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Patronage effects of off-peak service improvements in regional public transport

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Abstract

The purpose of this study is to look into patronage effects of extended supply outside peak hours on regional public transport services. Previous studies have shown that the service frequency is an attribute of great importance for regional passengers, but little is known about the details regarding peak and off-peak frequencies or service hours. The present study addresses this knowledge gap, departing from the hypothesis that additional off-peak supply means more flexibility for the passengers in terms of departure time options, and possibly also a sense of security for passengers who are uncertain about the time of their (return) trips. Essentially, the added off-peak departures may attract more passengers even if they normally do not or only occasionally use the off-peak services. The patronage effects are explored through four case studies from the region of Scania in southern Sweden. The cases include regional rail and bus services where substantial improvements have been made outside peak hours, resulting in at least hourly all-day services. The results of the study provide new insights into the fundamental planning policy trade-off between maximum frequency and span of public transport services in urban peripheries and rural areas. Importantly, the results suggest that improved time coverage may lead to substantial patronage growth, and this growth is evident also during peak hours, despite unaltered peak hour frequencies. Hence, off-peak departures cannot be assessed only through patronage levels in isolated time periods, let alone on the individual departures.

Keywords: Public transport, Rural accessibility, Regional bus, Regional rail, Timetable planning, Service hours, Daily variation

1 Introduction

The relatively low population density in urban peripheries and rural areas means that it is generally not considered feasible to provide high-frequency public transport services throughout the day in these areas. The regional bus and rail services that constitute the backbone of the rural public transport network are typically focused on commuter trips to school or to work [8, 19], with limited supply off-peak unless they operate along corridors linking nearby and highly populated urban areas. As a result, regional public transport services are, in general, not particularly well adapted for travel purposes other than commuting or for commuters with flexible working hours. By extension, there is a risk that an overly one-sided focus on commuter trips will contribute to social exclusion [7].

It is sometimes argued that such demand-oriented planning also leads to inefficient use of vehicles, with a large part of the fleet being idle during off-peak periods [17]. This means that all-day services can be introduced at lower marginal costs and that relatively high off-peak service levels may be feasible even in rural regions with low population densities [9]. By improving the time coverage, the idea is to make the public transport service available at any time, "much like the private car" [17, p. 12]. This may also be referred to as temporal availability [1].

The present study departs from the hypothesis that improved temporal availability means more flexibility for the passengers in terms of departure time options, and possibly also a sense of security for passengers who are

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uncertain about the time of their (return) trips. Essentially, the added off-peak departures may attract more passengers even if they normally do not or only occasionally use the off-peak services, provided that people are aware of these departures. If this hypothesis holds true, more frequent off-peak services would lead to increased patronage also during peak hours, at least after some time when new travel patterns begin to settle.

However, the results of previous studies into off-peak frequencies do not provide much evidence to support this hypothesis. Totten and Levinson [15] found that cross-effects between peak and off-peak periods are weak or non-existent. Currie and Loader [2] conclude that such effects do exist, specifically that extended evening services affect daytime travel, but suggest that the phenomenon can be explained by the fact that extended evening services enable daytime outbound-from-home trips with evening return trips. Furthermore, this pattern is more apparent on Saturdays and Sundays than on weekdays, where the increase in daytime patronage is relatively small. Similar findings are reported by Simmons and Haas [13], suggesting that extended service span leads to patronage growth during unaltered hours, albeit with relatively small percentages.

It should be noted that the aforementioned studies analysed short-term effects, ranging from a few months up to a year. This time horizon is supported by Wallis [18], who concludes that most of the patronage growth due to extended off-peak services occurs within the first year. Continued growth can be expected also after the first year, but at a considerably lower rate. However, with more extensive improvements 'across the board', e.g. establishing reasonable service levels throughout the day, considerable patronage growth can be detected several years after the improvement [6].

Consequently, there is a need for more research into cross-effects between peak and off-peak periods in such cases [18], particularly studies using panel data in order to analyse the longer-term effects [13]. Adding to this, previous studies have predominantly been conducted in urban contexts, with higher frequencies than those typically found on regional public transport services. Low frequencies may imply significantly different results compared to the identified previous studies [15].

Frequency is an attribute of great importance for regional passengers, but little is known about the details regarding peak and off-peak frequencies or service hours in regional contexts [5]. The present study addresses this knowledge gap by examining patronage effects of extended supply outside peak hours on regional public transport services. The results of the study may thereby provide new insights into the fundamental planning policy trade-off between maximum frequency and span of public transport services in urban peripheries and rural areas.

2 Material and methods

2.1 Study design

In this study, the patronage effects of improved off-peak frequency were explored through case studies, where patronage levels were analysed before and after changes in the off-peak supply. By using case studies, it is possible to study the changes and their effects in detail, and at the same time explore the contexts in which the changes take place [12]. The cases included regional rail and bus services with the purpose of offering public transport connections to some small towns and villages and their surrounding rural areas. Substantial improvements in the off-peak supply were made a few years ago on these services, but peak hour frequencies remained unchanged.

