Factors affecting public transportation in the Covid-19 period

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Research Article

Keywords: public transportation, Covid-19, service provider perspective, ARMA model, government measures

Posted Date: August 4th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-3215723/v1

Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Sustainability on October 26th, 2023. See the published version at https://doi.org/10.3390/su152115310.

Abstract

In the European Union Member States, the share of public transport use from the turn of the millennium to the beginning of the pandemic period was 17–18%, while in Hungary, it was 27%. The number of public transport users has fallen due to the Covid-19 virus to 13% in the EU and 21% in Hungary. The decrease can be attributed to changes in travel habits and the impact of the measures taken in the context of the virus situation. In Debrecen, Hungary's second-largest city, the situation is similar. During a shorter period of the first wave of the virus, the public service operator realized only 30% of its usual revenue. The present study analyzes the relationship between the number of active cases of Covid-19, the impact of the measures taken and the number of paying passengers on public transport in Debrecen. Four hypotheses were put forward: 1) travel tickets, 2) general passes, 3) discount passes and 4) supplement passes were influenced by the evolution of Covid-19's active caseload. The data were collected from the Debrecen Transport Company (DKV) for 2020.01–2021.12, and the active Covid-19 case numbers were collected from the Worldometers.info database. Statistical analyses were performed using the ARMA (autoregressive and moving-average) model. We found that all four of our hypotheses had to be rejected, as Covid's active caseload did not influence sales of tickets and various passes.

1. Introduction

With the intensification of urbanization processes, the evolution of urban mobility and the possibilities for its development are nowadays a focus of the transport profession (Barbosa et al., 2021). In recent decades, private transport has played an increasingly important role in passenger transport in the Member States of the European Union (EU). In contrast, the use of public transport has gradually decreased, which was also observed in Hungary (Hungarian Central Statistical Office (KSH), 2021). Increasing road congestion means it takes longer to reach our destinations (Pouliakas, 2018). These processes are becoming an increasing problem for the livability of cities, with more and more vehicles on the roads.

Several factors influence the decline in the number of passengers using public transport. In addition to the dynamic increase in the number of cars, the development of cycling, scooter transport and ridesharing systems may also reduce the number of people using public transport (Anagnostopoulou et al., 2020). In recent years, in addition to the underlying decline in passenger numbers, the effects of the Covid-19 pandemic and the measures taken during this period have also reduced the number of people using public transport. According to Continental's Mobility Study 2020, the Covid-19 pandemic has increased the importance of private or individual transport (Continental AG, 2020; Furcher et al., 2021). At the same time, the number of people using public transport has fallen, for example, by half in Germany and over 50% in Japan and China.

An analysis of the proportion of individual and public transport users in the EU Member States shows that from the turn of the millennium until the beginning of the pandemic, the proportion of people using public transport for passenger transport was around 17–18%. The share of rail and suburban and local transport users (Fig. 1) remained relatively stagnant during these years. Although these figures still show a more favourable picture for Hungary than the EU average, they show a significant downward trend over this period. The overall 38% in the early 2000s had fallen below Hungary's 27% modal split by the year before the pandemic.

On 11 March 2020, the World Health Organization (WHO) declared the outbreak of the new coronavirus a global pandemic (WHO, 2020). At the same time, the Hungarian government declared a state of emergency and a state of public health emergency for the whole country on the same day (Ministry of Justice, 2020b). The decree was followed by a series of restrictive measures, all with one thing in common: limiting personal contacts to prevent the spread of the epidemic. These provisions had severe economic and social implications, including mobility in all its forms. Today, the proportion of people using social networking tools has fallen further due to the viral situation, to 13% in the EU and 21% in Hungary. It can be argued that this is due to changes in travel habits during the pandemic period (people's fear of the virus spreading faster in confined spaces) and the effects of the measures taken in the context of the epidemic situation, which has had a significant impact on public transport in the city of Debrecen. The seat occupancy rate and fare revenues have been significantly reduced. During the first, shorter period of the first wave of the virus, the public service operator realized about 30% of its regular revenues. Transport experts had already predicted a slower "bounce-back" at the beginning of the virus' spread, expecting the population to return to public transport after up to five years. That ridership would return to the levels seen in previous years. The two years since then confirm these predictions, with a slow recovery in ridership and revenue.

This study examines the impact of the Covid-19 epidemic and the measures taken to evolve the number of paying passengers in the city of Debrecen. The following working hypotheses have been formulated:

H_1: Sales of travel tickets were influenced by the evolution of active caseloads.

H_2: Sales of general passes were influenced by the evolution of active caseloads.

H_3: Sales of discounted passes were influenced by the evolution of active caseloads.

H_4: Sales of supplement passes were influenced by the evolution of active caseloads.

2. Literature review

In this paper, we look at the impact of COVID-19 on public transport. The study's uniqueness lies in the fact that we analyzed not only the relationship between the number of active cases of Covid-19 but also the impact of the measures taken and the number of paying passengers on public transport. Many studies have examined the impact of the pandemic on the service sector since its spread in 2020 (Bittner & Gavaldi, 2021; Bittner & Posta, 2020; Dominiak, 2022; Gunay & Kurtulmus, 2021; Lee & Eom, 2023; Mazzucato & Kattel, 2020; Prentice et al., 2021; Vida & Popovics, 2020; Xiang et al., 2021). Still, only 44 in the Web of Science (WoS) database collection have examined the effects of Covid-19 restrictions on public transport. Research by Meena & Sharma (2020) and Tóth et al. (2022) shows that since the pandemic, consumers have preferred to travel individually rather than by public transport. The study by Fumagalli et al. (2022) in Curitiba, Brazil, showed an 80% drop in public transport in March 2020, with 1,36 million daily passengers down to 200.000. In line with our present research, they also showed that this was partly due to the spread of the virus, but they also highlighted that it was partly due to strict measures such as cancelling more flights. However, they did not investigate the role of case numbers and measures in this decline. They found that 90% of passengers use the same route every day, given that a large proportion of the travelling public are commuters and students, and suggested that their travel habits should be studied to design ways and services that are convenient for them.

Proper scaling and scheduling to connect people's daily activities can bring more comfort and safety during the Covid-19 pandemic and give users more time synchronized with their routines. Luo et al. (2022) also came to this conclusion when studying public transport in New York. Based on the Covid-19 pandemic, they stated that a well-planned subway system in New York City could sustain 88% of transit flow while reducing the risk of disease transmission by 50% relative to fully-loaded public transit systems. Wang et al. (2022) analyzed the effects of government measures by comparing data from 121 countries on morbidity and mortality. They highlighted misguided measures and their consequences, focusing on public transport. They concluded that without public transportation closures, cases and deaths would have been reduced by 40% and 10%, respectively. In Japan, Murano et al. (2021) examined the impact of government measures in the context of public transport, but they looked at the effect on the spread of the virus, not the economics, as this study does. However, many of their conclusions align with the present study's findings. Their analysis highlights that, instead of strict lockdowns that might seriously damage the economy, milder travel restrictions could have a similar impact on controlling the domestic transmission of Covid-19 without devastating economic damage. Tirachini & Cats (2020) stated if public transportation is perceived as unsafe and unhealthy by large segments of the population, it will not be able to fulfill the societal roles that it is set to serve, including accessibility, sustainability, and equity. Our societies need public transportation services to prosper and to address key societal challenges that are paramount and persistent. It is therefore critical to avoid contributing to stereotyping the use of public transportation as unhealthy, which may outlive the pandemic itself and hinder the long-term prospects of public transportation services.

