Economics from Outer Space

Instructor: Megha Patnaik

Spring Quarter 2023-2024

Please note the syllabus will go through revisions and updates as the course progresses. Keep checking in!

Course Description: The possibilities for economic measurement have been transformed through observation of the earth from satellites. In this course, we will study the array of possibilities in public and commercial imagery, and link up to applications in economic research and industry. The course will start from the physics foundations of how satellites see the earth, examine measurement opportunities at all frequencies, show research and business applications, and carry the students to the point of writing code in Julia for one small problem.

Prerequisites: ECON 1

Course objectives: The objective of the course is to give students a broad base of knowledge of how satellite data can be used to study economic questions and generate working code for one application through the class project that can be used as future resource. A portion of class time will be devoted to group assignments which are to begin in class with your groups (3-4 students in each group) and one submission per group is due by noon on the following week Monday.

Evaluation: In line with the course objectives, students will be evaluated on the basis of class participation (10%), group assignments (30%) group project presentation (30%), and final exam based on main readings (30%).

Logistics:

Lectures: 04/01/2024 - 06/05/2024 Mon, Wed, Fri 1:30 PM - 2:50 PM at STLC 119. Office Hours: Fri 3:00-4:30 PM in my office 142 in the Landau Economics Building. You can reach me at mpatnaik@stanford.edu. The TA is Tamri Matiashvili, who can be reached at tamrim@stanford.edu. Her Office Hours: Tue 2:00-3:00 PM in ECON 149 (Landau); Wed 11:30am-12:30pm on Zoom. [1] To facilitate any students who have accommodations from the Office of Accessible Education please fill out this google form: Accommodations Form.

Course outline:

Introduction to satellite data in economics. The physics of remote sensing: the electromagnetic spectrum, and potential economic applications of different wavelengths. Public sources of satellite data: Landsat, JPSS, and Sentinel. Private satellite data sources. Heights and orbits, geostationary orbits. Introduction to Julia and Raster data structure.

Nighttime lights as a measure of prosperity, sample applications, limitations of the measure. Observing nighttime light radiance: Satellites collecting the data: how to make a map of the world at night. Downloading data from Earth Observation Group, understanding the structure of the data. Working examples in the group assignments that give students code to adapt for the course project.

Illustration of a diverse set of applications of satellite data in economics in: economic growth, economic history, development economics, climate and political economy, COVID-19 lockdown effects, visual investigations in journalism, business applications. Working examples in the group assignments that give students code to adapt for the course project.

The course will conclude with student presentations using nighttime light data to study an economic question for a region and a time period of their interest. Instructions for the presentation will be provided.

INDIVIDUAL CLASS SCHEDULE

WEEK 1: FOUNDATIONS

Mon April 1: Introduction

Main resource: Dave Donaldson and Adam Storeygard. The view from above: Applications of satellite data in economics. *Journal of Economic Perspectives*, 2016

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[1] https://stanford.zoom.us/j/95290696988?pwd=M3NKQnFld2VJbm4yNjRqRVFYa1hMZz09 Password: 123456

Discussion: What are the advantages of remote sensing-based data? We discuss examples where satellite data is able to help us study economic questions based on the high resolution, wide coverage, and availability of data when other sources are unavailable. The Main resource provides an overview of what we will study in the course conceptually.

Wed April 3: A primer on remote sensing

Main resource: Dave Donaldson and Adam Storeygard. The view from above: Applications of satellite data in economics. *Journal of Economic Perspectives*, 2016

Discussion: We discuss the different divisions of the electromagnetic spectrum and the potential information in each of these available for observation. We see examples of data from satellites such as Landsat, Modis and Sentinel. We learn about sensors used to capture different bands of the electromagnetic spectrum and how this can be used to construct indices. We understand the heights and orbits different satellites operate at, and the resolutions provided by the sensors.

Fri April 5: Downloading Satellite data

Main resource: The NPP Mission Brochure and the Earth Observation Group website of which details are covered in the class worksheet.

Discussion: We will be studying the Suomi NPP Satellite which hosts the VIIRS sensor which collects the Day and Night band that we use to measure Nighttime Lights. We will visit the Earth Observation Group website together and navigate to data download.

WEEK 2: SETTING UP

Mon April 8: Introduction to Julia

Main resource: Worksheet provided in class

Discussion: Julia is a high-performance computing language that is particularly helpful for processing large datasets. We will install Julia on our computers and set up our coding environments. You will learn the basic tools needed to start with satellite data. These include writing a for loop, multiplying matrices, and processing images. Please bring your computers as you will work together with your groups in class. We will assist you with the setup and questions during the duration of the class.