The study made use of panel data with annual patronage measurements, covering ten years or more, in order to analyse long-term trends before and after the off-peak service improvements. To control for other factors with a potential influence on the patronage levels, such as population growth and ticket prices, an elasticity model was estimated through linear mixed regression with a random intercept effect. This means that the model could be fitted to the observations from all cases combined, despite the differing patronage levels from case to case. Based on the model, counterfactual scenarios with unaltered service levels were projected. These scenarios provided baseline estimates against which the actual patronage levels were compared. The model is further described in Sect. 3.

In addition, the weekday patronage levels before and after the service improvements were compared on an hourly basis in order to analyse changes at different times of the day. By paralleling these changes with the corresponding timetable alterations, potential cross-effects could be discerned. Weekdays were in these analyses divided into four periods: morning peak (from the start of services, generally between 5 and 6 a.m., to 9 a.m.), midday (from 9 a.m. to 3 p.m.), afternoon peak (from 3 to 6 p.m.), and evening (after 6 p.m.). Peak hours are the morning peak and the afternoon peak combined. The midday and evening periods are off-peak.

2.2 Data

The principal data source used in the study was manual passenger counts, typically conducted on nine consecutive days (two weekends and the five weekdays in-between, on similar dates each time), resulting in stop-level information about boardings and alightings for each departure. In the past few years, the manual passenger counts have gradually been replaced with automatic passenger counting systems on-board, but the studied

off-peak improvements were all made during the 'manual era'. The data were collected annually on the regional trains until 2016, and to avoid potential influence of the changed data collection method, the timelines terminate in 2016 for the rail services included in the study. For the bus services, the stop-level data were collected less frequently. To be able to create continuous time series in these cases, the stop-level data were supplemented with patronage statistics at the route level based on ticket validations.

2.3 Study area and case selection

The cases examined in this study are located in the region of Scania in southern Sweden. The regional public transport authority controls the planning of both regional and local public transport in Scania and provides the services through procured contracts with private operators. The number of regional trips in the public transport network is roughly equal to the number of local trips within towns and cities [11]. The share of costs covered by subsidies is slightly below 50% in a normal year, though with considerable variation within the network.

Since the turn of the millennium, there has been a rapid growth in public transport patronage in the region [11]. This growth has enabled, and is partly also a result of, continuous development of the supply in a gradually increasing part of the network. These gradual improvements follow a set of established guidelines, defining minimum frequencies and service hours for different types of services depending on their function in the regional network [11]. Most of the improvements have been incremental, typically comprising just one or two additional departures from one year to the next. However, this study focuses on some exceptional cases with more dramatic improvements for the purpose of producing as clear a picture as possible of the patronage effects of improved off-peak services.

Consequently, the selection of cases was information oriented in order to benefit from as much information as possible from each case [3]. The selection process consisted of three criteria. First, and most important, the off-peak improvements must have been quite extensive, resulting in at least hourly all-day services. Second, the improvements must have been made a few years ago to be able to study effects over several years. Third, no other substantial changes must have taken place within the time span studied. This includes, for example, unaltered peak hour frequencies and travel times.

Following the selection process, four cases that met all of the criteria could be identified. The locations of the cases are indicated in the map in Fig. 1. The four cases include rail and bus services that cover distances ranging roughly from 40 to 80 km. All of them can be described as interurban services, between towns, with intermediate stops that typically are located in smaller settlements en route [19]. The cases display similar patterns of settlement structure and population development, with yearly population growth stable around 1% during the studied period [14]. The parts of the region where the cases are situated are also similar in terms of modal split: the share of motorised trips made by public transport has increased from roughly 15% to 20% during the last decade in the municipalities where the studied services are located [10]. During the corresponding time span, car ownership has been stable around roughly 550 cars per 1000 inhabitants in all of the areas around the studied