The results of the above studies, while different in approach, confirm that over-restrictive measures and closures impose more burdens on the economy than they bring benefits. In the present study, we examine this at the firm level, from the perspective of a public transport operator, by looking at the effects of Covid-19 measures.

3. Public transportation in Debrecen

The evolution of passenger numbers in the city of Debrecen also shows changes in the modal split at the European and national transport levels (Tóth et al., 2022). In the years preceding the pandemic, passenger numbers showed a slight increase due to the stability and improvements in service quality.

Nearly 100 million trips are made to the city each year. Commuters mainly use the services on their daily commute to work and school. In Debrecen, tourism has become increasingly important in recent years, so the number of ad-hoc trips is also significant. These passengers mainly buy one-way travel tickets or day tickets.

Thanks to its geographical location and role as an economic, educational and health centre, the city is a prime destination for daily commuters from the agglomeration and the surrounding cities. In addition to the travel tickets, these residents can buy supplement passes to accompany general passes.

The city's sales figures show that around 25% of fare revenue comes from travel tickets and 75% from passes. Within passes, combined general passes represent about 51%, discounted passes 36%, and supplement passes 13% (Fig. 2). The most significant number of passengers buying passes comprises workers and students, representing over 90% of total passes.

In addition to fare revenue, a significant share of revenue is represented by social policy fare subsidies, which are the supplementary fare for discounted passes and the subsidy for free travel.

Data from travel ticket and pass sales cannot always be linked to the actual use of the service. While the actual use time can be well determined for general passes and travel tickets, this cannot be reported for pre-purchase tickets. Tickets are sold through external partners in addition to service ticket offices, ticket vending machines and onboard points. These partners tend to stock larger quantities at a time, which may distort the time series derived from the sales data and the time series characterizing the use of fare products. Typically, they occur at the beginning and end of the year, but also continuously.

Travel tickets are used in local public transport for ad-hoc journeys, including tourists arriving in the city, but the less frequent traveller population buys these fare products. A segment of the population also mainly uses these services in combination with private transport, for example, people who use these means of transport to access the city centre less frequently, to do business or for entertainment. Many car users also park their cars in external nonpaying zones and use public transport to reach their destination due to the high parking tariffs in the city centre. A slight increase in the consumption of travel tickets is most noticeable in the summer months, which is to a lesser extent linked to the school holidays when students no longer travel daily.

However, more frequent, daily travellers will buy longer distance, unlimited-use fare products, e.g. (monthly/yearly) passes, after considering whether the network and the associated timetable service is an appropriate transport alternative to reach their destination. Seasonality can also be observed for these passes, as, for example, a significant part of annual holidays is spent in the summer and winter months, so fractional months are solved by using a travel ticket for a shorter period or ad hoc travel or even by other means of transport. Discounted passes also show a diverging trend during school and non-school periods, primarily reflecting the travel habits of students.

The long-term trend in selling discounted passes for pensioners is affected by the constantly decreasing number of people entitled, as the number of retirees under 65 is falling yearly.

4. Materials and Methods

4.1. Used databases

The sales records of the DKV for the period between 01.01.2020 and 31.12.2021 were provided by the company's sales department. The sales data were provided monthly, but in the case of the means of transport entitlement, we aggregated the data and created four main groups, as follows:

- The group of travel tickets include the following items: single advance tickets, single mobile tickets, a single ticket from the driver, a block of 11 tickets, small group tickets, one our mobile tickets, one-, three- and seven-day tickets, tickets for student groups and three-day family tickets.
- General passes include half-monthly, monthly, yearly, and transferable passes as a group rate.
- The following passes have been grouped under discounted passes: student monthly combined passes, pensioner monthly combined passes and passenger with young children pass.

- The supplement passes include the general monthly pass supplements and the student monthly pass supplements.

The groups representing each travel entitlement are based on the DKV recommendation.

Data related to the Covid-19 epidemic are from Worldometers.info (2022). Worldmeters' publisher is a small, independent, US-based digital media company, and the operating team is made up of developers, cadres and volunteers. Worldmeter's data on the outbreak is obtained from official government reports or indirectly from local media sources deemed reliable by the publisher. For our calculations of the outbreak data, we used the Active Case Rate indicator, which is calculated using the formula below:

The Active Cases = (total cases) - (total deaths) – (recovered)

so the active case figure represents the current number of people detected and confirmed to be infected with the virus. Data published on the Worldmeters.info website are daily. Sometimes, we must combine daily data and produce monthly statistics.

4.2. Correlation analysis and stochastic time series ARMA model

Pearson's correlation coefficient (1901) was used to test the correlation between the different means of providing transport entitlements.

The correlation between active caseloads and travel entitlements was performed using stochastic time series analysis. We chose this method because we had a relatively short time series with only 24 months of data. On the other hand, we believe that random effects and stresses on the process are built into the phenomenon and have a process-building role in the longer term. Time series that considers the role of chance, stochastic time series, started to become known in the 1970s. During this period, Box and Jenkins popularized the use of autoregressive integrated moving average (ARIMA) models (Bartholomew, 1971; Box & Tiao, 1975).

First, we examined the stationarity of the data series. For this, we used the Augmented Dickey-Fuller (ADF) test. The null hypothesis of this test is that the time series has a unit root, i.e. it is not stationary. Based on the ADF test, we obtained significant results for all travel entitlements; the null hypothesis was rejected, i.e. the processes are stationary. The stationary time series do not contain trend effects, and the time series values fluctuate around a constant mean value with a constant standard deviation. Stationary time series is also characterized by the temporal constancy of the autocorrelation coefficients of the time series, representing the internal relationships between the data of the time series. The values of the autocorrelation coefficients depend on the distance between variables, on lags, but not on time. The autocorrelation coefficients as a function of the lag are given by the autocorrelation function, also known as the correlogram.

In the theory and practice of time series analysis, autoregressive and moving average (ARMA) processes have gained significant importance since the 1970s because ARMA processes are mathematically tractable, and many of the random processes that occur in practice and follow stationary behaviour can be well approximated and described by them (Zdjelar et al., 2019). Stationary processes can be well-modelled with ARMA models. Such processes can be economical, biological, industrial, chemical and others. Thus, the use of ARMA processes is indeed wide-ranging.

