Appendix B – Data

1. Satellite Nighttime Light Data

This paper aims to detect the different development patterns of closed and ordinary cities, focusing on economic performance and urbanization. However, Russia does not have readily available city-level GDP and other data which could represent the overall economic performance of smaller towns and cities. The situation is especially bad for ZATO cities, almost by definition, and above all for the chaotic economic implosion years of the 1990s. Therefore, this paper uses nighttime light data as a proxy for economic performance. The original nighttime light datasets cover 1992 to 2013, and the extended datasets contain information from 2014 to 2019. In sum, the available nighttime light data can cover the whole period after the dissolution of the USSR, which means it is feasible to use datasets to detect the city development under all three periods: the economic decline, the economic recovery and the boom of the early and mid-2000s, and the decelerated growth following the 2008 global financial crisis. This paper uses the sum of each city's urban light intensity to approximate city-level economic performance. In addition, this paper also uses the counts of urban lights of each city along with the luminosity sum to detect their urbanization and city expansion process.

The first dataset the paper uses is the satellite night light data. The original set is freely available from the National Centers for Environmental Information (NOAA) website[1]; the extended data are freely available on the website of Earth Observation Group from the Colorado School of Mines[2]. The satellites carrying the Operational Linescan System (OLS) of the Defense Meteorological Satellite Program (DMSP) collect night light data, generating large-scale spatial dynamic urban expansion data (Milesi et al., 2003). DMSP now has four such satellites, where three record night light data and carry

[1] https://ngdc.noaa.gov/eog/download.html
[2] https://eogdata.mines.edu/products/dmsp/

the OLS. The three main components of the OLS instrument are the visible telescope, the infrared telescope, and a photo multiplier tube (PMT). With different radiation sensitivity, these three components can detect different kinds of light. The various types of light include the visible and near-infrared reflected sunlight and moonlight, fires, upper atmospheric sources, aurora, natural gas flaring, and of course, night lights. Furthermore, OLS holds a constant rate to sample the continuous signal so that each pixel around the equator covers roughly 0.5 km. As for the way to collect night light data, the OLS "VIS" (the visible telescope) can detect moonlight reflected by clouds and other kinds of night light data, including human-made lights, fires, lightning, gas flaring, and so forth. Then by using OLS thermal infrared band to eliminate the influence of the moonlight reflected by clouds, a more accurate human-made night light dataset can be collected.

This paper uses the Version 4 DMSP-OLS Nighttime Lights Time Series. These data are mainly of two types: Average Visible, Stable Lights, & Cloud Free Coverage, and Average Lights X Pct. The Stable Lights of the first type of data will be an excellent proxy for human-made night lights and then economic performance, which is the target of this paper. However, the Stable Lights data are still under the potential influence of gas flares, where data from gas flares are usually not considered a proxy for economic performance. Fortunately, the OLS could detect and identify the gas flares without the impact of human-made lights (Elvidge et al., 2009). The NOAA provides data to eliminate the gas flares, but because none of the paper's target cities is related to oil and natural gas mining, we can ignore their potential effect. Furthermore, the data are collected using different satellites in different years, and in some years, two satellites collect data together. Table B.1 shows the coverage of different satellites.

TABLE B.1: YEAR COVERAGE OF DIFFERENT SATELLITES

1992	F10							
1993	F10							
1994	F10	F12						
1995		F12						
1996		F12						
1997		F12	F14					
1998		F12	F14					
1999		F12	F14					
2000			F14	F15				
2001			F14	F15				
2002			F14	F15				
2003			F14	F15				
2004				F15	F16			
2005				F15	F16			
2006				F15	F16			
2007				F15	F16			
2008					F16			
2009					F16			
2010						F18		
2011						F18		
2012						F18		
2013						F18		
2014							F15	

2015							F15	
2016							F15	F16
2017							F15	F16
2018							F15	F16
2019							F15	F16

No matter which satellites collect the data, the intensity value of night light ranges from 0 to 63, although the value of a particular night light level could vary based on the various satellites or even the different working years of a given satellite. One example of this inconsistency is that the values of many pixels are different for a particular year collected by different satellites (F10, F12, and 1994).

