicates the opening year, and a solid vertical line represents the removal of tolls. To make the results comparable, population is indexed to 100 in the opening year. The graphical representation provides an alternative assessment of the validity of the synthetic controls and the estimated impacts. The validity of the synthetic controls can be assessed by examining whether the actual and the synthetic controls share a common pre-fixed link trend. It is evident from the graphs that the synthetic controls match the pre-fixed links population trends for all the municipalities, except for Ulstein. By comparing the vertical distance between the actuals and the synthetic controls, it is also apparent that there is an effect on population for the fixed link municipalities: Askøy, Finnøy, Frøya, Hitra, Hvaler, Rennesøy, Ulstein, and Vestvågøy. The effect varies between the municipalities, but a common characteristic is that the effect increases gradually. In contrast, the timing of the effect for these municipalities varies. For Finnøy, Ulstein, Rennesøy, and Vestvågøy it appears that the impact on population occurs almost immediately after the construction of the fixed links, whereas there is a visibly lagged effect for Askøy, Frøya, Hvaler and Hitra. In the case of Hitra, the reason for the lagged effect is likely the effect of the opening of the fixed link to Frøya, which provided a fixed link between Frøya and Hitra. The effect for the remainder fixed link municipalities is either negligible or negative.

4.4 Significance (in-space placebo study)

The standard statistical inference is not applicable using the synthetic control method since only one unit is affected in each case and the fixed links are not randomly constructed. The in-space placebo study presented in Abadie et al. (2010) provides an alternative. In the in-space placebo study, the treatment status is assigned one-by-one to each municipality in the donor pool. Since in reality no fixed links are constructed in these municipalities, any estimated effect should be a random error. If the placebo study shows effects of similar magnitude as the fixed links, the interpretation is that our analysis does not provide significant evidence of impacts caused by fixed links. Conversely, if the effects are large compared to the placebo trials, the interpretation is that our analysis provides evidence of impacts from the fixed links on population.

Figure 3 shows the results of the placebo study. We apply the synthetic control method for all the municipalities in the donor pool. In this case, the estimated effects are only random errors since there are no fixed links (or other important interventions) constructed in the municipalities in the donor pool. All the lines show the percentage difference between the municipalities assigned the treatment status and the synthetic control. The gray lines represent the gap for each of the 20 placebo runs with lowest mean squared prediction error (MSPE) in the pre-fixed link period.[3] Finally, the thick black lines are the estimated gaps for the fixed link municipalities.

The impacts for the municipalities: Askøy, Finnøy, Rennesøy, and Ulstein are clearly larger than the placebo effects. A finding suggests that the results are unlikely to be driven by chance. For Hvaler and Hitra, the estimated effect lies within but at the border of the distribution of effects created by the placebo study. Since the figure compares the fixed link municipalities to 20 other random effects, the effect for Hvaler and Hitra could be interpreted as significant just above 5 percent. The impact for Vestvågøy is exceeded by several of the placebo trial, which questions the significance of the effect for Vestvågøy. The effect in the remainder municipalities seems to be insignificant.

[3] The MSPE measures lack of fit between the path of the outcome variable for any particular country and its synthetic counterpart. The pre-fixed link MSPE for each fixed link is defined as: $MSPE = \frac{1}{T_0}\sum_{t=1}^{T_0}\left(Y_{1t} - \sum_{j=2}^{J+1} w_j Y_{jt}\right)^2$.

4.5 Robustness checks

To examine possible biases from using control units from other geographical areas, we provide an analysis where the donor pool includes only municipalities from the same county. Figure 4 shows the resulting placebo studies, using only municipalities within the county as the donor pool. Except the difference in the donor pool, Figure 4 is identical to Figure 3. Municipality weights are reported in Table 7 and the quality of the match in Table 8, both in the appendix. In addition, we restrict the analysis to the 20 control municipalities with the lowest pre-fixed link MSPE. It is evident from the figure that both the impact on the population and the significance is consistent with the results using the baseline donor pool. The most substantial difference is the increased significance of the effect for Vestvågøy. Figure 4 readily shows that the estimated impact for Vestvågøy (black line) is clearly above the effects for the placebo trials (thin gray lines).

The impacts are also reported in Table 5, which is suitable when comparing estimated effects with the different donor pools. Concentrating on the links with significant effects, the largest difference is found for Rennesøy, with an impact that is 5 percentage points lower after 15 years. For Vestvågøy and Askøy, the impacts are, in contrast, higher using the within-county donor pool. Only minor changes are found for Hvaler, Hitra, Frøya, Ulstein and Finnøy. For the latter two, the comparison is only possible using the 5-year impact. In total, the evidence shows that the estimated effects on the population are robust to using only within-county controls.

Figure 5 shows that the results are robust when changing the opening year to seven years before the actual opening using the in-time placebo test, as suggested in Abadie et al. (2010). The objective is to test whether the change in population growth started before the fixed link opened, implying that the estimated impact is merely a continuation of change that occurred before the fixed link was established. The in-time placebo study will also identify the possible anticipation effect of the fixed link if individuals act on the future accessibility gain from the fixed link. The results displayed in Figure 5 strongly reject that the population effect started before the opening of the fixed link since the calculated effect is negligible for all the fixed links areas.

4.6 Discussion

Our analysis shows impacts on population from fixed links to several of the affected municipalities, but far from on all. The magnitude of the impact on population also varies considerably. The synthetic control method offers a novel approach to investigate the causal impact on the settlement pattern, but at the same time, it does not provide an explicit test of any causal mechanism. As a substitute, we use the three explanations suggested in Section 1.

The *urban model* should fit the municipalities where the fixed link connected islands to a substantially more populated area, with a manageable commuting time. This applies to cases such as Rennesøy and Finnøy where commuting from the islands to larger labor markets has increased considerably (Hagen et al., 2014). In these cases, population growth is to a considerable extent caused by people moving from the mainland to the islands because of the lower housing prices and commuting back to the mainland.