In this model, the number of active cases can be included as a regressor. Its coefficient shows how Covid-19 affects the evolution of different travel entitlements. The indicator autoregressive (AR) indicates that the process can be described as a linear regression in its history. Furthermore, the moving average (MA) indicator expresses that the "error term" of the linear regression is the moving average of the white noise ε_t, i.e. the linear combination of the present and the finite past.

The first-order ARMA(1, 1) model with regressor (R) was of the following form:

$$y_t = C + \phi_1 y_{t-1} + \beta R_t + \epsilon_t + \theta_1 \epsilon_{t-1}$$

where:

$\mathbf{y_t}$ Amount of travel entitlement for the *t* time;

C Intercept;

$\boldsymbol{\varphi_1}$ Coefficient of the autoregressive term;

$\mathbf{y_{t-1}}$ Amount of travel entitlement for the *t-1* time;

$\boldsymbol{\beta_1}$ Coefficient of active caseloads;

$\mathbf{R_t}$ Active caseloads at *t* time;

$\boldsymbol{\varepsilon_t}$ Error at the *t* time;

θ_1 : Moving average coefficient;

$\boldsymbol{\varepsilon_{t-1}}$ Error term of *t-1* time.

5. Public transportation in Debrecen during the Covid-19 pandemic

In Hungary, and with it in Debrecen, public transport has been significantly affected by the government and municipal measures in the emergency. The measures taken in the context of the emergency declared in March 2020 significantly impacted passenger numbers and, thus, the revenue from passengers and the costs incurred to facilitate the protection. The measures that have had the most significant impact on public transport ridership are presented in Table 1.

The changes in travel patterns brought about by the virus, the measures taken, and the emergence of atypical employment and distance learning have significantly impacted travel demand and the development of paying passenger numbers. The public service operator in the city of Debrecen has also suffered a significant drop in demand for travel and, thus, a significant loss of revenue. In the first months of the pandemic, with the launch of distance learning, sales of student passes fell to 6%, but sales of general passes also fell to 40%. Ad-hoc travel also dropped sharply, with ticket volumes below 13% in the first month of the pandemic.

Table 1
Government's restrictive measures during the Covid-19 pandemic

Measure	Begin	End	Government decision number
Remote learning I.	16 March 2020	15 June 2020	1102/2020 (Ministry of Justice, 2020c)
Curfew I.	28 March 2020	30 April 2020	71/2020 (Ministry of Justice, 2020a)
Wearing mask I.	01 May 2020	26 June 2021	168/2020 (Ministry of Justice, 2020e)
Free travel entitlement	01 April 2020	30 June 2022	486/2020 (Ministry of Justice, 2020f)
Free parking I.	06 April 2020	17 June 2020	87/2020 (Ministry of Justice, 2020d)
Curfew II.	04 November 2020	21 May 2021	479/2020 (Ministry of Justice, 2020h)
Free parking II.	04 November 2020	21 May 2021	478/2020 (Ministry of Justice, 2020i) and 512/2020 (Ministry of Justice, 2020g)
Remote learning II.	10 November 2020	10 May 2021	at the individual discretion of educational institutions
Wearing mask II.	21 November 2021	07 March 2022	597/2021 (Ministry of Justice, 2021)
Source: Own data collection and editing			

Several waves of the Covid-19 epidemic can be distinguished in Hungary, the periods shown in Table 2. The identification of each wave is based on the current active case numbers.

Table 2
Covid-19 pandemic waves in Hungary

	Begin	End
Wave 1	04 March 2020	17 July 2020
Wave 2	18 July 2020	16 February 2021
Wave 3	17 February 2021	02 September 2021
Wave 4	03 September 2021	04 January 2022
Wave 5	05 January 2022	22 June 2022
Wave 6	23 June 2022	currently
Source: Own editing based on Worldometer's (Worldometers.info, 2022) data		

During the pandemic wave and to adapt to the measures, several timetable changes had to be made while the service remained in operation. Driver ticket sales were suspended, and contactless purchase options were introduced, which also required service improvements in the city. During the second wave, increasing the proportion of articulated vehicles with a higher capacity was necessary to ensure adequate passenger spacing. The continuous daily disinfection of vehicles and public spaces also increased operator costs.

Combining the evolution of the active case numbers and the restrictive measures the government took, we get the following very suggestive graph (Fig. 3). The first wave of the epidemic is barely noticeable on the graph, but each subsequent wave is much more pronounced. It is also clear that the measures more specific to public transport, such as distance learning, curfew, and parking fees, were introduced almost simultaneously. These measures were repealed before the first wave (17 July 2020), even though the active caseload was no less than when the measures were introduced (Table 1). The second and third waves are not distinctly different, with curfews, free parking and distance learning being reintroduced during their duration.

It should be noted that distance learning does not affect all students, only those in secondary and higher education (Zeng & Zhang, 2019). The above measures will expire in May 2021, well before the end of the third wave (02 September 2021). The fourth and fifth waves will not be sharply different, but during this period, the only daily restrictions that public transport users will face will be wearing masks.

However, we highlighted a crucial moment in (Fig. 3) – 26.12.2020, marking the start of vaccination against Covid-19 uniformly in the EU countries. Our graph shows that the start of vaccination in Hungary coincides with the peak of the second wave.

6. Results

6.1. Correlation matrix

Correlation analysis aims to determine the extent to which entitlements for each mode of transport change simultaneously. The correlation coefficients are significant in all cases, with positive, medium and high

relationships between variables. We find higher correlation coefficients between the long-distance and unlimited-use fare products, with a strong relationship (0.795) for the General and Discounted passes. A solid dependent relationship for the General passes, the supplement passes, the Discount passes, and the supplement passes, with correlation coefficients above 0.9. The correlation coefficient between ticket-type vouchers and any fare product providing unlimited use over a more extended period shows a medium strength, typically between 0.48 and 0.57 (Table 3). The results of the correlation study in the transport professional context show that no strong relationship exists between the evolution of sales volumes of ad-hoc travel tickets and frequent travel passes.
Table 3: Pearson's correlation

	Tickets	*General passes*	*Discounted passes*	*Supplement passes*
Tickets	1			
General passes	0,486690357	1		
Discounted passes	0,566551282	0,794566473	1	
Supplement passes	0,497160484	0,900797812	0,959727311	1

Source: Own editing

The relationship between general and discounted passes is also not correlated, primarily because students did not purchase travel entitlements during the period under study because of the multiple distance learning restrictions, while the restrictions for the working population were lower, resulting in less change in their travel habits and options. The dependency between Supplement and General passes is because many supplement pass users are commuters from rural areas. Students who bought supplement passes during this period could travel to the county centre to access health and other services, despite distance learning.

6.2. ARMA model

We used the ARMA model to investigate how the evolution of different travel entitlements is influenced by the rate/shape of active case numbers during the epidemic. To conduct the study, we examined each travel entitlement separately.