Wed April 10: Nighttime Lights data

Main resource: Lecture slides
Link for data download: https://eogdata.mines.edu/products/vnl/

Discussion: We review the satellite and the sensor used to collect Nighttime Light data. We understand how a picture of the world at night is constructed. We review the file nomenclature and filesystem structure, and download TILE 1 data as well as a smaller dataset for California. We read these datasets into Julia and familiarize ourselves with rasters objects.

Fri April 12: Nighttime Lights as a measure of prosperity

Main resource: Lecture slides

Advanced resource: J Vernon Henderson, Adam Storeygard, and David N Weil. Measuring economic growth from outer space. *American Economic Review*, 2012

Other resource: Vernon Henderson, Adam Storeygard, and David N Weil. A bright idea for measuring economic growth. *American Economic Review*, 2011

Discussion: We discuss how nighttime light activity can proxy for economic prosperity. What are the advantages of this measure and what are the limitations? We look at a few applications together.

WEEK 3 (ECONOMIC GROWTH)

Wed April 15: Working with shapefiles in Rasters.jl

Main resource: https://rafaqz.github.io/Rasters.jl/dev/

Discussion: We understand how spatial data is organized in vector and raster forms. We use the Rasters.jl package to read, write and manipulate rasterized spatial data. We understand the concept of a Raster "stack" for a region of interest. You

will learn about shapefiles and how to use them on Nighttime lights data. Please bring your computers as you will work together with your groups in class where we will assist you during the duration of the class.

Wed April 17: Applications: economic growth

Main resource: https://www.youtube.com/watch?v=9nnQq4lP_6o

Advanced resource: Danny Quah. The global economy's shifting centre of gravity. *Global Policy*, 2011

Discussion: This week we have our first application of satellite data to an economic question: Has the center of economic activity shifted towards Asia? A question posed as early as 2011 based on GDP estimates is validated using satellite data. How far have we come from these predictions?

Fri April 19: Applications: economic growth

Main resource: Lecture Slides

Advanced resources: Peter Cauwels, Nicola Pestalozzi, and Didier Sornette. Dynamics and spatial distribution of global nighttime lights. *EPJ Data Science*, 2014

Discussion: This week we have our first application of satellite data to an economic question: Has the center of economic activity shifted towards Asia? A question posed as early as 2011 based on GDP estimates is validated using satellite data. How much variation is there within countries?

WEEK 4 (ECONOMIC HISTORY)

Mon April 22: Group assignment for using shapefiles in Rasters.jl

The assignments are designed to get you tooled up for the group project. Please bring in computers as you will work together with your groups in class where we will assist you during the duration of the class. You can continue to work on the assignment and submit one assignment per group by the following Monday at noon.

Wed April 24: Applications: Economic History

Main resource: On Roman roads and the sources of persistence and non-persistence in development

Advanced resources: Carl-Johan Dalgaard, Nicolai Kaarsen, Ola Olsson, and Pablo Selaya. Roman roads to prosperity: Persistence and non-persistence of public goods provision. 2018

Resources for the ORBIS class exercise: London to Rome on Horseback. The Economist, May 2012. and ORBIS Route finding tutorial

Discussion: Is economic prosperity persistent? We travel to Ancient Rome to explore areas where there was a high density of infrastructure historically and find that they show high economic activity as measured by nighttime lights in the present time. We will also explore the Roman Road Network with https://orbis.stanford.edu/

Fri April 26:

Main resources: (1) Economists Find Lost Cities Using This Simple Idea, Trade, Merchants, and the Lost Cities of the Bronze Age.

Advanced resources: Gojko Barjamovic, Thomas Chaney, Kerem Coşar, and Ali Hortaçsu. Trade, merchants, and the lost cities of the bronze age. *The Quarterly Journal of Economics*, 2019

Discussion: Is economic prosperity persistent? This week we look at two examples where areas where there was a high density of infrastructure historically show high economic activity as measured by nighttime lights in the present time. The second example is on finding lost cities in Assyria.

WEEK 5 (DEVELOPMENT ECONOMICS)

Mon April 29: Worksheet for sum of light using NighttimeLights.jl

Main resource: Worksheet provided in class.

Discussion: We use the Julia package NighttimeLights.jl to extract and analyze data on nighttime light intensity for the US. We use the data in combination with shape files to construct region-level sums of nighttime lights. Please bring in computers as you will work together with your groups in class where we will assist you during the duration of the class.