The explanation in terms of improvement in *local amenities* fits the findings for the Askøy Bridge and the Hvaler Bridge. In these cases, there are no clear effect on commuting but still an impact on the population. Hence, the people who moved to these islands tend to work where they live. Using the number of people commuting out from either Askøy or Hvaler relative to the number of employed by residence, commuting was almost constant from 1990 to 2015 (Statistics Norway, 1990a, b, 2016).

The third explanation, labeled *resources,* applies to the Eiksund connection, the Frøya-Hitra connection, and the Nappstraumen. The Eiksund municipalities use the “resource” of the industry cluster in the area, which is specialized in the maritime industry, while Frøya-Hitra and Nappstraumen utilize marine resources. In these cases, the explanation of the impacts centers on improvements in accessibility for areas with specialized industries using less footloose resources. This explanation, however, is contested by the results for the Triangle connection, where the affected municipalities of Bømlo, Fitjar, and Stord have a quite specialized industry within the maritime industry and industries connected to offshore petroleum activity. Thus, there are by no means deterministic population impacts for connections in areas, which in principle only obtain improved accessibility, but still are not a part of or have access to services and amenities in more urban areas. This may be interpreted as a potential two-way road effect, but as there is not necessarily a link between population and economic activity, the strength of this argument remains empirically weak.

A somewhat surprising finding is the lack of a relationship between short-run impacts on traffic (traffic growth the first year) and the long-run impacts on the population. The correlation coefficient between traffic impact and population impacts is 0.18 using population impacts after five years and falls to 0.07 using population impacts after 15 years. The short-term traffic impact, therefore, gives a poor bearing on future impacts on settlement patterns. Hence, the three sets of explanations suggested in this paper perhaps constitute a more instructive tool to be used to predict impacts on settlement patterns rather than the predicted impact on traffic.

A last observation is a clear inertia in the effects on the population size. For example, in the case of the Askøy Bridge, the impact on the population seven years after the opening of the connection is negligible, but the long-run effect 15 and 20 years after opening is substantial. Hence, the impact on settlement patterns a few years after opening also provide a poor prediction of the long-run effects. Moreover, from Figures 3 and 4, it is evident that the effects after 15 years are not fully exhausted for all the links with a significant effect.

5 Conclusion

In this paper, we have investigated impacts from fixed links on settlement patterns. Impacts are calculated using the synthetic control method by comparing the population trends after the fixed link opened to a weighted average of control municipalities, constructed such that the synthetic control has a similar size and trajectory in the period before the fixed link was established. Our results show a significant impact on settlement patterns for approximately half of the links. Moreover, we explain the effects in terms of integration in a larger labor market (*the urban model*), improved conditions for economic activity using less footloose resources (*resources*) or increased attractiveness of an area (*amenities*). The links where the urban model operates provide the largest impacts.

Our results provide valuable insights into the impact on population growth from large changes in accessibility. First, it provides an evaluation of the effectiveness of the Norwegian policy of using infrastructure investments to support a scattered population and shows when a large impact could be expected to occur. Second, it also indicates that neglecting impacts on settlement patterns can result in important impacts on traffic.

Although the results in this paper are robust to several specification tests, the synthetic controls do not comprise the optimal control municipalities. Ideally, the controls should include only municipalities of similar characteristics in terms of population trends, size and industry structure, but they should also all be municipalities without a fixed link, since the real counterfactual outcome for the fixed link municipalities is still a situation with no fixed link implemented. Most of the available areas without a fixed link are, however, far too small to represent a suitable control, although some of the control municipalities in our analysis indeed are areas without a fixed link to the mainland. The impacts from large infrastructure projects are also highly case specific. Future research on the impact of settlement patterns from large changes in infrastructure should be steered at increasing the body of knowledge by analyzing more projects using the novel approach suggested in this paper.

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References

Abadie, A., Diamond, A., Hainmueller, J., 2010. Synthetic control methods for comparative case studies: Estimating the effect of California's tobacco control program. Journal of the American Statistical Association 105(490), 493-505.

Abadie, A., Diamond, A., Hainmueller, J., 2015. Comparative politics and the synthetic control method. American Journal of Political Science 59(2), 495-510.

Abadie, A., Gardeazabal, J., 2003. The Economic Costs of Conflict: A Case Study of the Basque Country. American Economic Review 93(1), 113-132.

Alonso, W., 1964. Location and land use. Toward a general theory of land rent. Harvard University Press, Cambridge, Mass.

Angrist, J.D., Pischke, J.-S., 2010. The credibility revolution in empirical economics: How better research design is taking the con out of econometrics. The Journal of Economic Perspectives 24(2), 3-30.

Anguera, R., 2006. The Channel Tunnel—an ex post economic evaluation. Transportation Research Part A: Policy and Practice 40(4), 291-315.

Baldacchino, G., 2007. Fixed links and the engagement of islandness: reviewing the impact of the Confederation Bridge. The Canadian Geographer/Le Géographe Canadien 51(3), 323-336.

Bråthen, S., 2001. Do fixed links affect local industry? A Norwegian case study. Journal of Transport Geography 9(1), 25-38.

Bråthen, S., Hervik, A., 1997. Strait crossings and economic development: Developing economic impact assessment by means of ex post analyses. Transport Policy 4(4), 193-200.

Duranton, G., Puga, D., 2004. Chapter 48 Micro-foundations of urban agglomeration economies, In: Henderson, J.V., Jacques-François, T. (Eds.), Handbook of Regional and Urban Economics. Elsevier, 2063-2117.

Eliasson, J., Börjesson, M., Odeck, J., Welde, M., 2015. Does Benefit–Cost Efficiency Influence Transport Investment Decisions? Journal of Transport Economics and Policy (JTEP) 49(3), 377-396.

Glaeser, E.L., Kolko, J., Saiz, A., 2001. Consumer city. Journal of economic geography 1(1), 27-50.

Gutiérrez, M. D., Andersen, S.N., Nilsen, Ø.L., Tørset, T., 2015. Impacts on Land use Characteristics from Ferry Replacement Projects. Two Case Studies from Norway, Transportation Research Procedia, 286-295.

Hagen, K.P., Pedersen, K.R., Tveter, E., 2014. Ringvirkninger av samferdselsinvesteringer. SNF Bergen og Møreforsking Molde.

