The Impact of Non-Pharmaceutical Interventions on the Growth Rate of New COVID-19 Cases: Evidence From Kazakhstan and Kyrgyzstan.

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The Impact of Non-Pharmaceutical Interventions on the Growth Rate of New COVID-19 Cases: Evidence from Kazakhstan and Kyrgyzstan.

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Abstract

Background: This article explores the effects of non-pharmaceutical interventions (NPIs also know as quarantine restrictions) on the reduction of the growth rate in new COVID-19 cases in Kazakhstan and Kyrgyzstan. It turns out that empirically NPIs gradually reduce the growth rate of new cases. This is theoretically backed by an epidemic growth model shown in the paper. Once this growth rate turns negative, it is only then that the actual levels of new cases begin to fall.

Methods: The growth rate of new cases is regressed on NPIs. The contribution of NPIs is estimated via ordinary least squares. The paper is unique in that it uses the growth rate as the main dependent variable.

Results: The regression results are able determine the impact of particular NPIs on the growth rate of new cases. In turns out that all types of NPIs are effective in reducing the growth rate.

Conclusions: Interesting enough, comparing the results for the two countries, it appears that in the summer the partial-lockdown in Kyrgyzstan was just as effective as the full lockdown in Kazakhstan at reducing the growth rate. Therefore as a policy recommendation, and to avoid the economic impact of a full lockdown, these countries should stick with partial lockdowns. Lastly, a conservative counterfactual scenario indicates that total cases for 2020 would be 50% to 100% higher had the countries not imposed NPIs.

Section 1: Introduction

Like many countries around the world the COVID-19 pandemic has taken its toll on the Central Asian countries of Kazakhstan and Kyrgyzstan. By the end of 2020, Kazakhstan had officially over 150,000 cases and 2200 deaths while Kyrgyzstan had over 80,000 cases and 1300 deaths.[1] To stop the spread of the virus both countries imposed various non-pharmaceutical interventions (NPIs also known as quarantine restrictions). The goal of this research is to evaluate the impact of these various NPIs on the spread of the virus. Figure 1 shows the natural log of new cases from May to December 2020. As can be seen both countries are very similar and have very similar trends in the number of new cases.

Kazakhstan had a full lockdown from July 5th until August 16th, and zoning restrictions from October 24th onwards, while Kyrgyzstan had a partial lockdown between July 1st and August 15th and further restrictions from September 28th. The vertical bars represent these restrictions. The trend line is the Hodrick-Prescott (HP) filter used to smooth the series. At a first glance it appears that the measures taken did not really influence the number of new cases, at least initially. Although both countries entered lockdown in the beginning of July new cases peaked around July 20th. Further, their lockdowns ended mid-August but new cases continued to decline until mid September. Kyrgyzstan imposed further restrictions late September but its new cases did not start decreasing until the beginning of November. Kazakhstan also imposed zoning restrictions late October but its cases continued to increase.

From the perspective of new cases it does not appear that the restriction measures taken were effective. This research posits that these restriction measures do in fact influence new cases but not by their level but rather by their growth rate. In particular it is argued that they gradually reduce the growth rate of new cases; the growth rate eventually turns negative and that is when the reduction in the levels of new cases actually occurs. Theoretically, in the context of epidemiological models, it is argued that the growth rate of new cases is related to the reproduction number and that is what is gradually reduced during NPIs.

To compute the growth rate of new cases the trend line from the levels time series in Figure 1 is first differenced daily. Along with this growth rate computed from trend is a 2 week moving average of the actual daily growth rates. The results are shown in Figure 2. Both countries had strict lockdowns from late March until mid May.[2] From Figure 2, the growth rate increased in June for both countries and

[1] https://www.worldometers.info/

[2] This paper does not analyze this first lockdown as its time series was even more volatile with lower number of cases and many missing daily observations.

peaked around 10 days prior to the second lockdown. The growth rate then started slowing; as shown in the next section this is perhaps due to lack of testing kits and lockdown announcements in the end of June thus giving the population extra caution. After the lockdown implementations in the beginning of July, the growth rates continued to decrease until the end of the lockdown in mid -August and began increase again afterwards. The increase continued until a few days after the countries' respective third wave of restrictions in September 28, and October 24; a few days after the imposition of these the growth rate began to gradually decrease again. Overall it appears that the restrictions fit much better with the growth rates rather than the levels series.

The existing literature modeling the effect of NPIs mostly contains two types of papers; either more empirical or more theoretical.

The empirical literature studies the impact of NPIs on the number of cases (new, total, or deaths). Some studies use a negative binomial regression to regress the number of cases on NPIs; see Chaudhry et al. (2020) and Ajide et al. (2020). Other studies fit trends to existing data and show that new cases took 2 to 4 weeks to start decreasing after NPIs for Italy and Spain; see Timelli and Girardi (2020) and Siqueira et al. (2020). Lastly Alfano and Ercolano (2020) uses OLS panel fixed effects to regress NPIs on new cases in a cross country study. The results again indicate that new cases for Europe start to decrease roughly three weeks after NPIs have been imposed. Intuition would imply that NPIs should reduce the number of new cases if they drastically reduce the reproduction number and quickly turn their growth rate negative. However, there is a significant lag. This paper argues that the lag occurs because NPIs gradually reduce the growth rate and it might take a few weeks until it turns negative. It might even be even possible that growth never reaches a negative territory. In this case the restrictions are indeed effective, but the amount of growth reduction only slows down the increase of new cases.

The theoretical literature on the other hand uses epidemiological growth models to study the number of cases. See for example Flaxman et al. (2020), Roques et al. (2020), Lai et al. (2020), and Hyafil and Morina (2020). This literature posits that the infection behavior can be represented in some form of a compartmental model: SEIRD (susceptible, exposed, infected, recovered, dead). The model is typically a system of differential equations and consists of epidemiological parameters (like the infectious period, the contact rate, the reproductive number, and death rate). To solve the model for the type of cases the parameters are either estimated from real world data (generally by Bayesian estimation) or imposed. Although these models are meant to simulate different types of cases (susceptible, exposed, infected, recovered, dead), they don't provide theory as to how quarantine restrictions should affect these cases.