The nighttime light datasets contain the worldwide night light information; we only focus on Russian and Ukrainian city-level or the second administrative level data. This paper uses two shapefiles to finish the converting work: the worldwide country-level shapefile from IPUMS,[3] and Russian and Ukrainian second-level administrative divisions from the Museum of Vertebrate Zoology.[4]

2. Closed City List

Based on the available online information on closed cities, we create a closed city list, which includes information on:

- City name, country, region: Since some closed cities share the same name, country and region information are important identifiers.

[3] https://international.ipums.org/international/gis.shtml
[4] https://maps.princeton.edu/catalog/stanford-td486fb7677

- Former city name: During the Soviet period, many closed cities did not have their unique name, and instead were identified by the region name and a number. For example, the former name of Mezhgorye is Beloretsk-16.
- Nuclear-related indicator, military-related indicator, biological/chemical weapon-related indicator, aerospace-related indicator, and sci-related indicator: These five indicators are based on the former functions of these cities. Different types of closed cities should experience a different development pattern because their pre-Soviet-period conditions vary, especially for science-related closed cities. Science-related closed cities usually have a higher general education level, and even some universities are located in these places. Indeed, some now have become officially-designated Russian science cities. For example, Protvino was a science-related closed city and now is a Russian science city and one of the largest Russian physics research centers. Note that the science-related indicator generally overlaps with the other four indicators.
- City type: this indicator is mainly for closed cities in Russia. In Russia, some closed cities opened after the dissolution of the USSR, but some of them became ZATOs, which still have some restrictions. In addition, ZATO cities enjoy some federal support based on the law on a closed administrative-territorial entity, while those that simply became open did not get such benefits. Therefore, their development trajectories should be different.
- 2020 population: Population is the critical standard in selecting target closed cities for our analysis. Closed "cities" with tiny populations cannot be considered a city in the conventional sense, and those with large populations are not pure closed cities, as they almost certainly have some non-military and non-science activities as well. Therefore, we restrict consideration to closed cities with 2020 populations ranging between 10,000 and 200,000.

- The year of receiving closed city designation: The list also records the year of becoming closed. However, the information of more than half of the cities is missing.
- Administrative level: The administrative levels for most closed cities are urban-type settlements and cities. A designated city usually has a more developed center area and some underdeveloped rural places, while urban-type settlements only contain developed parts, which are similar to the city center. Therefore, these two levels should have different development patterns. One significant difference is that the urban-type settlement cannot experience spatial expansion because all surrounding areas usually are unsuitable, while a city's urbanization usually involves turning rural areas into part of the city.
- Area, distance to Moscow, latitude, and longitude: The list contains some geographic information on closed cities. Distance to Moscow could reveal the control power or the influence of the Russian government on these closed cities, especially for closed cities outside Russia. However, of the greatest importance for comparison purposes is the need to distinguish between the many closed cities reasonably close to Moscow (in Moskovskaya Oblast) and those in remote areas. The latitude and longitude also are essential: the ability to locate closed cities using shapefile information is limited, because these closed cities are generally too small to be identified as distinct zones. Therefore, we use geographic coordinates to locate each closed city and, based on the location, to get information on the second-level administrative (raions/counties or urban-type settlements) boundary using the shapefile.
- Tripadvisor indicator: The trip advisor indicator can reveal the closedness status of cities. Comments on restaurants and hotels on a city's TripAdvisor page, and especially if some are in English, provide evidence that a city is no longer restricted to foreigners' entry. However, having comments on the TripAdvisor page does not necessarily mean that this city is no longer closed or no longer belongs to ZATO, as it may be because some particular areas are strictly

closed in this city, especially in military-related close cities, while other areas are open for all. In short, TripAdvisor presences as a useful but imperfect indicator.

- Additional Information: The part contains the detailed former function of these closed cities, if available. Some closed cities have no information, especially in the case when, following the USSR's collapse, the city was abandoned immediately. Such an event was likely in military-related closed cities where army units were reassigned to other areas, making these cities die out. This section also contains some other influential events for particular cities (for example the 1993 nuclear processing facility explosion and radiation release in Tomsk-7/Seversk)