Haugen, K., Vilhelmson, B., 2013. The divergent role of spatial access: The changing supply and location of service amenities and service travel distance in Sweden. Transportation Research Part A: Policy and Practice 49, 10-20.

Krugman, P., 1980. Scale Economies, Product Differentiation, and the Pattern of Trade. American Economic Review 70(5), 950-959.

Krugman, P., 1991. Increasing Returns and Economic Geography. Journal of Political Economy 99(3), 483-499.

Krugman, P., Venables, A.J., 1995. Globalization and the Inequality of Nations. The Quarterly Journal of Economics 110(4), 857-880.

Leknes, E., Dybvik, B., 1996. Lokal næringsutvikling som følge av fastlandsforbindels? Case: Rennesøy og Askøy, Arbeidsnotat, Rogalandsforskning.

Lian, J.I., Rønnevik, J., 2010a. Ringvirkninger av store vegprosjekter i Norge. Transportøkonomisk institutt.

Lian, J.I., Rønnevik, J., 2010b. Wider economic benefits of major Norwegian road investments, Paper submitted for the World Conference on Transport Research, 11-15.

Melo, P.C., Graham, D.J., Brage-Ardao, R., 2013. The productivity of transport infrastructure investment: A meta-analysis of empirical evidence. Regional Science and Urban Economics 43(5), 695-706.

Melo, P.C., Graham, D.J., Noland, R.B., 2009. A meta-analysis of estimates of urban agglomeration economies. Regional Science and Urban Economics 39(3), 332-342.

Mills, D.E., 1981. Ownership arrangements and congestion-prone facilities. The American Economic Review 71(3), 493-502.

Munasib, A., Rickman, D.S., 2015. Regional economic impacts of the shale gas and tight oil boom: A synthetic control analysis. Regional Science and Urban Economics 50, 1-17.

Muth, R., 1969. Cities and housing: The spatial patterns of urban residential land use. University of Chicago, Chicago 4, 114-123.

Royle, S.A., 2007. Islands off the Irish coast and the bridging effect, In: Baladacchino, G., MacDonald, E., Spears, A. (Eds.), Bridging islands: The impact of fixed links. Acorn Press, Charlottetown, P.E.I., 203-218.

Skamris, M.K., Flyvbjerg, B., 1997. Inaccuracy of traffic forecasts and cost estimates on large transport projects. Transport Policy 4(3), 141-146.

Standing Advisory Committee on Trunk Road Assessment (SACTRA), 1999. *Transport and the economy*. London: Stationary Office.

Statistics Norway, 1990a. Housing and population census. Kommunehefte 1247 Askøy. Statistics Norway.

Statistics Norway, 1990b. Population and housing census 1999. Kommunehefte 0111 Hvaler. Statistics Norway, Oslo/Kongsvinger.

Statistics Norway, 2016. Table: 06913: Population 1 January and population changes during the calendar year (M).

Vickerman, R., 2017. Whider Impacts of Megaprojects. Curse or Cure? In: Flyvbjerg, B. (ed.), The Oxford Handbook of Megaproject Management (ch. 17). Oxford: Oxford University Press.

Tables and figures

Table 1 Opening year and treated units for fixed links

	Opening year	Traffic growth 1st year ˚AADT)	Affected municipality	Population ˚opening year)	Adjacent larger labor market	Minutes travel time ˚change)
Fv108 Hvaler Bridge	1989	75 %	Hvaler	3181	Fredrikstad	30 ˚25)
E10 Nappstraumen	1990	66 %	Vestvågøy	2566	Svolvær ˚Vågan)	70 ˚25)
E39 Rennfast	1992	42 %*	Rennesøy	2593	Stavanger-region	26 ˚30)
Rv70/E39 Krifast	1992	24 %	Kristiansund	18490	Molde	70 ˚25)
Fv562 Askøy Bridge	1993	101 %	Askøy	7009	Bergen	20 ˚25)
Fv566 Osterøy Bridge	1997	149 %	Osterøya	4038	Bergen	45 ˚15)
Fv714 Hitra	1994	40 %	Hitra	3181	Orkanger	80 ˚25)
Fv714 Frøya	2000	49 %	Frøya	4115	Orkanger	120 ˚25)
E39 Triangle Connection	2001		Bømlo	10839	Haugesund	65 ˚30)
E39 Triangle Connection	2001		Fitjar	2978	Haugesund	75 ˚30)
E39 Triangle Connection	2001	37 %	Stord	16241	Haugesund	60 ˚30)
Fv652 Eiksund Connection	2008		Hareid	6946	Ålesund	70 ˚0)
Fv652 Eiksund Connection	2008	102 %	Ulstein	4741	Ålesund	90 ˚0)
Fv519 Finnfast	2009	109 %	Finnøy	2790	Stavanger	45 ˚25)
Fv64 The Atlantic road	2009	109 %	Averøy	5444	Kristiansund	15 ˚25)

Note: Data for traffic before and after the opening er collected from the Norwegian Road authority ˚NPRA). Population data are collected from Statistics Norway. Current changes in travel time are collected from googlemaps and the change are the travel time for the old ferry connection ˚collected from NPRA) a rudimentary waiting time reduction of 15 minutes are assumed for all connections.

Table 2 Population growth before and after opening

		% population growth 5 years			% population growth 15 years		
Fixed link	Municipality	after opening	before opening	before-after	after opening	before opening	before-after
Fv108 Hvaler Bridge	Hvaler	6	10	-5	15	29	-14
E10 Nappstraumen	Vestvågøy	2	-3	5	2	-5	7
E39 Rennfast	Rennesøy	11	2	8	32	19	13
Rv70/E39 Krifast	Kristiansund	0	-1	1	2	-1	3
Fv562 Askøy Bridge	Askøy	4	<1	4	25	12	12
Fv566 Osterøy Bridge	Osterøy	1	<1	2	7	5	2
Fv714 Hitra	Hitra	<1	-3	2	12	-9	21
Fv714 Frøya	Frøya	<1	-6	6	12	-28	40
E39 Triangle Connection	Bømlo	<1	5	-5	8	13	-5
E39 Triangle Connection	Stord	3	7	-4	15	27	-12
E39 Triangle Connection	Fitjar	-3	-5	2	5	18	-13
Fv652 Eiksund Connection	Ulstein	13	3	10			
Fv652 Eiksund Connection	Hareid	6	<1	6			
Fv519 Finnfast	Finnøy	9	-1	10			
Rv70/E39 Krifast	Averøy	4	-1	5			
All links	Average	4	1	3	13	4	9

Table 3 Municipalities with positive weight for the synthetic controls.

