Alternative Economic Indicators

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Measuring Economies from Space

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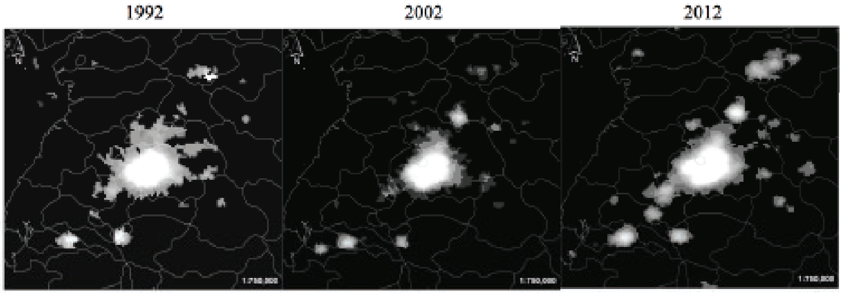
Why do we use satellite data for economic research and policymaking? Satellite data have several features that help us answer the kinds of causal questions about economic phenomena, and the effects of policies, that we care about as economists and policymakers. In particular, there are six advantages that I see as key. In this chapter, I address each one in turn, highlighting one or two pieces of economics research that use each and what we can learn from them. This chapter deals with data and methods, but throughout I'll show how they've been used to generate some very concrete lessons that are relevant to policy.[1]

SIX ADVANTAGES OF SATELLITE DATA

The first advantage of satellite data is that they exist where other data do not. Collecting data via household surveys and censuses is expensive and can be logistically difficult, especially in poor countries. The same is true of many kinds of administrative data that rich countries regularly collect.

To take an extreme example, Lee (2018) uses satellite data on lights at night from North Korea, a country that essentially does not publish credible economic data, to study the effect of sanctions there. Relying on the fact that changes in lighting are correlated with changes in economic activity, as demonstrated by Henderson, Storeygard, and Weil (2012), Lee uses the lights data to show that sanctions pushed economic activity toward Pyongyang (Figure 7.1) and to cities where trade with China was concentrated. China was not part of the sanctions regime. He argues that instead of primarily punishing ruling elites, as intended,

Figure 7.1 Lights Near Pyongyang, North Korea, in 1992, 2002, and 2012



SOURCE: Lee (2018).

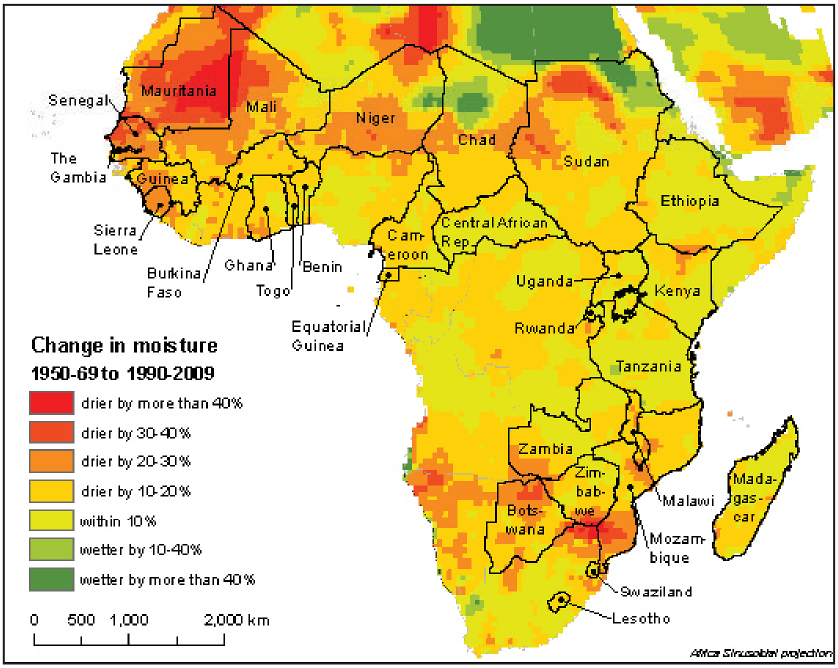
sanctions thus likely had their largest impacts on the "already marginalized hinterlands" (Lee 2018, p. 34).

A lack of data, of course, affects many places other than North Korea, in less extreme ways. In my work focused on how African cities grow, I have used the same night lights data as a measure of city-level economic activity, because other sources are rarely available, and almost never for every year. The paper by Henderson, Storeygard, and Deichmann (2017) considers how a drying climate throughout much of sub-Saharan Africa over a 50-year period (Figure 7.2) affected cities. The authors demonstrate that a drying climate appears to have pushed economic activity into some African cities but not others. Consistent with a simple theory, it is the cities most likely to have a preexisting export manufacturing base that attract new activity in times of drought, while cities that are more local in orientation are not affected. In the theory, the manufacturing-oriented cities are less affected by the drought because it affects neither their production technology nor the demand for their products. The more locally oriented cities, however, face a drop in demand from their customers: local farmers, whose production and therefore income fall.

These lights data have been used to address many other questions in data-poor environments, including how transport costs affect African cities (Storeygard 2016) and the effects of refugee camps on local economies in Kenya (Alix-Garcia et al. 2018).