Wed May 1: Applications: Development Economics

Main resource: Combining satellite imagery and machine learning to predict poverty 1,

Advanced resource: Combining satellite imagery and machine learning to predict poverty 2

Advanced resource: Neal Jean, Marshall Burke, Michael Xie, W Matthew Davis, David B Lobell, and Stefano Ermon. Combining satellite imagery and machine learning to predict poverty. *Science*, pages 790–794, 2016

Fri May 3: Applications: Development Economics

Main resource: Mapping urbanisation in India with satellite imagery

Advanced resource: Kathryn Baragwanath, Ran Goldblatt, Gordon Hanson, and Amit K Khandelwal. Detecting urban markets with satellite imagery: An application to india. *Journal of Urban Economics*, 2019

Discussion: Developing countries have poor data collection on the ground, and official statistics may reflect actual economic activity poorly relative to developed countries. Satellite data allows supplementing on-the-ground measures with measures that are not affected by the quality of economic institutions.

WEEK 6 (CLIMATE AND POLITICAL ECONOMY)

Mon May 6: Group assignment for sum of light using NighttimeLights.jl

The assignments are designed to get you tooled up for the group project. You will bring in computers and work together with your groups in class where we will assist you during the duration of the class. You can continue to work on the assignment and submit one assignment per group by the following Monday at noon.

Wed May 8: Climate and Political Economy

Main resource: National Policy Reversals and Deforestation in the Amazon

Other reading: Rainforests provide a public good. The world should pay to conserve them

Advanced resource: Robin Burgess and Benjamin A Olken. The power of the state: National borders and the deforestation of the amazon. 2024

Discussion: Satellite data can be used to track changes in forest cover and emissions. This can be used to verify countries are on track for climate commitments. We discuss two applications focusing on deforestation this week.

Fri May 10: Climate and Political Economy

Main resource: Lecture slides

Advanced resource: Mounu Prem, Santiago Saavedra, and Juan F Vargas. End-of-conflict deforestation: Evidence from colombia's peace agreement. *World Development*, 2020

Discussion: Satellite data can be used to track changes in forest cover and emissions. This can be used to verify countries are on track for climate commitments. We discuss two applications focusing on deforestation this week.

WEEK 7 (COVID-19 LOCKDOWN EFFECTS)

Mon May 13: Worksheet to cut a circle around a coordinate in NighttimeLights.jl

Please bring your computers as you will work together in class. We will assist you with the setup and questions during the duration of the class.

Weds May 15: COVID-19 lockdown effects

Main resource: Lecture slides

Advanced resource: Amjad Muhammad Khan, Hogeun Park, Mark Roberts, and Putu Sanjiwacika Wibisana. Lights out: The economic impacts of covid-19 on cities globally. *Journal of Regional Science*, 63(5):1251–1283, 2023

Discussion: One advantage of satellite data is that it provides a common measurement tool that can be applied across countries. This week we study the impact of COVID-19 lockdowns on economic activity measured by nighttime lights using satellite data.

Fri May 17: Group assignment to cut a circle around a coordinate using NighttimeLights.jl

The assignments are designed to get you tooled up for the group project. You will bring in computers and work together with your groups in class where we will assist you during the duration of the class. You can continue to work on the assignment and submit one assignment per group by Memorial Day at noon (extra time for this assignment).

WEEK 8 (COVID-19 LOCKDOWN EFFECTS CONTINUED)

Mon May 20: No class with optional lecture participation We have the author from last week's paper Santiago Saavedra of Universidad del Rosario presenting on *Digging for Votes: Machine-Learning Detection of Illegal Mining and its Effects on Political Outcomes* at Landau A. This would be especially valuable you are interested in environmental and development economics and have sufficient background in econometrics to follow along.

Wed May 22: Mock exam session with Tamri

Wed May 24: Guest lecture by Alex Finan: Golfing from Home

Main resource: Golfing from home by Nick Bloom & Alex Finan

Other readings: Zsolt Katona, Marcus Painter, Panos N Patatoukas, and Jean Zeng. On the capital market consequences of alternative data: Evidence from outer space. 2018

Discussion: Private satellite providers collect data that can be used for a variety of business applications. We discuss one application looking at the occupancy of golf courses with the introduction of remote work where Alex will lead the class. In case we have time we will also discuss a paper that builds a trading strategy using the parking lot occupancy of retailers.

WEEK 9 (SateLLITE WEEK- MISCELLANEOUS MATERIALS)

Mon May 27: Memorial Day (No Class)

Wed May 29: Callisto Group presentation + Review session with Tamri Group presentation by Callisto. Discuss solutions for the Mock exam with Tamri and review for exam.

Fri May 31: Presentation from the Stanford Space Initiative

Discussion: Theo Makler from the Stanford Space Initiative group to speak with the class on physics and infrastructure for satellites plus industry trends. Please attend as he will be bringing a prototype to class for us!

WEEK 10 (STUDENT PRESENTATIONS)

Mon June 3: Group presentations: Artemis, Nio

Group presentations on a chosen area using nighttime light data on an economic context of interest.

Wed June 5: Group presentations: Prometheus, Titan

Group presentations on a chosen area using nighttime light data on an economic context of interest.