Synthetic Askøy	Weight	Synthetic Hareid	Weight	Synthetic Hvaler	Weight	Synthetic Osterøy	Weight
Nedre Eiker	0.59	Austevoll	0.58	Våler	0.53	Risør	0.51
Stange	0.32	Froland	0.19	Siljan	0.42	Sande ˚Vestf.)	0.36
Nes ˚Ak.)	0.09	Nord Aurdal	0.12	Gjerdrum	0.05	Løten	0.08
		Nærøy	0.05			Alstahaug	0.05
		Seljord	0.07				

Synthetic Vestvågøy	Weight	Synthetic Fitjar	Weight	Synthetic Kristiansund*	Weight	Synthetic Hitra	Weight*
Odda	0.44	Namsos	0.59	Rana	0.56	Bø ˚Nordl.)	0.20
Åsnes	0.23	Stokke	0.37	Stange	0.30	Høyanger	0.15
Østre Toten	0.33	Nome	0.03	Nedre Eiker	0.07	Stranda	0.08
				Ski	0.04	Gol	0.02

Synthetic Finnøy	Weight	Synthetic Rennesøy	Weight	Synthetic Ulstein	Weight	Synthetic Bømlo	Weight
Rennebu	0.53	Bjerkreim	0.59	Haram	0.79	Haram	0.46
Hjelmeland	0.19	Skiptvet	0.22	Gjerdrum	0.21	Time	0.22
Bjerkreim	0.13	Samnanger	0.15			Gjesdal	0.18
Suldal	0.09	Vik	0.04			Klepp	0.14
Fusa	0.07						

Synthetic Frøya	Weight	Syntheic Stord	Weight
Øksnes	0.51	Grimstad	0.60
Stranda	0.35	Eigersund	0.40
Vardø	0.14		

Note: Weights<0.01 are excluded. Weights come from the solution to the quadratic-minimization problem displayed in equation ˚1).

Table 4 Observed and matched values for predictors.

Panel A: Population

	15 year before opening year			Opening year		
Municipality	Treat	Synthetic control	Diff.	Treat	Synthetic control	Diff.
Askøy	17765	17433	2 %	18490	18311	1 %
Averøy	5470	5421	1 %	5444	5444	0 %
Bømlo	9727	9610	1 %	10839	10598	2 %
Finnøy	2856	2884	-1 %	2790	2818	-1 %
Fitjar	3086	3062	1 %	2978	2955	1 %
Frøya	4293	4543	-6 %	4115	4452	-8 %
Hareid	4721	4550	4 %	4741	4636	2 %
Hitra	4404	4381	1 %	4178	4179	0 %
Hvaler	2554	2607	-2 %	3181	3162	1 %
Kristiansund	22109	22424	-1 %	22044	22045	0 %
Osterøy	6908	6905	0 %	7009	7007	0 %
Rennesøy	2393	2439	-2 %	2566	2571	0 %
Stord	14684	14350	2 %	16241	16138	1 %
Ulstein	6385	6714	-5 %	6946	7138	-3 %
Vestvågøy	11111	10745	3 %	10547	10340	2 %

Panel B: Employment ˚place of work in opening year)

Municipality	Treat	Synthetic control	Diff.
Askøy	3754	4529	-17 %
Averøy	2209	2211	0 %
Bømlo	4403	4449	-1 %
Finnøy	1436	1325	8 %
Fitjar	1113	1137	-2 %
Frøya	1964	2087	-6 %
Hareid	2162	2290	-6 %
Hitra	1514	1514	0 %
Hvaler	526	563	-7 %
Kristiansund	7844	7746	1 %
Osterøy	2189	2247	-3 %
Rennesøy	723	725	0 %
Stord	8388	7125	18 %
Ulstein	4610	3094	49 %
Vestvågøy	3111	3153	-1 %

Panel C: Employment share ˚by place of work)

	Most important			2nd most important		
Municipality	Treat	Synthetic control	Diff.*	Treat	Synthetic control	Diff.*
Askøy	.	.	.	.	.	.
Averøy	.	.	.	.	.	.
Bømlo	0.09	0.09	0.00	0.06	0.06	0.00
Finnøy	.	.	.	.	.	.
Fitjar	0.17	0.14	0.03	.	.	.
Frøya	0.12	0.11	0.01	0.21	0.18	0.03
Hareid	0.09	0.08	0.01	0.07	0.07	0.00
Hitra	.	.	.	.	.	.
Hvaler	.	.	.	.	.	.
Kristiansund	.	.	.	.	.	.
Osterøy	.	.	.	.	.	.
Rennesøy	.	.	.	.	.	.
Stord	0.24	0.07	0.17	.	.	.
Ulstein	0.11	0.08	0.03	0.12	0.08	0.04
Vestvågøy	.	.	.	.	.	.

Note: Employment shares from Table 8 in the opening year of the fixed link. * Difference in shares

Table 5 Estimated impact on population.