6.2.1. Analysis of the correlation between travel ticket sales and active cases

There was a sharp drop in ad-hoc travel of almost 90% in the first period of the pandemic. In Fig. 4, we have graphically depicted the evolution of ticket types and active case numbers by month for 2020 to 2021. The graph shows the duration of each Covid-19 wave and the trends in ticket sales over this period. However, it is not suitable to establish a clear correlation between whether the trend in active caseloads is due to a decrease in ticket sales or other external influences. In our case, by external influence, we mean the government measures listed in Table 1.

Applying the first-order ARMA(1,1) model to the time series of travel ticket sales and active case numbers, the parameters given in Table 4 are obtained.

Table 4
Parameters of the ARMA(1,1) model describing the effect of Active cases on Travel ticket sales in Debrecen, Hungary

Coefficient	Estimate	Standard error	t value	Pr (>|t|)[1]
Intercept	172138,927	24398,210	7,06	< 0,0001*
ϕ_1	0,603	0,206	2,93	0,0083 *
β_1	-0,199	0,127	-1,56	0,1333
θ_1	0,390	0,170	2,29	0,0328*

1 * significance level P < 0.05 (dup: 6 ?)

Source: Own calculations

The most important is the value of the coefficient β_1. As shown in Table 4, the coefficient is negative (β_1 = -0,199), indicating an opposite shift in travel ticket sales and active caseload evolution. However, the coefficient is not significant, as Pr is greater than 5%, so the working hypothesis H_1 could not be confirmed. In conclusion, active case numbers did not affect travel ticket sales during the Covid-19 outbreak.

There was a significant drop in travel ticket sales in the first months of the first wave of the pandemic, which is certainly related to the fact that several government measures during this period resulted in a significant reduction in the use of community facilities. People feared a greater risk of infection in the confined spaces of public vehicles and preferred to use private transport. With the gradual lifting of restrictions, a more significant increase in travel ticket volumes was observed after the first, second, third and fourth waves, which occurred close together in time, peaked. The pandemic has led to a change in travel habits, with a return to greater use of public transport, albeit on an ad hoc basis. With the lifting of restrictions, domestic tourism also resumed, bringing occasional visitors and passengers to the city.

6.2.2. Analysis of the correlation between general pass sales and active cases

The pandemic has also brought about significant changes in travel patterns in this segment. The spread of atypical forms of employment has reduced daily commuting, and the lack of comfort for passengers in public transport has led to a preference for individual transport to reach their destination. Similar fluctuations can be observed for the general pass in the first wave, but there were no increases in magnitude after the subsequent waves (Fig. 5). The general passes are mainly used by employees who are not eligible for discounted passes, usually for frequent travel, even several times a day. This group is most likely to be able to afford to maintain and even use their vehicle daily, thus requiring more time for them to return to public transport.

Applying the first-order ARMA(1,1) model to the time series of general passes and active caseloads, the parameters given in Table 5 are obtained.

Table 5
Parameters of the ARMA(1,1) model describing the effect of Active cases on the General pass sales in Debrecen, Hungary

Coefficient	Estimate	Standard error	t value	Pr (>|t|)[1]
Intercept	13486,750	1761,697	7,66	< 0,0001*
ϕ_1	0,635	0,2691	2,36	0,0285 *
β_1	-0,005	0,0107	-0,49	0,6296
θ_1	0,067	0,2371	0,28	0,7795

1 * significance level P < 0.05

Source: Own calculations

The coefficient β is also negative for general rents. Although it is very low (-0.005), it is not significant in this case, so we cannot confirm working hypothesis H_2. In this case, our conclusion is that the number of active cases did not influence the sales of general passes.

6.2.3. Analysis of the correlation between discounted pass sales and active cases

Several factors also influenced the development of discounted passes. Mandated remote learning is reflected in the declining number of student pass sales, with the biggest drop in this case also being caused by the first wave, with a significant "bounce back" in 2020 at the start of school in September (Fig. 6). The trend was quickly broken by the new measures taken in November, with volumes remaining low until the end of the school year due to remote learning. With the fourth wave, remote learning was not mandated, and sales resumed upward until winter break. The decline in December is due to the usual seasonal effect when a large part of the population travels by ticket or other means of transport because of the holidays.

The discounted passes also include passengers under 65 who are already retired. In their case, the fear of viral infection may have been the main factor influencing the change in travel habits.

Applying the first-order ARMA(1,1) model to the time series of discounted passes and active caseloads, the parameters in Table 6 are obtained.

Table 6
Parameters of the ARMA(1,1) model describing the effect of Active cases on the Discounted pass sales in Debrecen, Hungary

Coefficient	Estimate	Standard error	t value	Pr (>|t|)[1]
Intercept	16382,925	2604,826	6,29	< 0,0001*
ϕ_1	0,457	0,259	1,76	0,0932
β_1	-0,016	0,018	-0,87	0,3968
θ_1	0,307	0,264	1,16	0,2578

1 * significance level P < 0.05

Source: Own calculations

The coefficient β is also negative in the case of concessionary season tickets. Although low (-0.016), it is not significant, so we cannot confirm working hypothesis H_3. In this case, we conclude that the active caseload did not influence discounted pass sales.

6.2.4. Analysis of the correlation between supplement pass sales and active cases

When examining the trend in the number of supplement passes, it can be seen that the trend is similar to that of discounted passes (Fig. 7). After a significant recovery following the first wave, there was a significant decline during the second and third waves. The decline was also due to the introduction of remote learning. In the fourth wave, as with the discounted pass type, a larger volume increase was observed due to the normal schooling regime. A smaller increase reduces the spike intensity in sales of supplement passes for employees. The seasonal decline at the end of the year can also be observed for this type of pass.
Applying the first-order ARMA(1,1) model to the time series of supplement pass sales and active caseloads, we obtain the parameters in Table 7.

Table 7
Parameters of the ARMA(1,1) model describing the effect of Active cases on the Supplement pass sales in Debrecen, Hungary

Coefficient	Estimate	Standard error	t value	Pr (>|t|)[1]
Intercept	5812,682	909,627	6,39	< 0,0001*
ϕ_1	0,484	0,266	1,82	0,0840
β_1	-0,054	0,007	-0,83	0,4193
θ_1	0,2083	0,253	0,82	0,4199

1 * significance level P < 0.05

Source: Own calculations

The coefficient β for the supplement passes are also negative, very low (-0.054), but not significant, so we cannot confirm working hypothesis H_4. In this case, our conclusion is that active caseloads did not influence the sales of supplement passes.