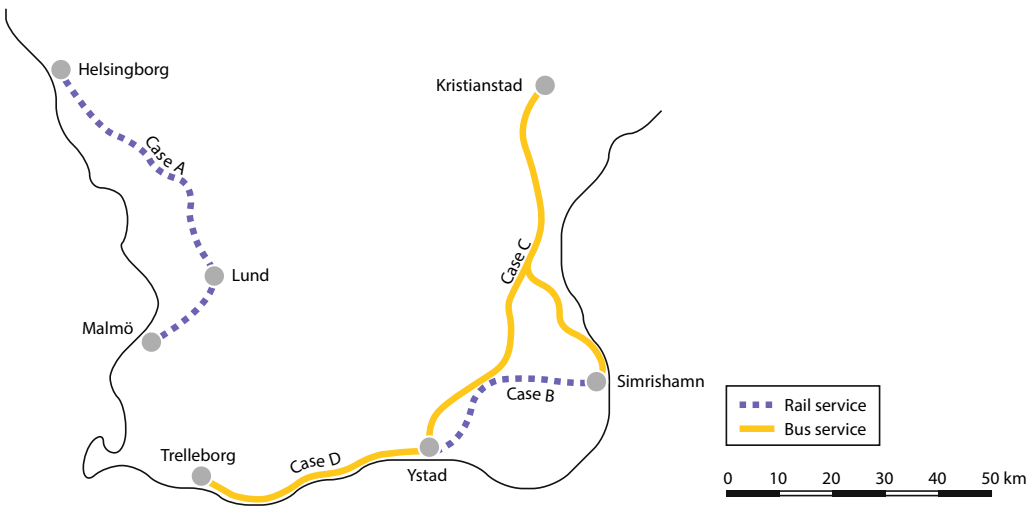

Fig. 1 Locations of the analysed cases in the region of Scania in southern Sweden

services [16]. Each of the cases, denoted A through D, is portrayed in more detail in the description of the results in Sect. 4.

3 Model for patronage effect estimations

3.1 Baseline model

The dataset contains weekday, Saturday, and Sunday patronage numbers for each of the four cases, resulting in twelve subsets of annual observations spanning 10–14 years. These twelve subsets were combined in a linear mixed model to form the basis of the patronage effect analyses. In order to avoid complex lags or ramp-up profiles in the model, observations within three years after major service improvements were removed from the sample in the model estimation process. The three-year limit was chosen based on an initial analysis of the subcases, together with findings presented by Wallis [18]. After this time, the average effect on the number of trips will typically be just a few percent per year. A total of 110 observations remained for the regression analysis.

A simple log-log model was formulated [4] using the number of departures, population, ticket price, and petrol price as predictors. Due to correlation between ticket price and petrol price, together with the small number of observations stressing the importance of limiting the number of predictors, these variables were combined into a price ratio variable. Also, a dummy variable representing the introduction of new trains or coaches was added. The resulting equation can be written as

$$\ln(\hat{y}_{ij}) = \beta_0 + u_{0j} + \beta_1 \ln(x_{1ij}) + \beta_2 \ln(x_{2ij}) + \beta_3 \ln(x_{3ij}) + \beta_4 x_{4ij}$$

where $\hat{y}_{ij}$ is the predicted daily number of trips in year i and subcase j, $\beta_0 + u_{0j}$ is the intercept for subcase j, x_{1ij} is the number of daily departures, x_{2ij} is the population in urban areas en route, x_{3ij} is the ratio between ticket price and petrol price, x_{4ij} is a dummy variable for the introduction of new vehicles, and $\beta_1, \beta_2, \beta_3$ and β_4 are fixed-effect coefficients whose estimates are presented in Table 1.

Based on this model, patronage levels were estimated for the counterfactual scenarios, without off-peak service improvements, by holding the daily departures variable constant. The dummy variable for new vehicles was also held constant in cases where new vehicles and improved off-peak services were introduced simultaneously. The estimated effect of new vehicles was then subtracted in the next step of the analysis.

3.2 Ramp-up profiles

The observations after the off-peak service improvements were compared to the counterfactual baseline estimates by fitting the differences to ramp-up profiles. The ramp-up profiles take into account that the patronage effects are not immediate, but rather build up over time, which is particularly evident after substantial service improvements [6]. A saturation growth function was assumed for the ramp-up profiles [18]:

$$\hat{z} = A\frac{t}{B+t}$$

where $\hat{z}$ is the patronage growth (in percent) at time t (in months after the service improvement) and A and B are parameters representing the long-run patronage effect and the rate of convergence, respectively.

In the figures showing the patronage development in Sect. 4, the ramp-up profiles have been added to the baseline model in order to illustrate the overall model fit. The differences between the observations and the model in the figures represent random errors. The patronage effects are illustrated by the difference between the ramp-up model estimates and the counterfactual baseline estimates.

Table 1 Estimated coefficients with 95% confidence intervals

Predictor	Coefficient	Estimate	95% CI
Ln daily departures	β_1	0.80	[0.65, 0.95]
Ln population	β_2	0.40	[−0.09, 0.89]
Ln price ratio	β_3	−0.35	[−0.73, 0.03]
New vehicles	β_4	0.17	[0.09, 0.24]

Ln denotes the natural logarithm

4 Results

4.1 Case A: Rail service Råådalsbanan

Råådalsbanan in the northwestern parts of Scania serves a number of small towns and villages (population ranging from 500 to 2000) with connections to some of the larger towns in the region. Råådalsbanan used to be the main line from north to south in this part of Scania, but following the opening of a new railway in 2001 most of the through trips were relocated there. Råådalsbanan was retained as a rural railway, with hourly departures on weekdays, though with a few gaps, and every other hour on Saturdays and Sundays. Three new stations were opened in 2001, but these stations were excluded from the analysis to make sure that the effects of the new openings did not influence the results.