Fixed link	Municipality	Percentage impacts after opening			
		Baseline		County specific	
		5 year*	15 year*	5 year*	15 year*
Fv108 Hvaler Bridge	Hvaler	-2	10	-2	10
E10 Nappstraumen	Vestvågøy	5	8	4	12
E39 Rennfast	Rennesøy	10	32	10	27
Rv70/E39 Krifast	Kristiansund	-1	-4	-1	-5
Fv562 Askøy Bridge	Askøy	-1	15	1	18
Fv566 Osterøy Bridge	Osterøy	-1	-1	-1	-5
Fv714 Hitra	Hitra	-1	4	-1	5
Fv714 Frøya	Frøya	2	18	4	18
E39 Triangle Connection	Bømlo	-5	-12	-4	-17
E39 Triangle Connection	Stord	-1	-4	-1	-2
E39 Triangle Connection	Fitjar	1	1	1	-3
Fv652 Eiksund Connection	Hareid	-1	.	-1	.
Fv652 Eiksund Connection	Ulstein	6	.	7	.
Fv519 Finnfast	Finnøy	9	.	9	.
Rv70/E39 Krifast	Averøy	<1	.	1	.
All links	Average	1	6	2	5

Note: *Difference between actual and synthetic control 5 and 15 years after opening.

Table 6 Most important industries in municipalities

Municipality	Most important industry	Second most important industry
Averøy	15 Manufacturing of food products ˚0.09)	45 Construction ˚0.08)
Bømlo	29 Manufacture of machinery and equipment ˚0.09)	35 Manufacture of other transport equipment ˚0.06)
Finnøy	15 Manufacturing of food products ˚0.06)	4 Construction ˚0.09)
Fitjar	35 Manufacture of other transport equipment ˚0.17)	
Frøya	05 Fishing, fish farming and related ˚0.12)	15 Manufacturing of food products ˚0.21)
Hareid	52 Retail trade and repair ˚0.09)	61 Water transport ˚0.07)
Stord	35 Manufacture of other transport equipment ˚0.24)	.
Sveio	35 Manufacture of other transport equipment ˚0.07)	52 Retail trade and repair 0.07
Ulstein	35 Manufacture of other transport equipment ˚0.12)	28 Manufacture of fabricated metal products ˚0.07) 29 Manufacture of machinery and equipment ˚0.06)
Vestvågøy	05 Fishing, fish farming and related ˚0.09)	15 Manufacturing of food products ˚0.06)

Note: SIC-2002 ˚level two). Employment share in industry in 2001 between parentheses.

Table 7 Municipality weights in the synthetic controls ˚county donor pool)

Synthetic Askøy	Weight	Synthetic Hareid	Weight	Synthetic Hvaler	Weight	Synthetic Osterøy	Weight*
Kvinnherad	0.55	Eide	0.46	Råde	0.57	Os ˚Hord.)	0.4
Os ˚Hord.)	0.45	Sande ˚M. & R.)	0.15	Våler ˚Østf.)	0.43	Samnanger	0.32
		Vestnes	0.06			Fedje	0.09
		Haram	0.05			Radøy	0.02
Synthetic Averøy	**Weight**	**Synthetic Vestvågøy**	**Weight**	**Synthetic Sveio**	**Weight***	**Synthetic Kristiansund**	**Weight***
Fræna	0.38	Fauske	0.47	Fitjar	0.27	Molde	0.68
Aukra	0.20	Bø ˚Nordl.)	0.36	Modalen	0.26	Smøla	0.32
Sandøy	0.16	Rana	0.17	Samnanger	0.26		
Synthetic Finnøy	**Weight**	**Synthetic Rennesøy**	**Weight***	**Synthetic Ulstein**	**Weight**	**Synthetic Bømlo**	**Weight***
Hjelmeland	1.00	Forsand	0.51	Eide	0.72	Os	0.69
		Bokn	0.24	Aukra	0.28	Austevoll	0.21
		Gjesdal	0.22			Fusa	0.09
		Bjerkreim	0.01				
Synthetic Hitra	**Weight***	**Synthetic Frøya**	**Weight**	**Synthetic Stord**	**Weight**		
Roan	0.22	Osen	0.73	Os ˚Hord.)	0.89		
Osen	0.11	Klæbu	0.26	Voss	0.11		
Snillfjord	0.08	Trondheim	0.01				

Note: Weights<0.01 are excluded. Weights come from the solution to the quadratic-minimization problem displayed in equation (1).

Table 8 Observed and matched values for predictors °county donor pool).

Panel A: Population °opening year)

Municipality	Treat	Control	Diff
Askøy	18490	18467	0 %
Averøy	5444	5387	1 %
Bømlo	10839	10657	2 %
Finnøy	2790	2818	-1 %
Fitjar	2978	2955	1 %
Frøya	4115	3943	4 %
Hareid	4741	4636	2 %
Hitra	4178	4171	0 %
Hvaler	3181	3162	1 %
Kristiansund	22044	22041	0 %
Osterøy	7009	7014	0 %
Rennesøy	2566	2567	0 %
Stord	16241	15567	4 %
Ulstein	6946	6042	15 %
Vestvågøy	10547	10340	2 %

Panel B: Employment °place of work in opening year)

Municipality	Treat	Control	Diff
Askøy	3754	3755	0 %
Averøy	2209	2244	-2 %
Bømlo	4403	3914	12 %
Finnøy	1436	1325	8 %
Fitjar	1113	1137	-2 %
Frøya	1964	2026	-3 %
Hareid	2162	2290	-6 %
Hitra	1514	1512	0 %
Hvaler	526	563	-7 %
Kristiansund	7844	7824	0 %
Osterøy	2189	2190	0 %
Rennesøy	723	723	0 %
Stord	8388	6873	22 %
Ulstein	4610	2354	96 %
Vestvågøy	3111	3153	-1 %

Panel C: Employment share

	Most important			2nd most important		
Municipality	Treat	Control	Diff*	Treat	Control	Diff*
Askøy	.	.	.	.	.	.
Averøy	.	.	.	.	.	.
Bømlo	0.09	0.09	0	0.06	0.06	0
Finnøy	.	.	.	.	.	.
Fitjar	0.17	0.14	0.03	.	.	.
Frøya	0.12	0.11	0.01	0.21	0.18	0.03
Hareid	0.09	0.08	0.01	0.07	0.07	0
Hitra	.	.	.	.	.	.
Hvaler	.	.	.	.	.	.
Kristiansund	.	.	.	.	.	.
Osterøy	.	.	.	.	.	.
Rennesøy	.	.	.	.	.	.
Stord	0.24	0.07	0.17	.	.	.
Ulstein	0.11	0.08	0.03	0.12	0.11	0.01
Vestvågøy	.	.	.	.	.	.