In general the authors either estimate the model during the period of restrictions and compare to a period prior, or incorporate a time varying parameter with an indicator function representing quarantine dates. Both of these ways imply that quarantine reduces the reproduction number immediately and not gradually. This implies that new cases should immediately decrease, but this is not seen in the data.

The modeling approach taken in this paper is empirical with a theoretical drive. It fits a regression model that studies the impact of the NPIs on the growth rate of new cases. It argues that that NPIs decrease the reproductive number which leads to a reduction in the growth rate but lets the data decide how this reduction is done. It thus empirically models the growth rate as the dependent variable of interest but the model is not as restrictive as the system of differential equations used in the theoretical literature.

The rest of the paper is organized as follows: Section 2 provides a summary of the NPIs used in Kazakhstan and Kyrgyzstan. Section 3 fits an empirical model to the data. The model evaluates the daily effect of NPI on the growth rate of new cases. The section also explores a counterfactual scenario where NPIs did not occur. The result is a drastic increase in new cases. Section 4 discusses the results. Lastly section 5 concludes. The figures and tables are at the end. The appendix provides an explanation as to why NPIs would decrease the growth rate in new cases. It uses a simple epidemiological growth model that shows how the reproduction number (and its contact rate component) is linked with the growth rate in new cases.

Section 2: NPIs in Kazakhstan and Kyrgyzstan

Both Kazakhstan and Kyrgyzstan registered their first Covid-19 cases around the same dates in March 2020. On March 13, two Kazakh citizens were tested positive on their return from Germany, whereas Kyrgyzstan officially acknowledged positive coronavirus cases in the country on March 18. In Kazakhstan, President Tokayev immediately declared a countrywide state of emergency effective from March 16 (Presidential Decree 2020). The government created a State Commission responsible for ensuring the state of emergency and coordinating the fight against Covid-19 in the country. As for Kyrgyzstan, a countrywide state of emergency was introduced on March 22 (Azattyk 2020a, 2020b). Moreover, on March 25, President Jeenbekov announced an even more restrictive regime with curfews in Bishkek, The content of preventive measures under a state of emergency was largely similar in Kazakhstan and Kyrgyzstan. *The first group of measures* related to a restriction of people's movement. First of all, both countries restricted cross-border movement for citizens as well as for foreigners, except for the personnel of diplomatic services. Operation of public transportation, access to public spaces, and organization of public events and large family gatherings were limited or fully prohibited in both countries. These measures significantly restricted people's movement internally. *The second group of measures* restricted the functioning of business objects. The activities of trade and shopping centers, entertainment objects, cinemas and theaters, and etc. were suspended in both countries. Cafes and restaurants were allowed to work for delivery only. Only essential businesses like groceries and pharmacies continued operating during fixed working hours. *Finally, the third group of preventive steps* related to sanitary and anti-epidemic measures, including disinfection of streets and buildings, installation of hand sanitizers and temperature checks in public places, as well as obliging people to maintain social distance and wear masks.

Although the state of emergency was initially introduced for one month only, it lasted until May 10 and May 11 in Kyrgyzstan and Kazakhstan, respectively, when the governments of these countries started gradually easing some of the restrictions. For instance, a limited number of internal flights and train/bus connections resumed; parks and squares became accessible for people; and some business objects including open-air markets, non-food stores, and cafes and restaurants partially renewed their work (Resolution of the Chief Sanitary Doctor 2020a; Governmental Decree 2020).

With the easing of quarantine restrictions, Kazakhstan and Kyrgyzstan witnessed a surge in the growth rate of coronavirus cases from late May and early June. The situation became critical in the second half of June with shortages in hospital-beds, lack of medical equipment and testing kits, and long queues in pharmacies (Azattyk 2020c; Kloop 2020).

The growth rate in Kyrgyzstan reached its peak on June 22, whereas Kazakhstan registered the highest growth rate on June 26. After these dates, we see the decline in the growth rate despite the fact that new restrictions in both countries were introduced in early July only. This decline in growth rate before the introduction of new restrictions could possibly be explained by the serious shortage of Covid-19 testing-kits observed in Kazakhstan and Kyrgyzstan in the last weeks of June and early July. For example, two biggest private laboratories in Kazakhstan suspended a coronavirus PCR testing on June 18 (Azattyk 2020g). On June 23, the Chief Sanitary Doctor of the country officially recognized the shortage of testing-kits, and asked people to take a test only if they had Covid-19 symptoms (Sputnik 2020d). A similarly difficult situation with PCR tests for Covid-19 was reported from Kyrgyzstan too (Vlast 2020; Knews 2020).

Another reason for the decline in growth rates before the beginning of summer lockdowns was perhaps extra caution exercised by the public. In particular for Kazakhstan starting on June 26th, some regions started to impose restrictions (Zhuravleva 2020a). In the context of such an alarming situation, on June 29, President Tokayev of Kazakhstan criticized the government for its failure to tackle the spread of Covid-19, and ordered to prepare a proposal on the re-introduction of strict lockdown in the country, despite its sensitivity for the economy (Tokayev 2020). The second countrywide lockdown in Kazakhstan started on July 5 and lasted until August 16. It implied that the government had to return again some of the restrictions applied in March-May. Yet, compared to the first lockdown, now people were given access to parks and squares, and some business objects were allowed to function with certain restrictions (Resolution of the Chief Sanitary Doctor 2020b).