In June 2006, the gaps in the weekday timetable were filled so that the trains started to run on an unbroken hourly schedule from 6 a.m. to midnight. This meant an increase from 15 to 19 daily departures (+27%). The

new departures were at 11 a.m., 2 p.m., 9 p.m., and 11 p.m. In other words, two new departures during the midday period and two new departures in the evening.

The sparser frequency on Saturdays and Sundays continued until December 2014, when the number of weekend departures was doubled, resulting in an hourly service from 8 a.m. to midnight on Saturdays and to 11 p.m. on Sundays.

The patronage development from 2002 to 2016 is shown in Fig. 2. As can be seen in the figure, the introduction of an all-day hourly service on weekdays in 2006 was followed by a notable increase in the weekday patronage. The patronage growth after one year was estimated to be 27%, which is on par with the frequency increase, and the growth continued before levelling off at roughly 40% after three to four years. The Saturday and Sunday patronage was relatively stable in this time span, without any signs of cross-effects from the increased frequency on weekdays. New trains were introduced in 2010, resulting in additional growth but to a smaller extent.

Further along on the timeline, the doubled frequency on weekends from 2014 to 2015 led to a roughly 50% increase in patronage on both Saturdays and Sundays. With only two observations after the weekend improvement, it is not possible to estimate the ramp-up parameters, but in contrast to the 2006 improvement, the increase after 2014 seems to have levelled off already after one year. This is confirmed by statistics for the years after 2016, indicating no further patronage increase, neither on Saturdays nor on Sundays. Also, the improved weekend service did not seem to have any notable effect on the weekday patronage.

A more detailed picture of the patronage growth following the 2006 improvement is presented in Fig. 3, showing the number of trips over the course of the day in 2005 and 2008. To facilitate comparison, the values have been averaged over a moving three-hour period. The most conspicuous increase is in the morning peak, where the number of trips increased by 42%, despite the unaltered frequency in that period. The increase in the afternoon peak is less prominent, and taken together the number of off-peak trips increased more than the number of trips during peak hours (+36% off-peak compared to +28% peak). However, trips during peak hours increased more in absolute numbers (+200 peak trips compared to +170 off-peak trips).

4.2 Case B: Rail service Österlenbanan

Österlenbanan is a railway between Ystad (pop. 20,000) and Simrishamn (pop. 6800), via Tomelilla (pop. 7200) and some smaller settlements en route, in the southeastern parts of Scania. The railway was electrified in 2001–2003, and after the reopening the service was operated with departures every two hours. Supplementary departures in the morning and in the afternoon meant that an hourly service was offered on weekdays 6–8 a.m. and 4–6 p.m.

The span of the hourly service was extended in January 2009 to 5–8 a.m. and 2–8 p.m., an increase from 12 to 15 daily departures (+25%). Two and a half years later, in August 2011, another five daily departures were added

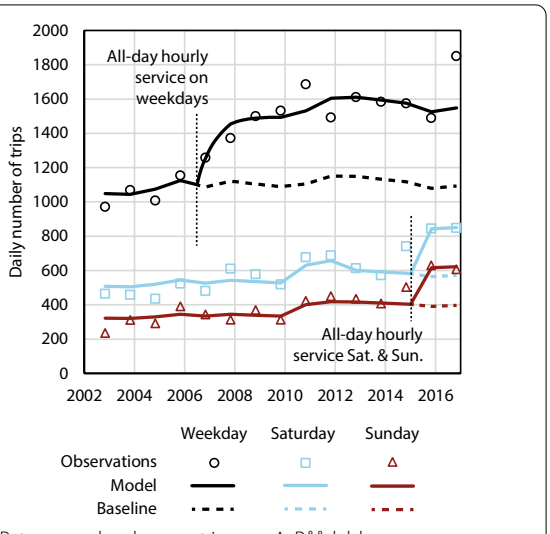

Fig. 2 Patronage development in case A, Råådalsbanan (excluding the new stations opened in 2001), showing annual autumn measurements and model estimations of the patronage development with and without off-peak service improvements (the latter corresponds to the counterfactual baseline scenario)

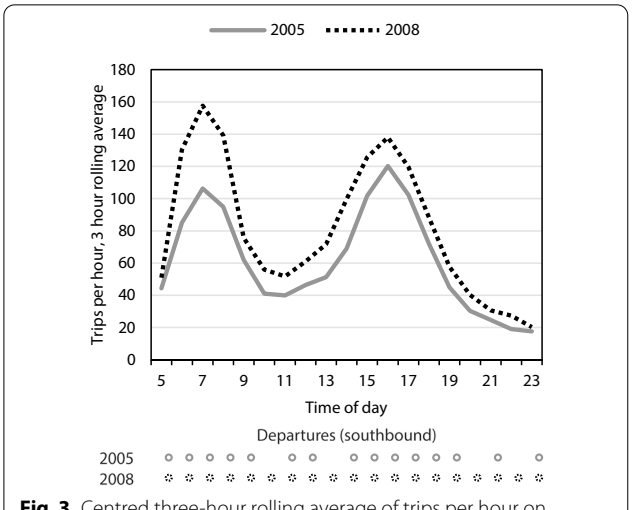

Fig. 3 Centred three-hour rolling average of trips per hour on Råådalsbanan (case A) on a typical weekday in 2005 and 2008. The circles below the chart represent departure times

on weekdays (+33%), resulting in an hourly service from 5 a.m. to midnight. Simultaneously, the frequency on Saturdays and Sundays was doubled to be able to introduce an hourly service all days of the week (from 6 a.m. to midnight on Saturdays and from 7 a.m. to 10 p.m. on Sundays).