Note: Important industries according to Table 8 in the opening year. *Difference in shares.

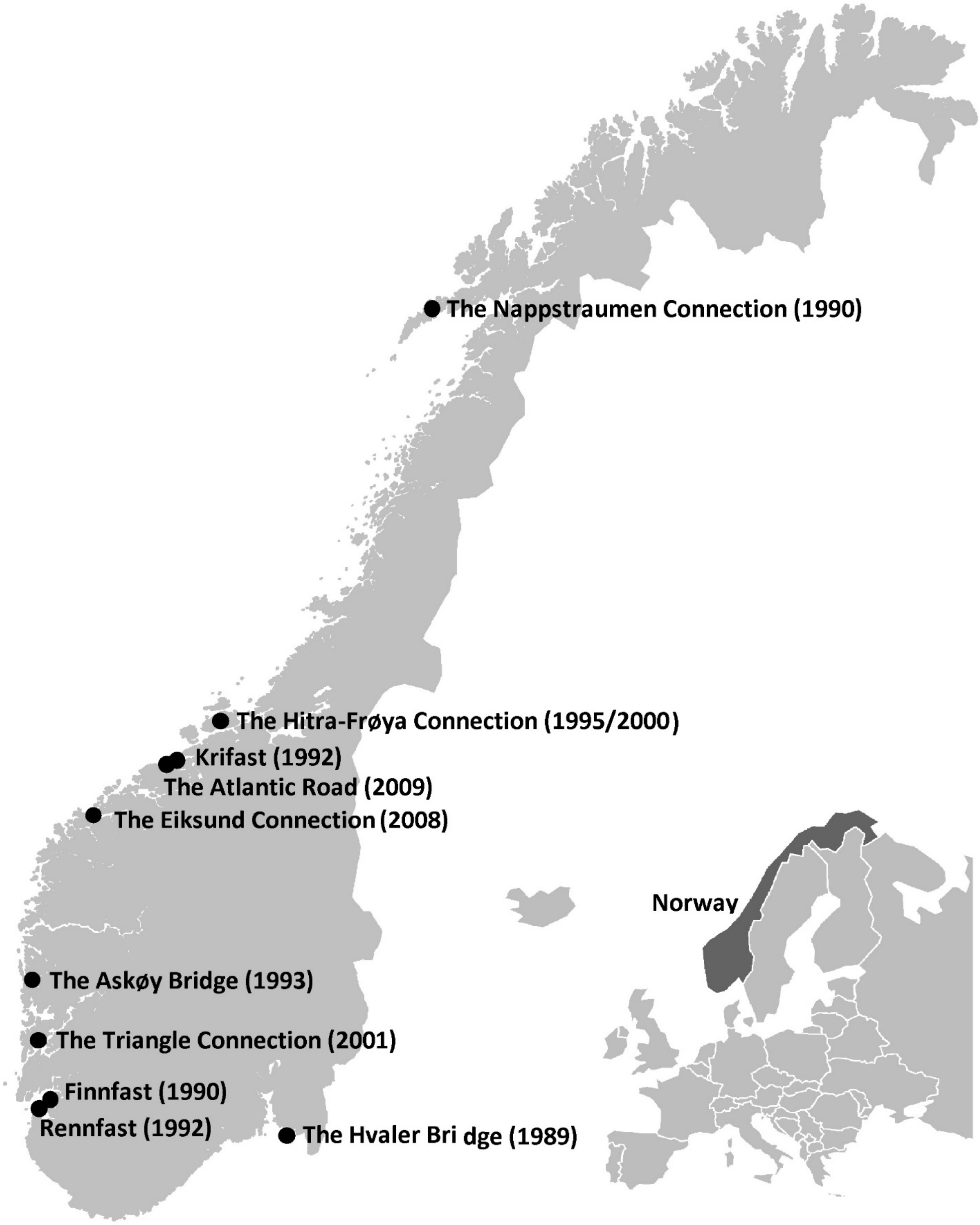

Figure 1 Location and opening year of the fixed links

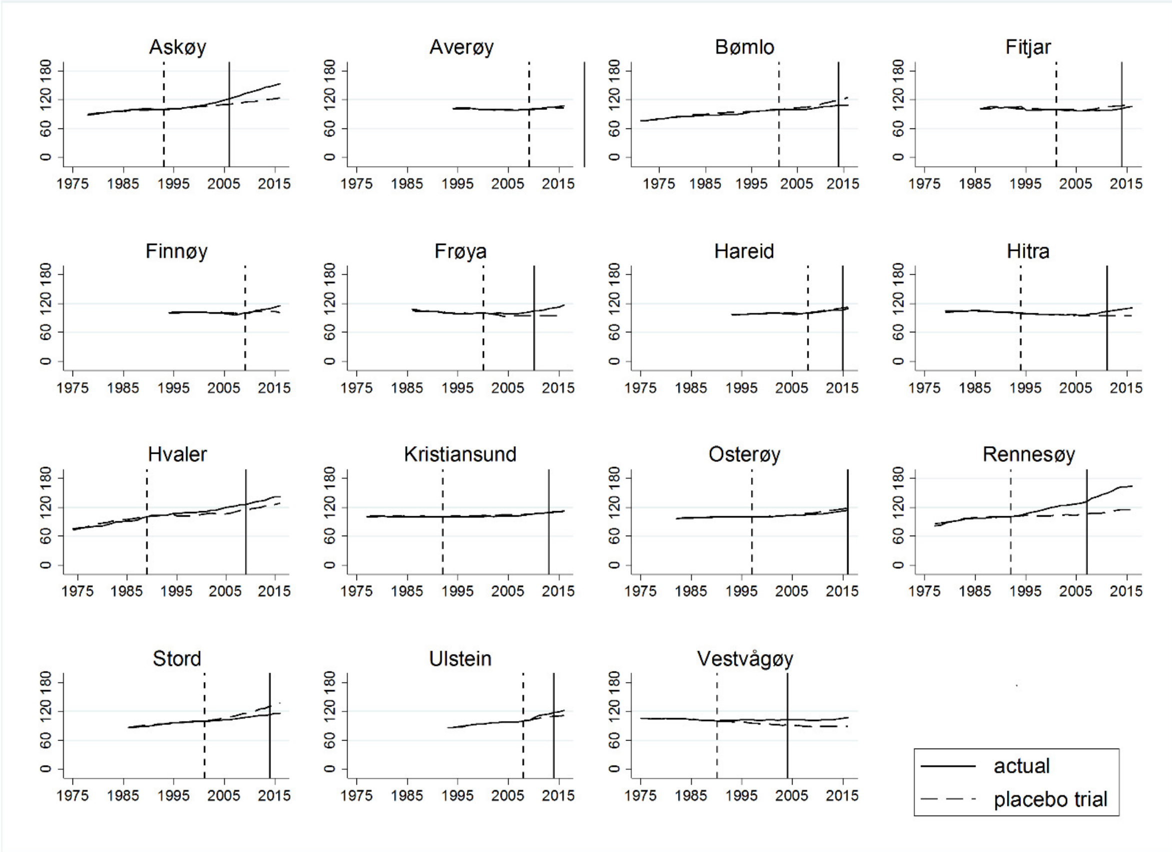

Figure 2 Population trends (opening year=100): Fixed links vs. the synthetic controls