Starting on June 22nd Kyrgyzstan reached over 205 new cases, the highest since the begging of the pandemic; at the same time people were unable to reach the call center (Azattyk 2020d). Unlike in Kazakhstan, government officials in Kyrgyzstan refused to go to a countrywide lockdown again despite the seriousness of the situation. On June 30, President Jeenbekov stated that not only the well-being of citizens but also the economy of the country was important (Azattyk 2020e). As a result, there was no full lockdown in Kyrgyzstan during the summer of 2020, and many business objects remained operational, though with certain quarantine regulations and curfews. Only targeted additional restrictions were introduced in cities such as Bishkek and Osh in early July, where the most severe situation was observed. For instance, working hours for business objects such as restaurants, cafes, supermarkets, and open-air markets were shortened in these cities (Sputnik 2020a, 2020b). Restrictions also applied to public transportation.

Table 1 compares the summer lockdowns for both countries. They lasted until mid-August, when the situation in both countries stabilized. The governments then again started gradually removing some of the restrictions. For example, Kyrgyzstan expanded working hours for some business objects and opened its borders for citizens of several countries starting from mid-August. Similarly, Kazakhstan allowed the work of some business types with strict precursory measures, resumed the operation of public transport with restrictions on weekends, and recommenced international flights in several directions.

During the fall of 2020, the situation in both Kazakhstan and Kyrgyzstan still remained unstable, yet, relatively better compared to the summer period. Given the increase in the number of registered Covid-19 cases in September-November, some experts even predicted the second wave of the pandemic in these countries (Tengrinews 2020; Azattyk 2020f). In this context, the governments did not rush to announce new country-wide restrictions given their sensitivity to the economy. Instead, a more targeted approach was adopted, meaning that the response was more local and targeted at only those cities and regions, which witnessed a significantly worsening situation. For instance, Kyrgyzstan introduced localized restrictions in the Batken region from September 28, including the suspension of public transportation and more control over the mask regime and social distancing (Republican Operational Headquarters 2020). The government in Kazakhstan was more reactive to the aggravation of the situation during the fall period. Starting from mid-October, regional Chief Sanitary Doctors in several regions of the country had to announce new restrictions due to the increasing number of coronavirus cases. From October 21-24th, the Ministry of Healthcare introduced the zoning system with green, yellow, and red zones and respective restrictions for each zone (Sputnik 2020c). On October 24th Nursultan, the capital of Kazakhstan was added to the restriction zone (Zhuravleva 2020b).

Since then, the kind of restrictions to be introduced depends on in which zone a particular city/region is. During November-December, several regions, mostly in Northern, Eastern, and Western parts of the country, appeared in the red zone, but then successfully returned to the yellow and green zones. Although state officials reiterated the possibility of announcing another state of emergency in the country, in practice, the restrictions introduced during the fall period appeared to be much softer, and mostly related to the limiting of working hours for both the public and private sectors; restricting a number of visitors for business objects; restrictions during weekends, including for the public transportation; and also stricter control over the mask regime and social distancing. In other words, compared to the summer period, the fall restrictions in both Kazakhstan and Kyrgyzstan did not significantly paralyze the operation of businesses, the public sector, as well as people's movement.

Despite a still alarming situation, both Kazakhstan and Kyrgyzstan tried to lift the restrictions sooner than later where it was possible given their high economic cost. Kyrgyzstan, for instance, allowed the opening of cinemas, food-courts, and computer clubs in Bishkek from December 1, as well as lifted restrictions for foreigners coming to the country from December 4. Also, kindergartens and schools opened doors to students of certain grades in Bishkek in the second half of January 2021. Similarly, Kazakhstan re-opened cinemas and some other business objects in those regions/cities with a stable epidemiological situation. Also, schools were allowed to function in a combined format, again, depending on the situation in a particular city or region. All these and other similar easing of restrictions led to another increase in the number of infected cases in March 2021, especially in Kazakhstan. See Sputnik (2021a), Sputnik (2021b), and Resolution (2021).

Section 3: Methods and Results

The goal of this section is to quantize the results from the graphs. It first builds an empirical model which gives estimates for the daily impact of the NPIs on the reduction of the growth rate in new cases. It then shows that the model can reasonably predict the growth rate and the level of new cases. Lastly a thought experiment is done that shows how new cases would have evolved had NPIs not occurred.

3.1 Empirical Model

As seen from the graphs, and as derived from theory (in the appendix) it appears that the quarantine restrictions are able to gradually decrease the growth rate of new cases g. In this case the change in the growth rate (the acceleration) of new cases should be negative when a restriction is imposed. Therefore what is modeled is the daily change in the growth rate of new cases for both countries:

$$\Delta g_t = \alpha + \beta_1 NPI1_t + \beta_2 NPI2_t + \beta_3 A_t + e_t$$

As the trend is only of interest, Δg_t is the daily change in the growth rate computed from an HP filtered daily time series as indicated in Fig. (2). $NPI1_t$ is a dummy variable coded as 1 during the summer lockdown days. $NPI2_t$ is a dummy variable coded as 1 during the fall restrictions period for both countries. Lastly A_t is the announcement period that occurred at the end of June for both countries. It is coded as 1 at 10 days before the countries' respective summer lockdowns. As argued in Section 2, this was a time of increased caution due to a new peak in cases and lockdown announcements. Further this period experienced a shortage of CPR tests in both countries. All the specific dates can be seen in Sections 1 and 2.

The coefficients also have an interesting interpretation. α is the constant and represents the daily gradual increase in the growth rate without any quarantine restrictions. The betas represent the daily additional impact of quarantine. Whenever a quarantine is in place for the day it additionally (relative to the day prior) reduces the growth rate by β points for that day on average. The average daily net effect of reduction is a $\alpha + \beta$.

As seen in the figures, May was a very volatile month in terms of growth rates. Therefore, the model is run for six months from June 1st until December 1st for both countries. The results are shown in table 1. As can be seen the average daily increase in the growth rate without quarantine was .00211 and .003 for Kazakhstan and Kyrgyzstan respectively. The average daily impact of the first quarantine on the reduction of the growth rate for Kazahstan was -.00494 per day (or -.494 percentage points). The net effect (after accounting for the natural increase in the growth rate was) -.00494+.00211 = -.00283.[3] Similarly for Kyrgystan the impact of the first quarantine was a reduction of -.00591 and a net effect was -.00591 + .003 = -.00292. The rest of the coefficients can be similarly interpreted. Notice that the impact of quarantine in Kyrgyzstan was larger (more negative) than Kazakhstan although Kyrgyzstan never had a full lockdown! This indicates that the partial lockdown with curfews was just as effective. The rest of the coefficients may be similarly interpreted. It can be seen that the fall restrictions were less effective in reducing the growth rate.