Since the reopening in 2003, the trains on Österlenbanan have continued from Ystad towards the more densely populated western parts of the region. However, to avoid any influence from events in other parts of the network, trips passing through Ystad have been excluded from the analysis. Consequently, the number of trips in the analysis corresponds to the number of boarding passengers on eastbound trains, from Ystad to Simrishamn, and to the number of alighting passengers on westbound trains, from Simrishamn to Ystad.

The patronage development from 2004 to 2016 is shown in Fig. 4. The first extension of the hourly service in 2009 appears to have resulted in an increase in weekday patronage of approximately 16%.

The response to the introduction of the all-day hourly service in 2011 is more tangible. As in case A, the estimated patronage growth on weekdays exceeded the relative frequency increase already after the first year. The long-term effect was estimated to be 50%, most of which was attained after three to four years.

The growth was greater on Saturdays and Sundays, although it did not quite reach the corresponding increase in frequency in this case. The doubled frequency was estimated to result in a roughly 70% increase in patronage on Saturdays and an 85% increase on Sundays. In contrast to the patronage growth on weekdays, the weekend patronage seems to have grown faster but to have levelled off considerably already after one to two years.

Patronage growth at different times of the day is shown in Fig. 5. The extended span of the hourly service in 2009 seems to have primarily affected the afternoon peak, with a substantial patronage growth in the early afternoon. This is followed by a clear increase over all times of the day after the introduction of the all-day hourly service in 2011. The increase is particularly evident in the midday period, where the number of trips appears to have more than doubled from 2010 to 2013. The increase is less prominent during peak hours, but still substantial despite the unaltered frequency in those periods. The number of trips made during peak hours increased by 24% from 2010 to 2013, compared to a 75% increase during off-peak hours. In absolute numbers, the increase in off-peak trips was approximately twice as large as the increase in peak trips (+ 330 off-peak trips compared to +160 peak trips).

4.3 Case C: Coach services Kristianstad–Simrishamn/Ystad

The main public transport connections from north to south in the eastern parts of Scania are the coach services from Kristianstad (pop. 41,000) to Simrishamn (pop. 6800) and to Ystad (pop. 20,000). The services are called SkåneExpressen 3 and SkåneExpressen 4, but despite being branded as express services they have quite dense stopping patterns so that they also cover the rural

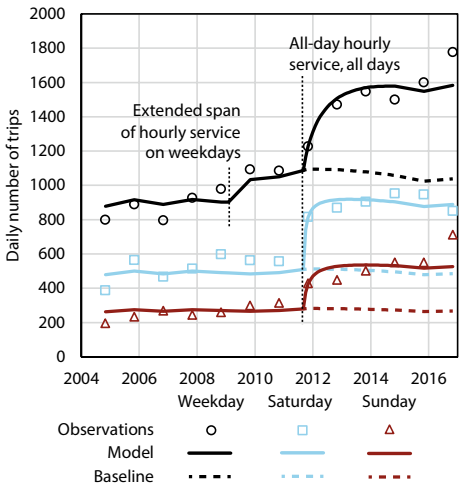

Fig. 4 Patronage development in case B, Österlenbanan (excluding trips with origins or destinations in other parts of the network), showing annual autumn measurements and model estimations of the patronage development with and without off-peak service improvements (the latter corresponds to the counterfactual baseline scenario)

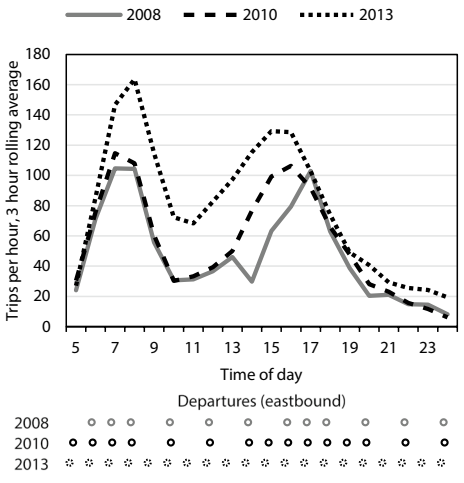

Fig. 5 Centred three-hour rolling average of trips per hour on Österlenbanan (case B) on a typical weekday in 2008, 2010, and 2013. The circles below the chart represent departure times

settlements en route. The services were analysed together because their routes are parallel for about half the distance on the northern section.