7. Discussion and conclusion

The emergence and spread of the Covid-19 virus have changed our lives dramatically, affecting our daily lives in several distinct waves of active cases (Fig. 3). In Hungary, government measures to control and slow the spread of the virus have affected our mobility patterns in the city of Debrecen. The analysis showed that most measures affecting public transport were taken during the first two waves regarding their number and restrictive effect. These included the introduction of remote learning, curfews and free parking. The mandatory use of masks and distance control has further increased the minimization of the use of public spaces. Travel habits changed radically during this period, with the fear of contamination by the virus making private transport the preferred form of mobility for the population.

However, the ARMA model results show that the evolution of active caseloads did not influence the evolution of sales volumes. All of our hypotheses, whether logical or evident, had to be rejected.

Many factors may have influenced the decline in demand for public transport, but this study only examined government action as an objective factor. The Oxford Coronavirus Government Response Tracker (Hale et al., 2021) scored countries based on governmental stringency measures, with Hungary's stringency (Fig. 8) index ranking among the most stringent throughout the pandemic.

Source: Hale et al. (2021)

Of the two impact factors examined, the number of active cases had a minor impact on the decline in ticket and pass sales, while government measures had a more significant impact.

Our analysis, although different in approach, confirms the studies by Meena & Sharma (2020), as well as Tóth et al. (2022), Fumagalli et al. (2022) and Wang et al. (2022), where these authors highlight that strict restriction that severely damages the economy are not essential to control the spread of Covid-19. Stochastic, i.e. probabilistic, systems can be modelled using random walk models, even if these phenomena are not necessarily random. Such or similar correlations exist in the field of Covid-19 evolution. The stochastic random walk process leads to the best solution in systems for which we do not know how it works (Malkiel, 2007). We assume that the economic disadvantages of direct intervention are more significant for DKV than if there had been no governmental-municipal restrictive action. In contrast to the sudden and significant negative impact on the transport sector at the onset of the virus, the reversal of travel patterns during the pandemic is likely to be a long process, lasting several years.

The DKV has had to take several forced steps to ensure the sustainability of the service. To adapt to changes in travel demand, it has had to adjust its capacity, sometimes by reducing the number of timetables and increasing them. Unfortunately, these measures have led to an even more unfortunate shift away from public transport. The effects of these measures can still be felt today in the travel habits of the city of Debrecen and the proportion of people using public transport because travel habits have shifted towards individual modes of transport (Bittner et al., 2023; Tóth et al., 2022). To encourage people to choose public transport again, it is necessary to rationalize timetables and improve service quality.

A significant challenge for public transport operators in the coming period will be to attract people back from private transport to public transport. To achieve this as soon as possible, continuous service improvement is necessary to ensure that public transport offers people a suitable mobility alternative regarding journey time and comfort.

Limitations and further research directions

The present research only examines the relationship between active caseloads, travel entitlements sold and government measures, not other factors influencing travel. The conclusions drawn are valid only for the region under study.

In the future, the impact of the measures and Covid-19 on public transport should be further investigated, and the results used to help decision-makers to reorient travel demand towards public transport.

Declarations

Authors The authors confirm that neither the manuscript nor any part of its content is currently under consideration or published in another journal.

Authors have no financial or non-financial interests that are directly or indirectly related to the work submitted for publication.

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Figures

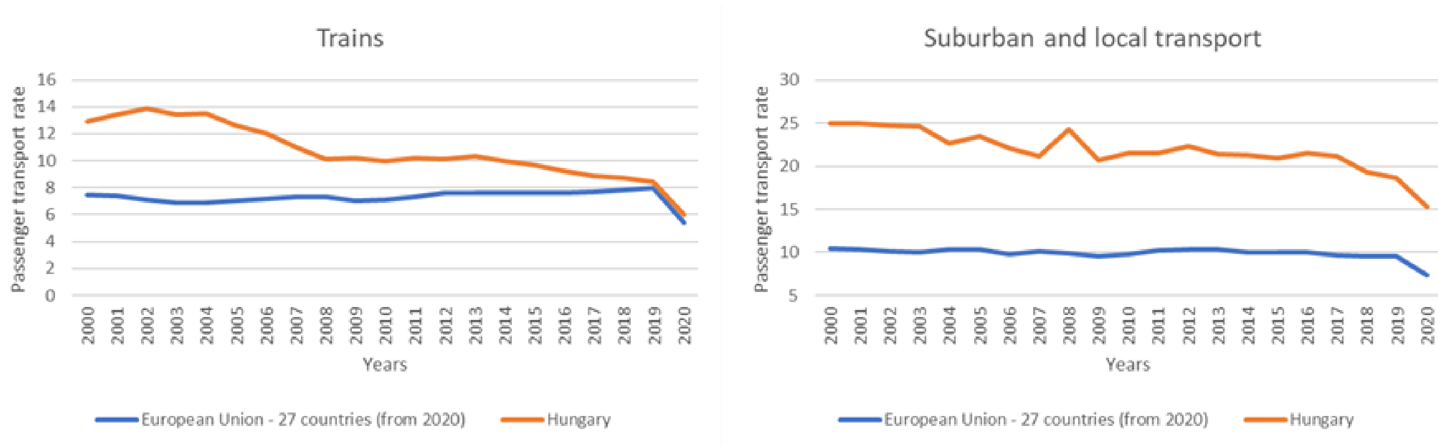

Figure 1

The percentage share of modal split transportation

Source: Own editing based on the Eurostat database (European Commission, 2022)