How well do NPIs explain the growth rate of new cases? As can be seen the R squared in the regressions from Table 1 is close to .85 and .8, indicating that the NPIs explain 85% and 80% of the variation in the growth rate in new cases for Kazakhstan and Kyrgyzstan respectively.

Section 3.2 Simulation and counterfactual scenarios

It is also possible to do simulations of the model to predict the growth rate and the (log of) new cases. Given starting values of the growth rate in early June the model can solve for all future growth values. Similarly, given starting values of the growth rate and new cases the model solves for all trend new cases until December.

The results are given in Figures 3-4 for both countries. As can be seen, due to the dynamic nature of the solution (the previous value is used to solve the future value) the simulated values closer to the initial value (in June) will be closer to the actual. The model appears to be pretty good fit for the data considering that it is only based on the variation of NPIs.

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[3] This result is reasonable. In the observed data Kazakhstan had a growth rate of roughly .04 (or 4%) per day at the start of the quarantine and after a month and a half it went to -.08 per day. This is a .12 points drop in 45 days or .00266 points per day.

What will be the impact on new cases if NPIs were never implemented? In the counterfactual scenario the growth rate of new cases is assumed to stay constant and is at the level of growth at the time of implementation of the NPI. The results are shown in Figure 5. In it, if the summer lockdown did not occur, Kazakhstan registers 6,000 cases per day while Kyrgyzstan 10,000 per day by the mid August. In the fall scenarios, by December first, Kazakhstan registers 2,500 while Kyrgyzstan 5,000 cases per day. Table 2 shows the difference between the counterfactual and actual levels depending on the day after NPI is imposed. As can be seen, the totals are significant in magnitude. If NPIs were not implemented, by the end of 2020, Kazakhstan would have roughly fifty percent more cases while Kyrgyzstan would have twice as many.

Section 4: Discussion

The main argument in this research is that quarantine restrictions influence the growth rate of new cases. Therefore, it argues that when one studies the data of a country that has recently imposed restrictions, the country might not experience a reduction in new cases, but it should experience a reduction in the growth rate of new cases; this is what should be measured as a success. A theoretical epidemiological model in the appendix also confirms that if restrictions do indeed reduce the reproductive number, then this would show as a reduction in the growth rate of new cases in the data.

To confirm the theory, results show that quarantine restrictions explain the growth rate in new cases very well for Kazakhstan and Kyrgyzstan. When they are present the growth rate is decreasing and when they are absent the growth rate is increasing. Interesting enough the decrease in growth was slightly more for Kyrgyzstan than Kazakhstan in the summer quarantine period although Kyrgyzstan never had a full lockdown.

This study also has two main limitations.

First, as shown in the data, for these two countries the growth rate continues to increase when there are no restrictions and continues do decrease when there are restrictions. The data does not show a maximum or minimum in the growth rate, although in theory this could be reached given both countries reach specific steady states in their corresponding reproduction numbers; this does not appear to be the case.

Furthermore, as the population becomes infected, recovered, and develops immunity, they are removed from being in the susceptible population. As more and more people recover there would be less and less susceptible people who could get infected. This immunity overtime should impact the growth rate in new cases in a negative way as the susceptible population decreases. However, taking into account immunity overtime will overcomplicate this simple model. If one assumes that for a short quarantine period the susceptible population remains roughly the same then the present results will hold. In the case of the two countries, the official statistics indicate that roughly one percent of the population was ever infected with the virus, and in accordance with the data the growth rate did not tend to decrease without restrictions. Therefore, in this context the decline in the susceptible population overtime was insignificant.

Section 5: Conclusions

This paper studies the impact of NPIs (quarantine restrictions) on the growth rate of new COVID-19 cases for Kazakhstan and Kyrgyzstan. The figures and formal results of the model indicate that both rounds of summer and fall NPIs were effective in decreasing the growth rate of new cases gradually. The paper further explores the impact and magnitude of the different restrictions provided in Table 2. The empirical model fits reasonably well. NPIs explain 80% and 85% of the variation in the growth of new cases for Kazakhstan and Kyrgyzstan respectively. Further the model is simulated and provides a good fit with the actual growth rate and levels data for both countries. Conclusions based on a conservative counterfactual scenario indicate that if the countries had not imposed NPIs, Kazakhstan would have fifty percent more cases while Kyrgyzstan would have had twice as many cases in 2020.

In accordance with the estimates from the summer, the partial lockdown in Kyrgyzstan was slightly more effective than the full lockdown in Kazakhstan in the reduction of the growth rate. As Kazakhstan and Kyrgyzstan are similar countries, evidenced by their very similar trends in the number of new cases, it can be reasoned that they would both react a similar way due to policies. Therefore, in accordance with the results a partial lockdown is just as effective as a full lockdown. The policy recommendation is indeed have NPIs to reduce the spread of the virus; however, a full lockdown is not necessary, a partial lockdown is just as effective. The partial lockdown imposed by Kyrgyzstan let businesses such as restaurants and shopping centers continue to operate but with curfews; there were closures however on cinemas, bars, karaoke, nightclubs, and fitness gyms. Perhaps these are locations more prone to spreading the virus.

Abbreviations:

NPI: Non-pharmaceutical interventions. This is also known as quarantine restrictions.

SEIRD: susceptible, exposed, infected, recovered, dead

Declarations:

Eithics approval and consent to participate: Not applicable

Consent for publication: Not applicable

Availability of data and materials:

Data on number of new cases is available from https://www.worldometers.info/.