Both services run on hourly schedules, supplemented during peak hours by a couple of additional bus services running parallel on the busiest sections. These bus services were also included in the analysis.

The hourly schedules used to only apply on weekdays but were extended to include Saturdays and Sundays in December 2014. This was a dramatic improvement, from 10 to 18 departures in each direction on Saturdays (+80%) and from 6 to 15 departures on Sundays (+150%). The improvement was made possible by integrating the timetables, thus enabling transfers instead of operating on parallel routes. The weekday schedules were also adjusted in December 2014, largely without any notable changes in the supply, except for some additional evening departures on the Ystad branch.

The patronage development from 2010 to 2019 is shown in Fig. 6. As can be seen in the figure, the weekday patronage was relatively stable across the entire time span. In contrast, a swift increase was seen on Saturdays and Sundays as a response to the service improvements at the end of 2014. The long-term effects were estimated to be a roughly 60% patronage increase on Saturdays and a 90% increase on Sundays. These levels were reached already after one to two years.

Changes in patronage over the course of the day on weekdays were also analysed. Except for a slight increase in evening patronage due to the additional evening departures, the results did not reveal any substantial changes that could be related to the improvements of the off-peak frequencies.

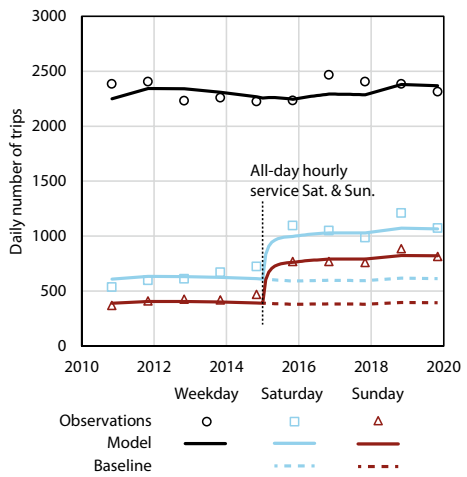

Fig. 6 Patronage development in case C, coach and bus services from Kristianstad to Simrishamn and Ystad (SkåneExpressen 3 and 4 together with route 337 and 573), showing annual autumn measurements and model estimations of the patronage development with and without off-peak service improvements (the latter corresponds to the counterfactual baseline scenario)

4.4 Case D: Bus service Trelleborg–Ystad

Bus service 190 operates along the southern Scanian coast between Trelleborg (pop. 31,000) and Ystad (pop. 20,000). The operations in their present form began in 2008, when a couple of previous services were combined to form a coherent route along the coast. Until 2015, the timetable was irregular, with a strong focus on the morning and afternoon peaks. During roughly two hours in the morning and two hours in the afternoon, there were at least two buses per hour in each direction. At other times of the day and during the weekends, the departures were much more sporadic.

In December 2015, a regular-interval timetable was introduced with at least hourly departures on weekdays from 5 a.m. to 8 p.m. At the same time, the departures during peak hours were redistributed so that half-hourly services could be offered 5–9 a.m. and 2–6 p.m. In effect, this meant that the span of the peak hour frequency was extended. All in all, the number of departures on weekdays increased from 19 to 27 (+42%), but the number of departures during peak hours was held constant, and the entire increase took place during the midday period and in the evening.

The hourly service was also extended to Saturdays, with an increase from 8 to 15 daily departures (+88%). On Sundays, however, the new schedule was limited to departures every other hour, which meant a less dramatic improvement, from 5 to 7 daily departures (+40%).

The patronage development from 2010 to 2019 is shown in Fig. 7. The data for this case suggested a relatively slow rate of convergence after the off-peak service improvements. The patronage growth exceeded the relative frequency increase on weekdays as well as on Saturdays and Sundays within three years or so and appears to have continued after that as well. The estimated long-term patronage growth effects were roughly 50% on weekdays, 100% on Saturdays, and 70% on Sundays.

Patronage growth at different times of the day is shown in Fig. 8. The largest increases occurred in the late morning and late afternoon in the transitions from peak hours to midday and evening hours, respectively. This is in line with the extended span of the peak hour frequency, resulting in less sharp peaks. The number of off-peak trips increased more than the number of trips during peak hours in relative terms (+39% off-peak compared to +28% peak). However, trips during peak hours increased more in absolute numbers (+140 peak trips compared to +120 off-peak trips).