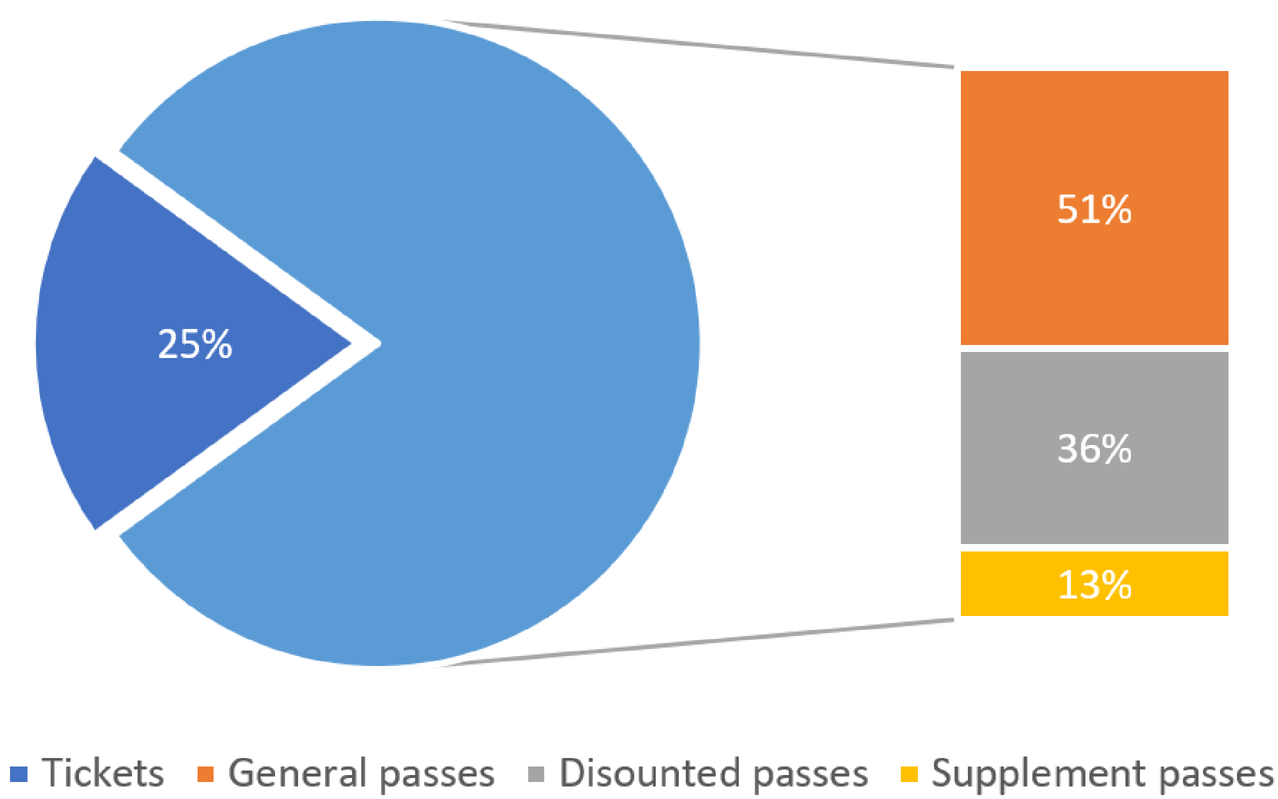

Figure 2

Distribution of fare revenues

Source: Own editing

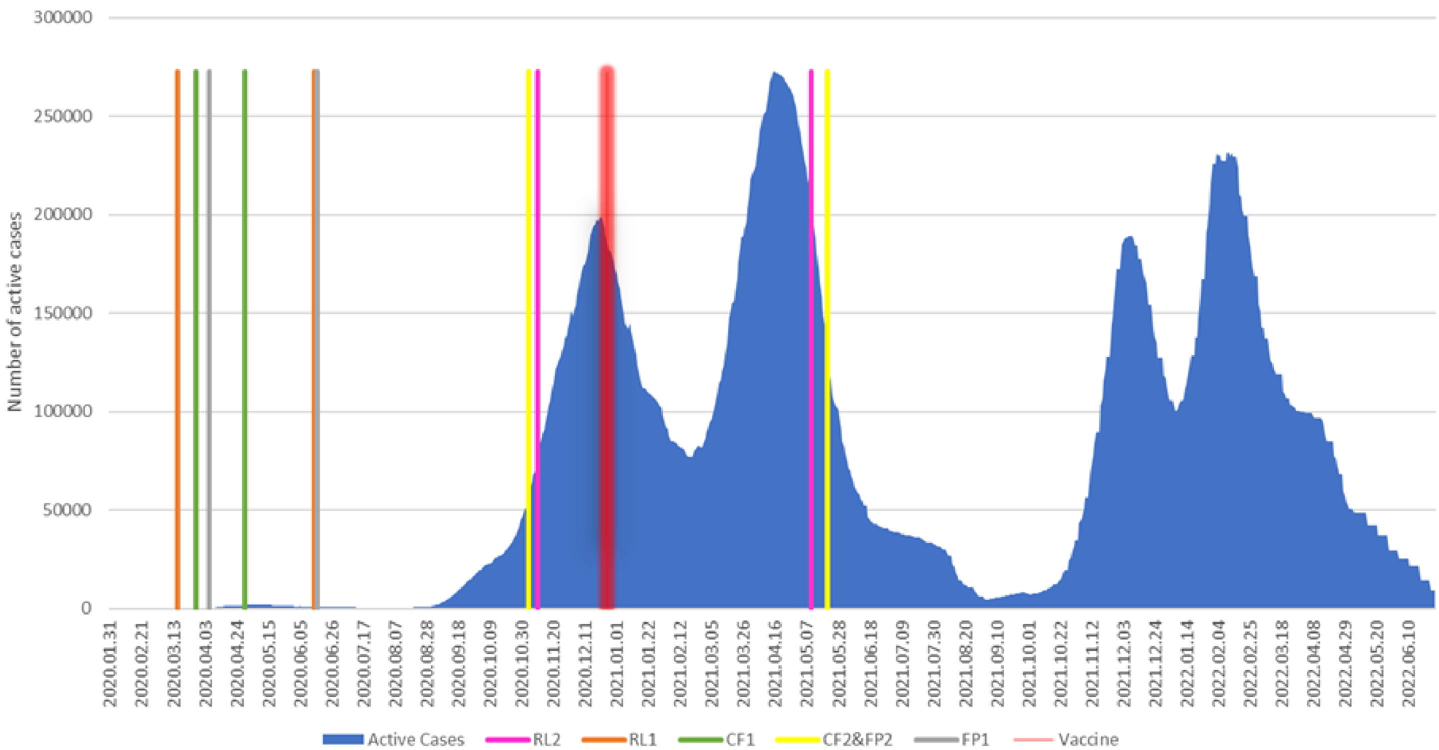

Figure 3

Trends in active caseloads and various restrictive measures

Source: Own editing based on Worldometer's (2022) data and authors' data collection