Data on quarantine restriction dates is available from official government resources and news articles that are cited in the paper.

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Authors' Contributions:

SN is the corresponding author of the paper, he helped establish the idea and wrote the main draft of the introduction, methodology, results, and conclusion.

ZA, and AA gathered the data, investigated the quarantine restrictions information, and wrote the section describing the NPIs in the countries - the second section of the paper.

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Appendix: Theoretical Model

Why would NPIs decrease the growth in new cases? It is theorized that NPIs should reduce the reproductive number in particular the contact rate between individuals. This section shows that the growth rate of new cases is related to the components of the reproductive number.

From epidemiology, let $R = BT$. Where R is the reproductive number; this is the total number of infections caused by an infectious individual. B is the contact rate; that is number of new infections per day caused by an infectious individual, and T is the infectious period and represents the total number of days an individual stays infectious. Epidemiological arguments for quarantine restrictions argue that quarantine should decrease R by decreasing B, while T is assumed to be little affected by restrictions.

Shown below links reproductive number to growth rate

1) $n_{t+1} = BI_t$

Where n_{t+1} is the future period’s new total infections and I_t is the total number of infectious individuals and is equal to the sum of all past “new” infections up to the number of days a person remains infectious: $I_t = n_t + n_{t-1} + n_{t-2} + n_{t-3} \dots n_{t-(T-1)}$.

Define the growth rate of new infections as g where:

2) $n_{t+1} = (1 + g)n_t$

It turns out that if B stays constant over time then the growth rate g also stay constant over time.

Now take the ratio: $\frac{I_t}{n_t} = \frac{n_t+n_{t-1}+n_{t-2}+n_{t-3}\dots n_{t-(T-1)}}{n_t} = 1 + \frac{1}{1+g} + \left(\frac{1}{1+g}\right)^2 + \left(\frac{1}{1+g}\right)^3 + \cdots \left(\frac{1}{1+g}\right)^{T-1}$

Solve the above ratio for I_t and insert back into eq. (1) to obtain:

3) $n_{t+1} = B(1 + \frac{1}{1+g} + \left(\frac{1}{1+g}\right)^2 + \left(\frac{1}{1+g}\right)^3 + \cdots \left(\frac{1}{1+g}\right)^{T-1})n_t$

Now using eqns: (2) and (3) and solving for B:

$$B = \frac{1+g}{1+\frac{1}{1+g}+\left(\frac{1}{1+g}\right)^2+\cdots\left(\frac{1}{1+g}\right)^{T-1}} = \frac{1}{\frac{1}{1+g}+\left(\frac{1}{1+g}\right)^2+\left(\frac{1}{1+g}\right)^3+\cdots+\left(\frac{1}{1+g}\right)^T}$$

If $g = 0$ then $B = 1/T$ and $R = 1$

If $g > 0$ then $R > 1$

If $g < 0$ then $R < 1$

Solving for the growth rate in the above let $g = f(B,T)$. Then notice that that $\frac{dg}{dB} > 0$ and $\frac{dg}{dT} > 0$. Notice that a higher growth rate of new cases (g) is positively related to the number of new infections per day per infectious individual (B) and to the number of days the person is infectious (T). If B, or T could be decreased with restrictions then theoretically the growth rate of new cases will decrease as well.

In the literature NPIs are seen as reducing B while T is generally assumed to be constant. There is no theory however that states how B is reduced. In particular, is the reduction immediate or gradual? In the model above $B, and\ g$ are kept constant over time. However, mathematically, it is hard to show how decreasing B will change g. One way is to experiment with numbers. Let starting $B = .15$ and $T = 14$ days. Then one can solve for g. If B is gradually reduced over time due to quarantine then g is also gradually reduced and mimics the observed smoothed growth data.