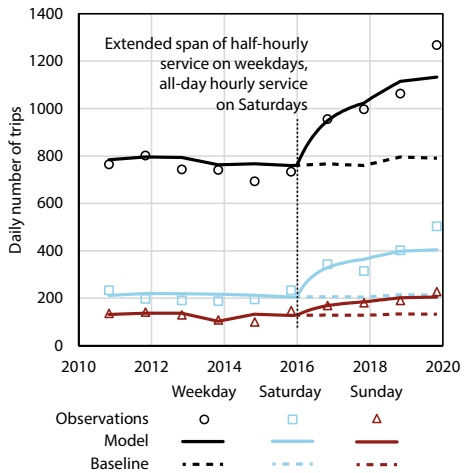

Fig. 7 Patronage development in case D, the bus service between Trelleborg and Ystad, showing annual autumn measurements and model estimations of the patronage development with and without off-peak service improvements (the latter corresponds to the counterfactual baseline scenario)

5 Discussion

In this article we have examined patronage effects of extended supply outside peak hours on regional public transport services. This was done by exploring four cases that have been subject to substantial improvements in the off-peak frequency, generally resulting in at least hourly services throughout the day. All four cases clearly demonstrated considerable patronage growth following the improvements. It has previously been suggested that half-hourly or better service frequencies are needed to be able to attract new patronage [6]. However, that conclusion was drawn in an urban context. By the same logic, our results suggest that the corresponding minimum standard in regional public transport is an hourly all-day service.

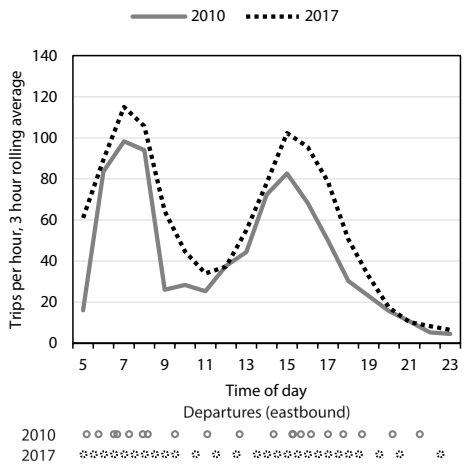

Fig. 8 Centred three-hour rolling averages of trips per hour on the bus service between Trelleborg and Ystad (case D) on a typical weekday in 2010 and 2017. The circles below the chart represent departure times. Some departures in 2010 were very close to each other and thus are difficult to distinguish in the figure

The cases with off-peak improvements on weekdays showed notable increases in peak hour patronage, despite unaltered peak hour frequencies. These results contradict the findings presented by Totten and Levinson [15], who concluded that midday and evening frequencies do not have any noticeable effects on peak hour patronage. However, there are a couple of important differences between the studies. First, Totten and Levinson studied urban local routes. The geographical context may in itself affect the results, but the higher frequencies on these services are probably even more influential. The regional services in the present study generally had less frequent than hourly services during off-peak periods before the upgrades. Increasing the frequency to hourly departures is then a drastic improvement in the availability of the service compared to, for example, moving from departures every 30 minutes to every 15 minutes. Second, Totten and Levinson studied short-term elasticities with a one-year horizon, while the results of the present study indicate that patronage levels may continue to increase for several years, particularly on weekdays. It is possible that the cross-period effects are results of a relatively slow process, meaning that the patronage during peak hours only begins to increase after a while, allowing some time for new travel patterns to be established.

The increased peak hour patronage as a result of improved off-peak services in the present study can be viewed as an addition to the results presented by Currie and Loader [2], who focused on extended evening services. However, their hypothesis that the effects can be explained by daytime outbound-from-home trips with evening return trips proves insufficient in a couple of the cases in the present study. The results for cases A and D demonstrate larger increases in the number of trips during peak hours than in off-peak hours. This implies that it is not possible to link all new trips during peak hours to outbound or return trips during the midday and evening periods. This finding supports the hypothesis outlined in the introduction that improved off-peak frequency may attract more passengers even if they normally do not or only occasionally use the off-peak departures. Plausibly, this effect can only be fully achieved with proper marketing of the service upgrade, so that people become aware of the added flexibility in terms of departure time options. Again, it is important to note the longer time perspective in the present study compared to the study

by Currie and Loader [2]. The suggested hypotheses are not mutually exclusive, and it is possible that they come into effect at different stages after a service improvement.

Because no additional vehicles are required, off-peak service improvements may offer a cost-effective option for substantially increasing public transport patronage and at the same time reducing social exclusion. In the region studied, capital costs make up about a quarter of the bus operating costs and about half of the train operating costs. This means that the marginal costs for off-peak service improvements are considerably lower than the relative increase in frequency. Interestingly, if these values are applied to the cases in this study, the marginal cost increase is typically exceeded by the patronage growth within a couple of years. This means that the share of the operating costs covered by ticket revenues increased and that the service improvements could be implemented with very limited impact on the amount of subsidies needed.