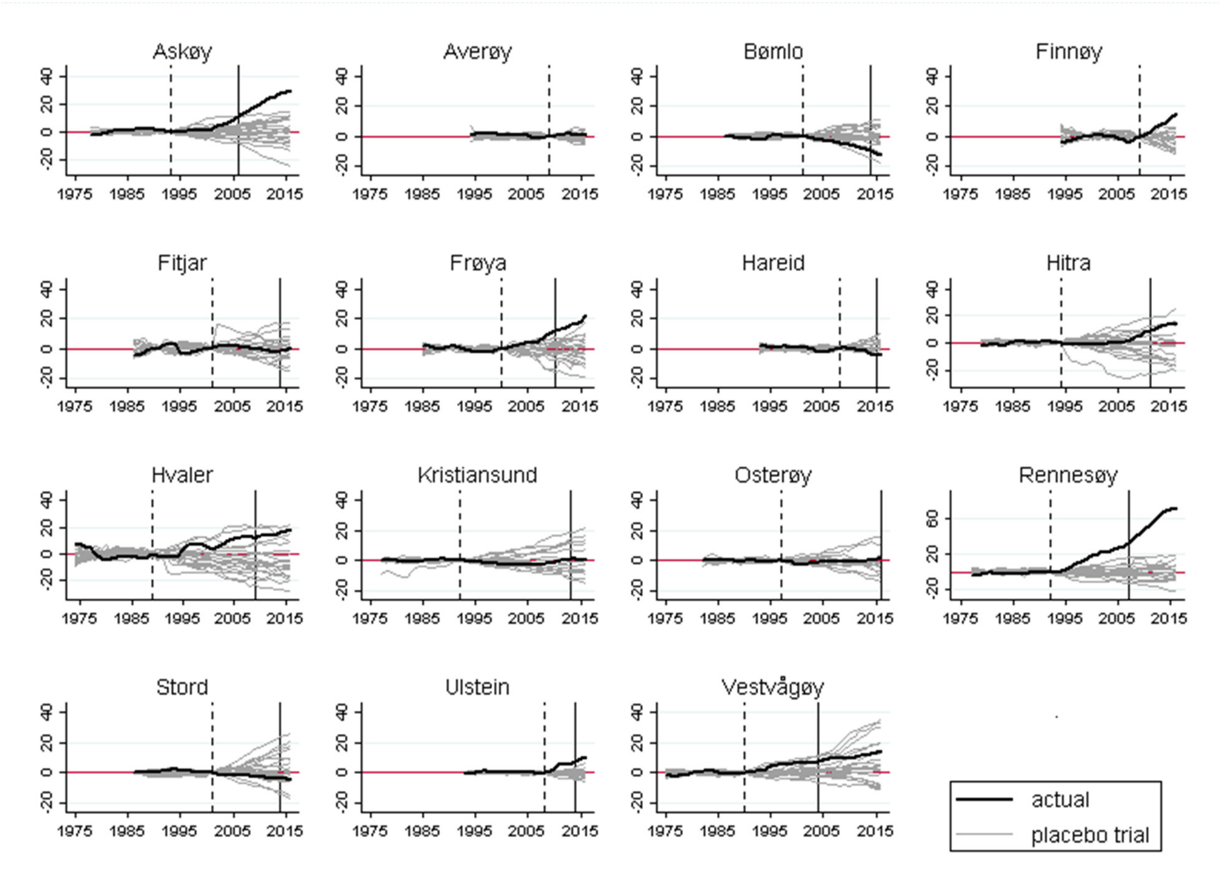

Figure 3 Placebo study. Percentage impact on population

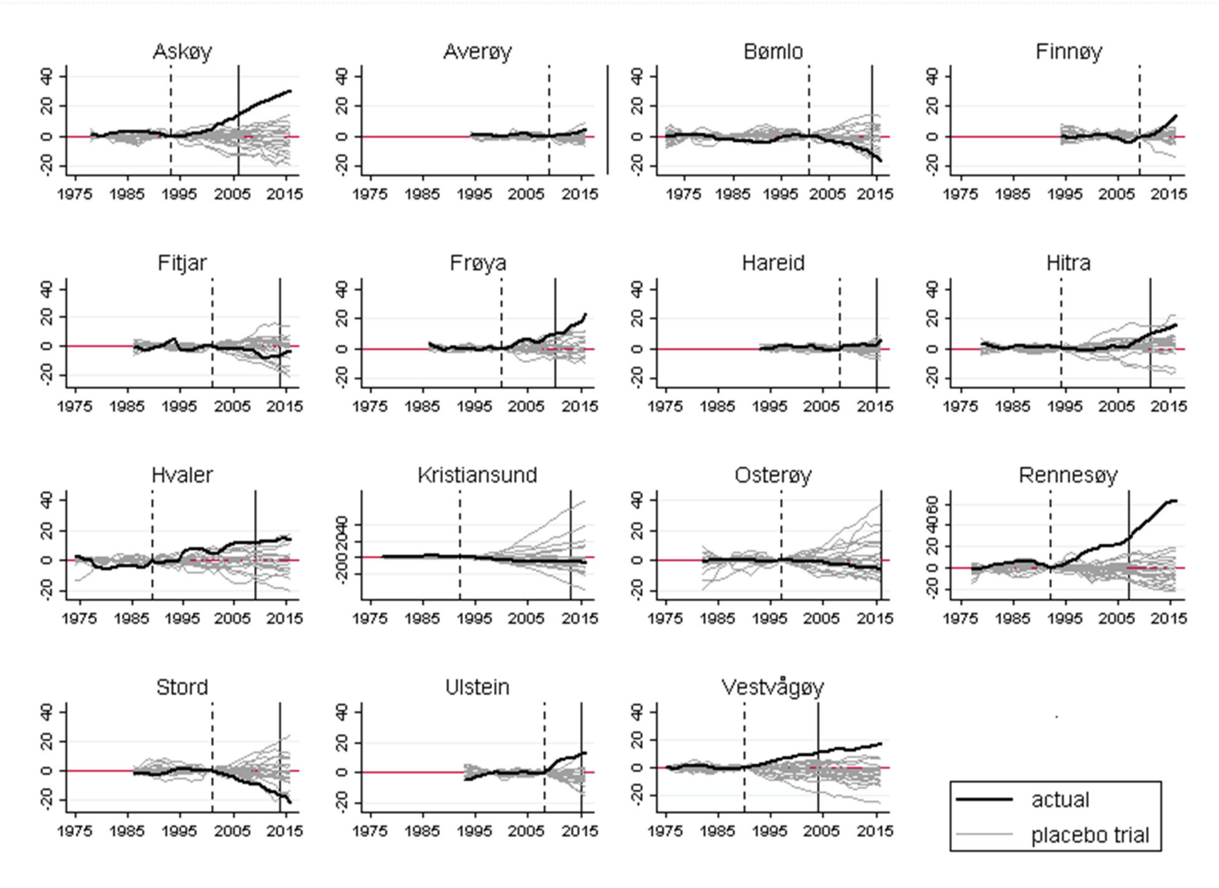

Figure 4 Placebo study for all fixed links (county-specific donor pool). Percentage impact on