Figures

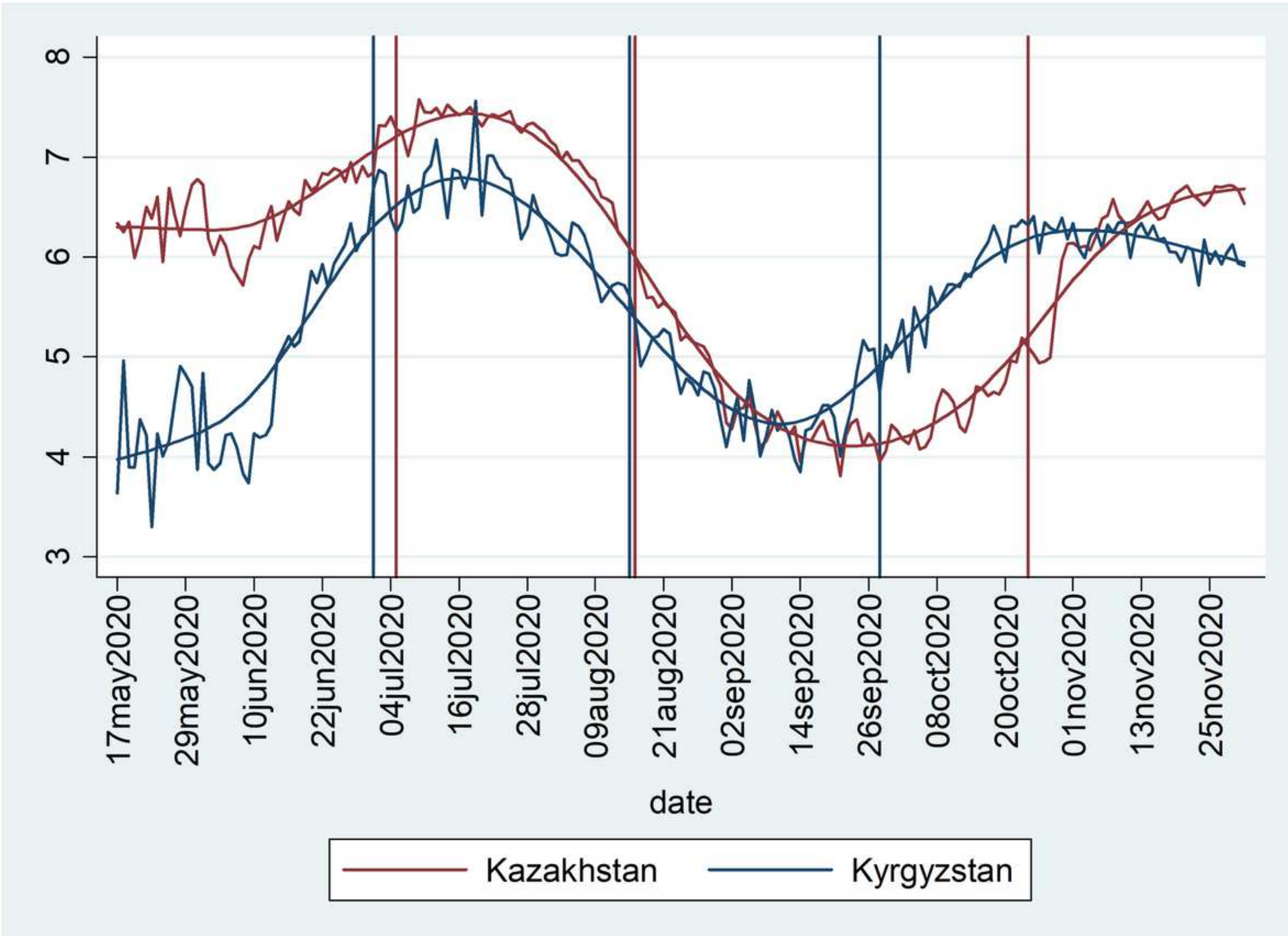

Figure 1

Natural log of new cases with an HP trend

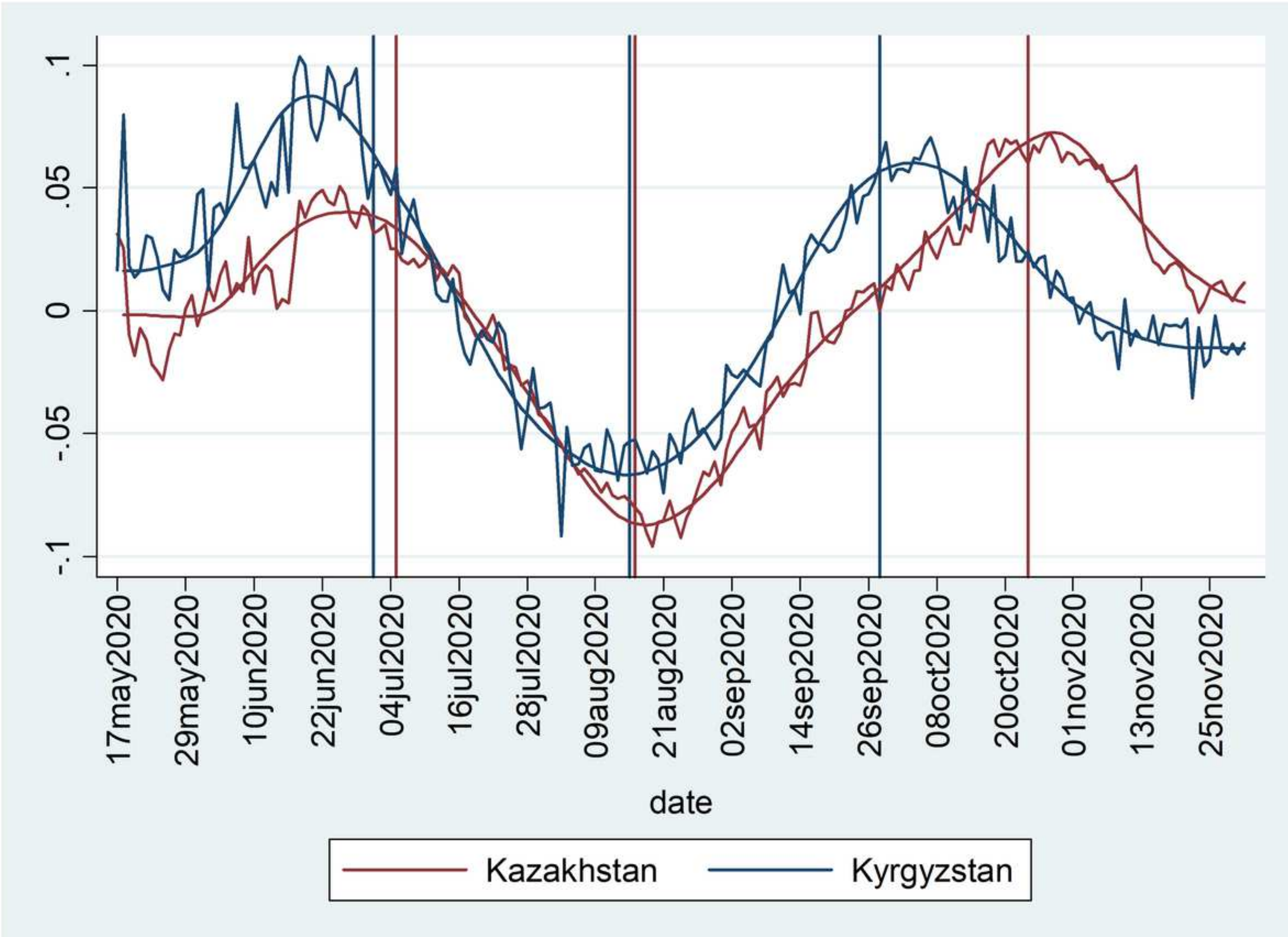

Figure 2

Growth rate of new cases: two week moving average and first difference of HP trend line