The main contributions of this study in relation to previous research into off-peak frequencies are the regional perspective and the use of panel data, which facilitated the analysis of long-term effects. Due to the strict requirements placed on these data in the selection process, the analysis was limited to four cases. This enabled detailed exploration of the off-peak service improvements and their effects in the specific context of each case, but at the same time it is a numerically weak basis for drawing generalisable conclusions. Consequently, a suggestion for future research is to expand the basis with more cases in other regions. Another interesting research direction would be to adopt a qualitative approach focusing on the passengers' experiences. In addition, studies into effects on different types of users and trip purposes would be helpful in deepening the understanding of the importance of off-peak frequencies.

6 Conclusions

The results of this study suggest that the span and frequency of off-peak services are important service quality aspects in regional public transport. Making the public transport service available throughout the day with regular, at least hourly, departures from morning to evening is in all of the studied cases succeeded by substantial patronage growth. In some cases, the growth continues for several years to levels considerably higher than the short-term effects that are recognised during the first year.

The results also suggest that off-peak service improvements on weekdays affect travel demand during peak hours. In fact, the patronage growth during peak hours may be larger than in the off-peak periods, despite unaltered peak hour frequency. Hence, off-peak departures cannot be assessed only through patronage levels in isolated time periods, let alone on the individual departures.

All four of the analysed cases demonstrate substantial growth of the weekend patronage after improvements in the Saturday and Sunday services. However, in contrast to the interaction between peak and off-peak periods on weekdays, there are no signs of cross-effects between weekends and weekdays.

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Author contributions
JH: Conceptualization; Formal analysis; Investigation; Data Curation; Methodology; Visualization; Writing—original draft. FPL: Supervision; Writing—review and editing. HS: Supervision; Writing–review and editing. AW: Supervision; Writing—review and editing. All authors have approved the manuscript for submission.

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Availability of data and materials
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Declarations

Competing interests
The authors declare that they have no competing interests.

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References

1. Cass, N., Shove, E., & Urry, J. (2005). Social exclusion, mobility and access. *The Sociological Review, 53*(3), 539–555. https://doi.org/10.1111/j.1467-954X.2005.00565.x
2. Currie, G., & Loader, C. (2009). High ridership growth from extended transit service hours: An exploration of the causes. *Transportation Research Record, 2110*, 120–127. https://doi.org/10.3141/2110-15
3. Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative Inquiry, 12*(2), 219–245. https://doi.org/10.1177/1077800405284363
4. Greer, M. R., & van Campen, B. (2011). Influences on public transport utilization: The case of Auckland. *Journal of Public Transportation, 14*(2), 3. https://doi.org/10.5038/2375-0901.14.2.3
5. Hansson, J., Pettersson, F., Svensson, H., & Wretstrand, A. (2019). Preferences in regional public transport: A literature review. *European Transport Research Review, 11*(1), 1–16. https://doi.org/10.1186/s12544-019-0374-4
6. Loader, C., & Stanley, J. (2009). Growing bus patronage and addressing transport disadvantage—The Melbourne experience. *Transport Policy, 16*(3), 106–114. https://doi.org/10.1016/j.tranpol.2009.02.001

7. Markovich, J., & Lucas, K. (2011). *The social and distributional impacts of transport: A literature review (working paper 1055)*. Transport Studies Unit, School of Geography and the Environment, University of Oxford.
8. Metelka, S., & Janoš, V. (2021). Demand variation in regional transport. *Smart City Symposium Prague (SCSP), 2021*, 1–5. https://doi.org/10.1109/SCSP52043.2021.9447373
9. Petersen, T. (2016). Watching the Swiss: A network approach to rural and exurban public transport. *Transport Policy, 52*, 175–185. https://doi.org/10.1016/j.tranpol.2016.07.012
10. Region Skåne. (2019). *Så reser vi i Skåne: Resvaneundersökningen 2018*.
11. Region Skåne. (2020). *Trafikförsörjningsprogram för Skåne 2020–2030*.
12. Rowley, J. (2002). Using case studies in research. *Management Research News*. https://doi.org/10.1108/01409170210782990
13. Simmons, J., & Haas, P. J. (2016). Impact on bus ridership from changes in a Route's span of service. *Transportation Research Record, 2539*(1), 48–54. https://doi.org/10.3141/2539-06
14. Statistics Sweden. (2021). *Folkmängd per tätort efter region och vart 5:e år*.
15. Totten, J. C., & Levinson, D. M. (2016). Cross-elasticities in frequencies and ridership for Urban local routes. *Journal of Public Transportation, 19*(3), 117–125. https://doi.org/10.5038/2375-0901.19.3.7
16. Trafikanalys. (2022). *Personbilar: Antal i trafik per 1000 invånare efter år, län och kommun*.
17. Tzieropoulos, P., Emery, D., & Buri, J.-D. (2010). Regular-interval timetables : Theoretical foundations and policy implications. In: *12th World conference on transport research* (pp. 1–15).
18. Wallis, I. P. (2013). *Experience with the development of off-peak bus services (research report 487)*. NZ Transport Agency.
19. White, P. (2016). Rural public transport. In *Public transport: Its planning, management and operation* (6th ed., pp. 201–221). Routledge.

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