population in fixed link municipalities and placebo controls

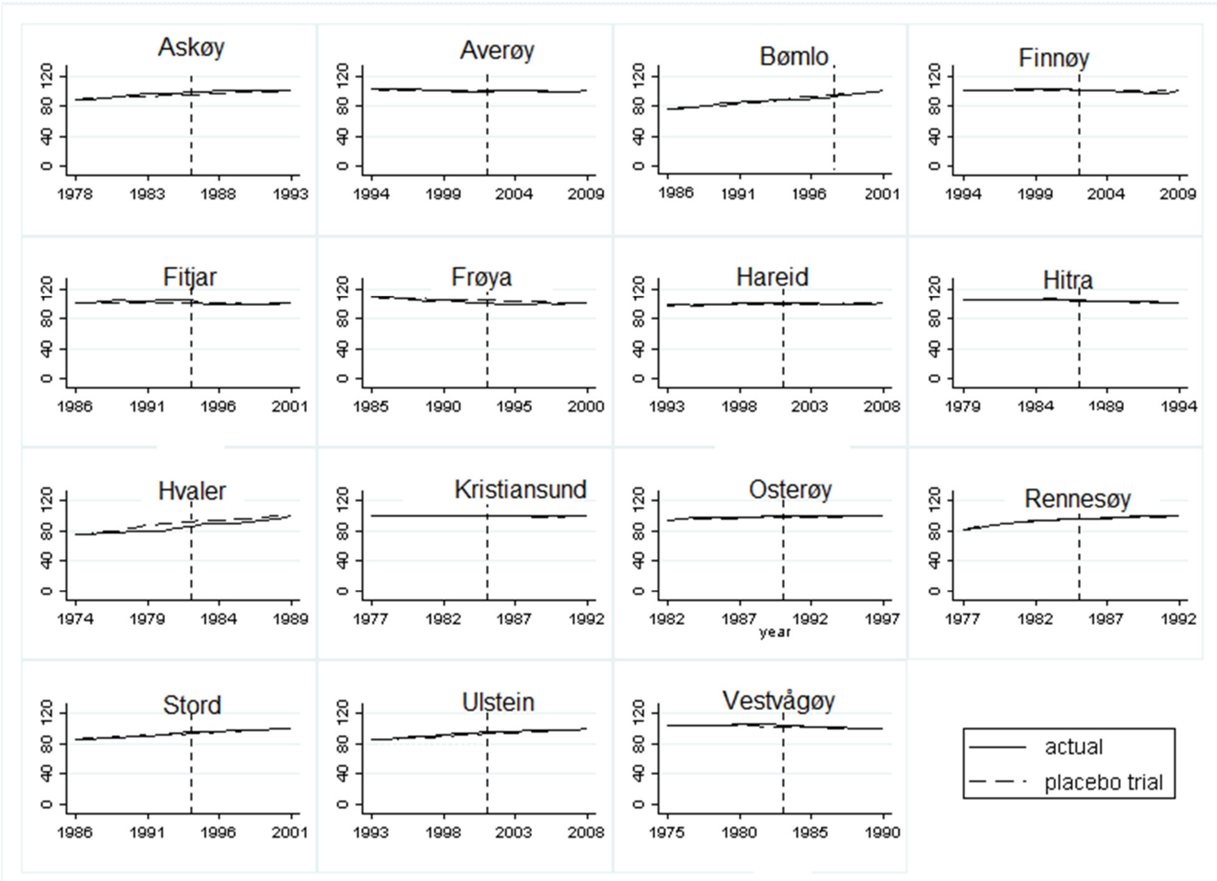

Figure 5 In-time placebo (opening 7 years before actual). Population trends: Fixed link municipalities vs. the synthetic controls