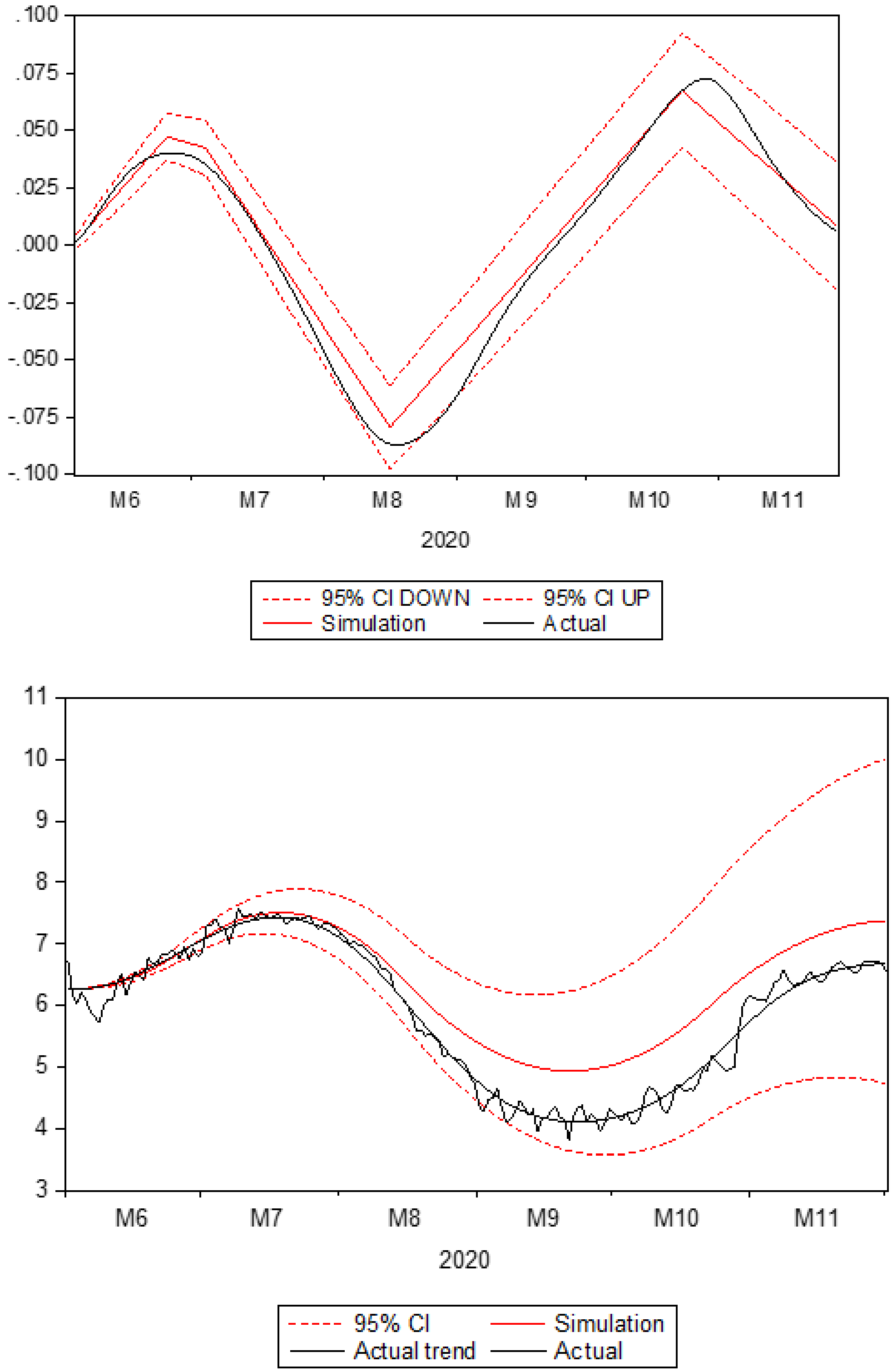

Figure 3

Kazakhstan model fit: Growth rate of new cases (above) and natural log of new cases (bottom)