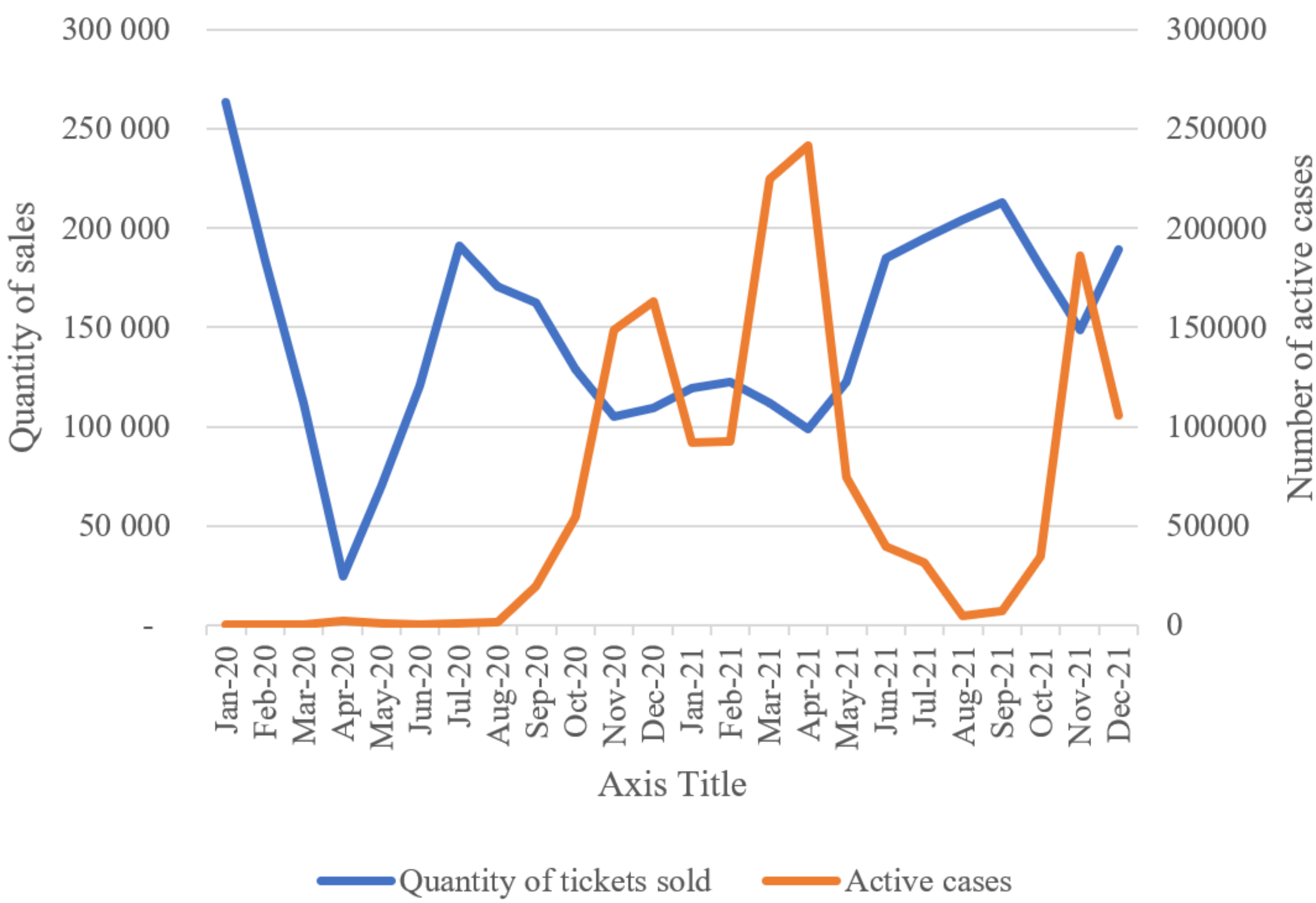

Figure 4

Travel ticket sales and evolution of active cases between 2020 - 2021

Source: Own editing

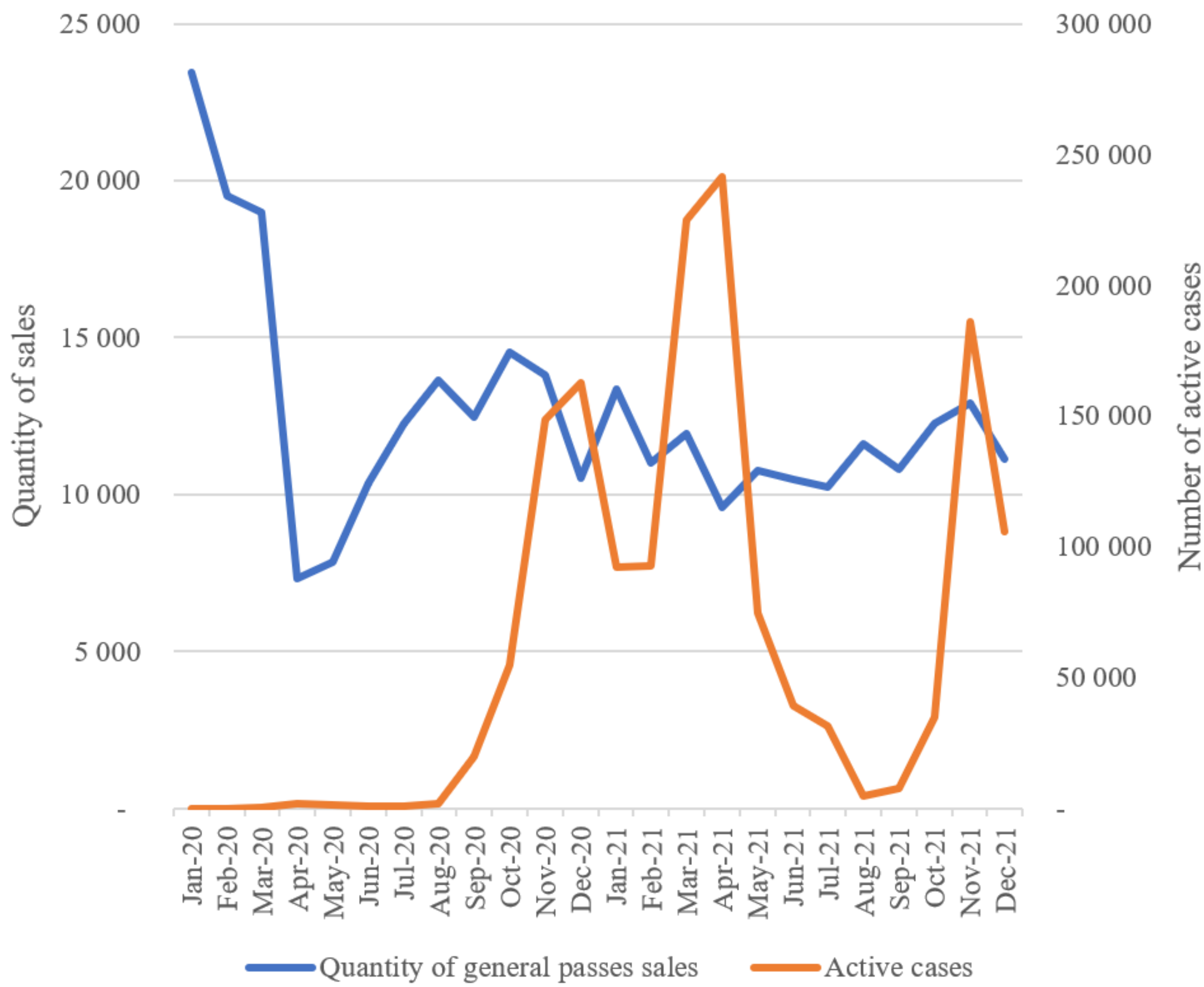

Figure 5

General pass sales and evolution of active cases between 2020 - 2021

Source: Own editing

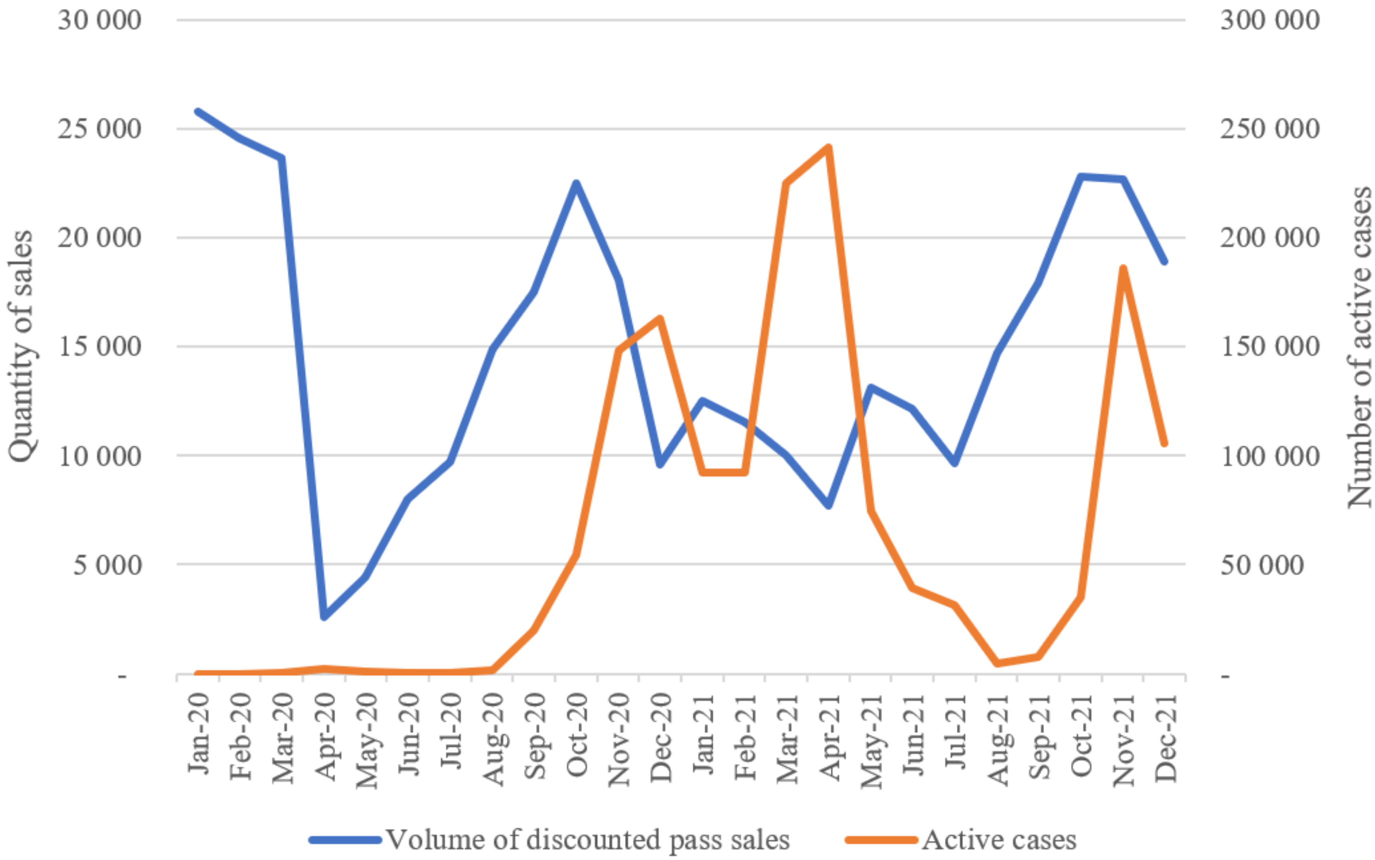