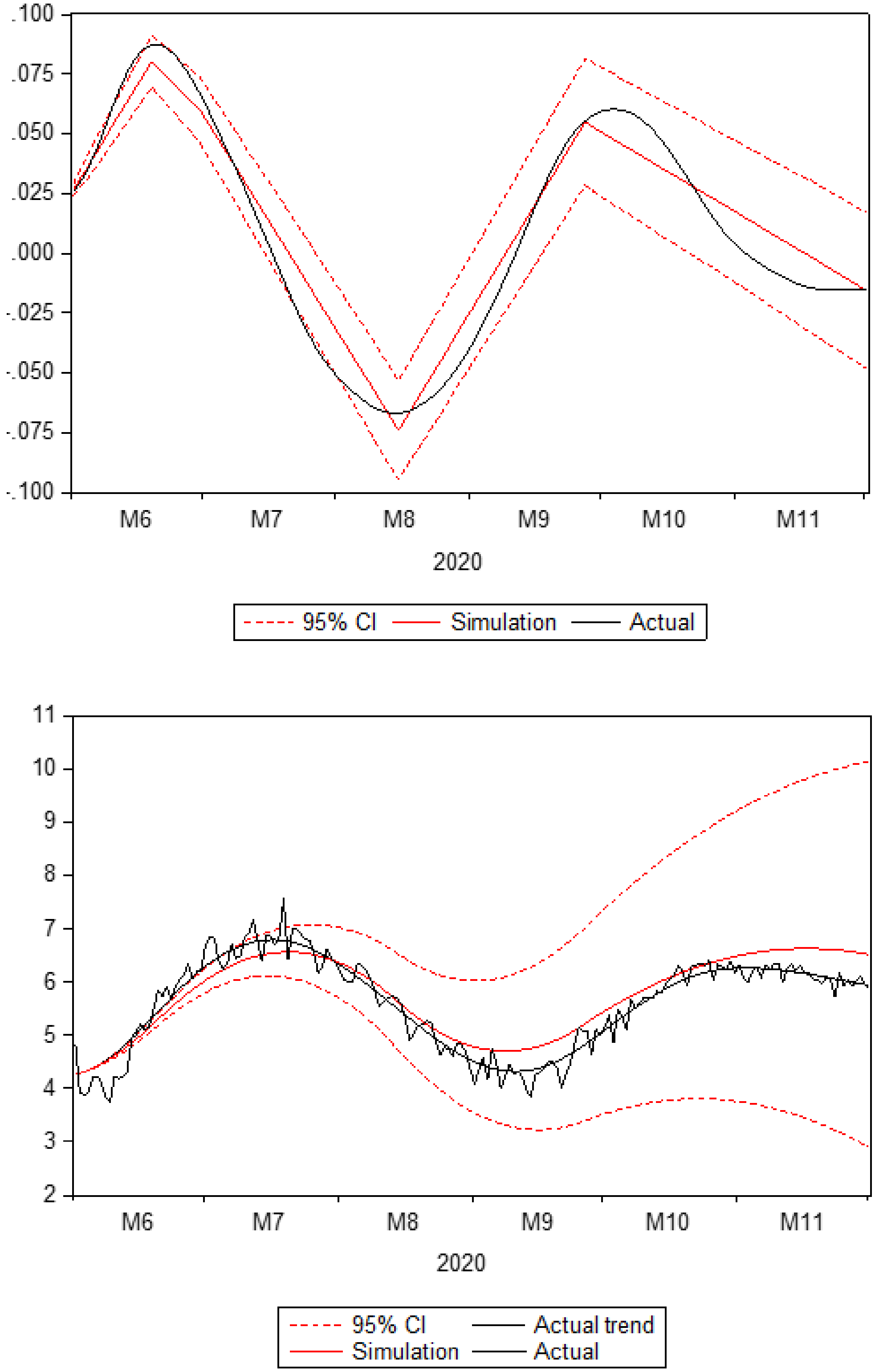

Figure 4

Kyrgyzstan Model fit Growth rate of new cases (above) and natural log of new cases (bottom)

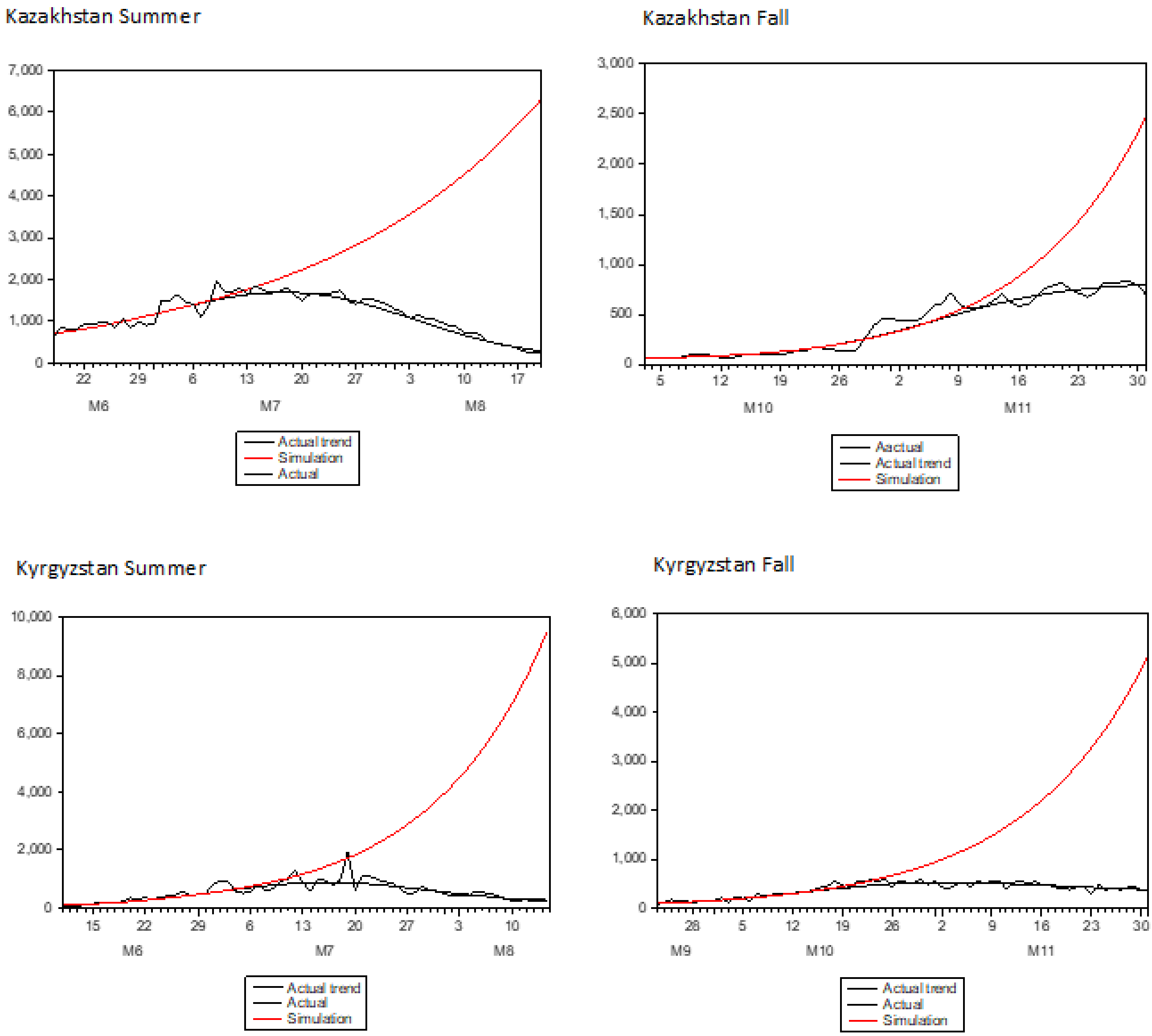

Figure 5

Counterfactual Simulations