Figure 6

Discounted pass sales and evolution of active cases between 2020 – 2021

Source: Own editing

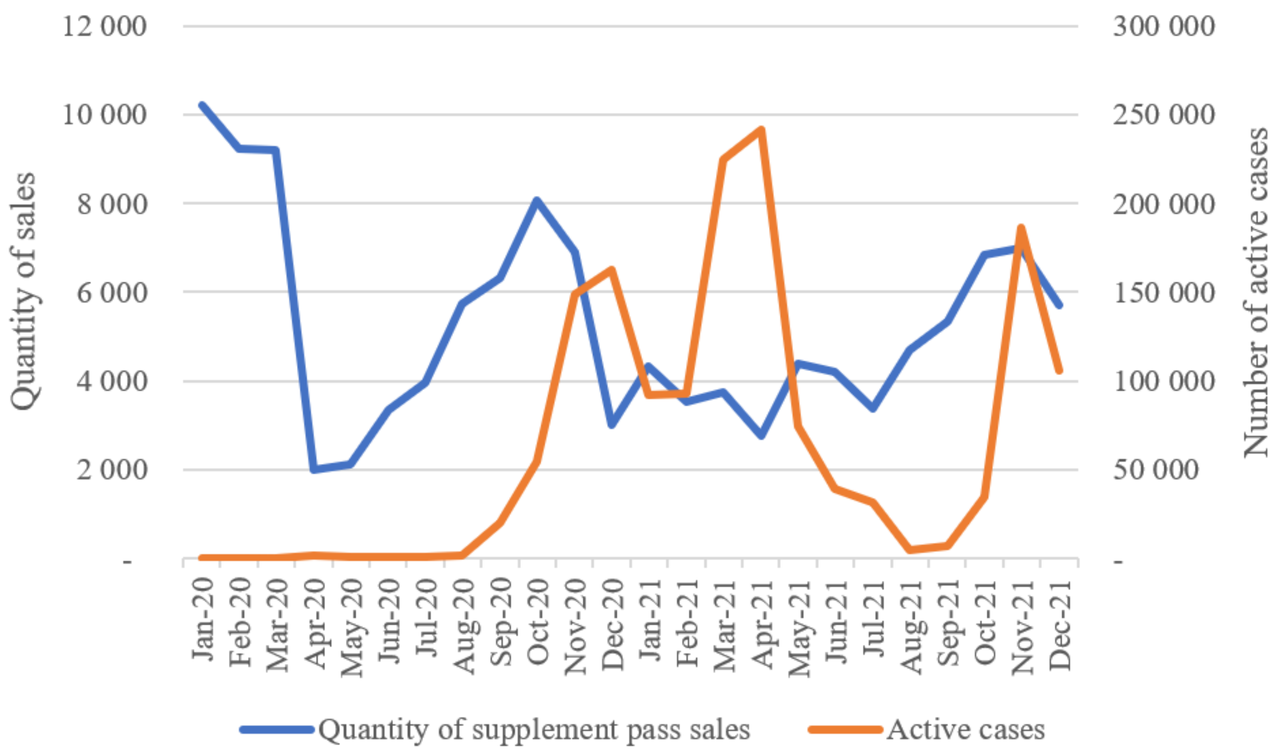

Figure 7

Supplement pass sales and evolution of active cases between 2020 - 2021

Source: Own editing

Figure 8

Covid-19 stringency index in Hungary

Source: Hale et al. (2021)