A second advantage is that satellite data are often collected at extremely high spatial resolution, sometimes now less than one square

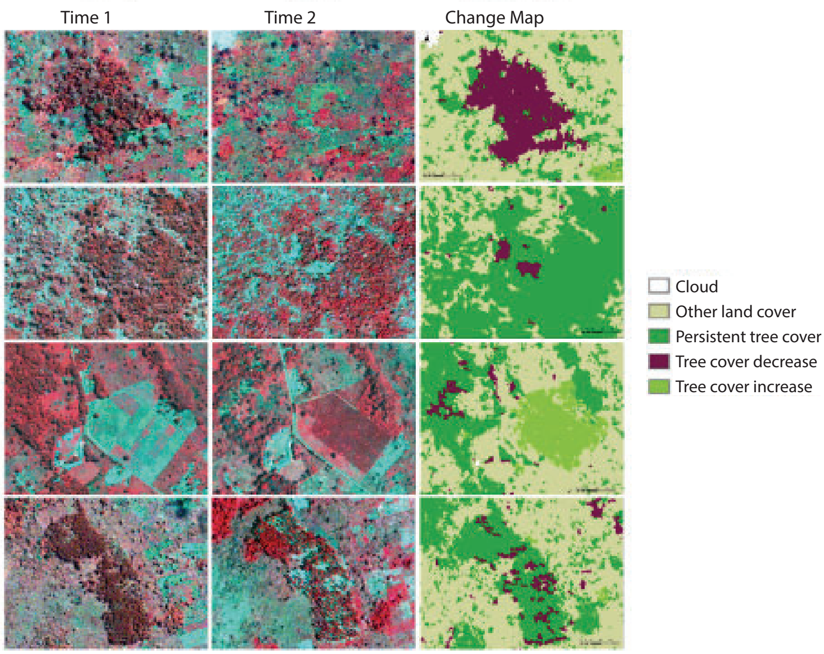
Figure 7.2 Moisture Change in Africa, from the Period of 1950–1969 to the Period of 1990–2009



SOURCE: Henderson, Storeygard, and Deichmann (2017).

meter. Jayachandran et al. (2017) have used this feature to evaluate a program of payments for ecosystem services in rural Uganda. The program paid private forest owners not to cut down trees for up to two years. The satellite data are fine enough that one can detect individual trees and assign them to the land of an individual household. Figure 7.3 shows what happened in four particular sample locations, each corresponding to a row in the figure. The first two columns of images show trees at the beginning and end of the two-year period, and the last column shows changes in tree cover. The authors link these data with a household survey about the program, using the location of each household's land. This link is of course critical—very little social science can be done with remote data alone. The authors found that people who were randomly assigned to the payments group cut down substantially

Figure 7.3 Changes in Forest Cover on Four Plots in Uganda



SOURCE: Jayachandran et al. (2017). Reprinted with permission from AAAS.

fewer trees than a control group that did not receive payments, and that the payments group did not displace tree harvesting onto other nearby lands. The difference was large enough that even if these effects were completely undone in four years, this delay in cutting down trees would be a cost-effective means of decreasing carbon emissions.

A third advantage is that repeat measurements with satellites are extremely cheap. Once analysts develop the methods for measuring something once, the satellite keeps orbiting and collecting data, so they, and often others, can apply the same algorithm to next month's or next year's data.

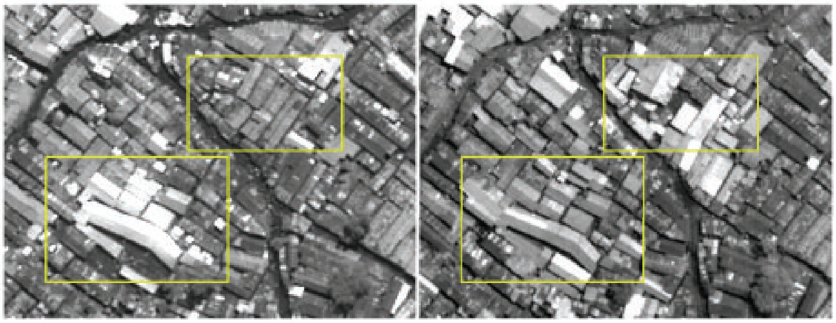
An excellent example of this is work done on ethnic patronage in the Kibera neighborhood of Nairobi, Kenya, by Marx, Stoker, and Suri (2019). These three authors are interested in the rents people pay relative to the quality of their house, but housing quality can vary over time.

To get a proxy for that, they measured the reflectance of the metal roofs (i.e., the amount of light reflected off the roofs). Roofs get less reflective as they get rustier (Figure 7.4, left and right lower yellow boxes), but when they get replaced, their shiny surfaces reflect more light (left and right upper yellow boxes). The authors were able to extract four measures of this reflectance for the whole neighborhood over a short period of time. Again, they could link the images of each house with a survey respondent.

The authors were able to document and quantify the fact that renters pay less rent, and get better housing quality, when they are of the same ethnicity as the local political boss. Conversely, they pay more rent and get worse housing quality when their landlord is of the same ethnicity as the local political boss.

In addition to reporting data for many points in time, most satellites report data for nearly the whole world on a regular basis. This was particularly useful for a study on the effect of subway systems on air pollution by Gendron-Carrier et al. (2018). The authors wanted to see whether air pollution fell in the weeks and months after subways

Figure 7.4 Changes in Roof Reflectivity from Old and New Roofs in Kibera, Nairobi, Kenya, July 2009 to August 2012



NOTE: "Both pictures are taken over the same area of the slum with the same resolution (0.5 meters panchromatic). The picture in the left panel was taken in July 2009 and that in the right panel in August 2012. The yellow rectangles highlight clusters of roofs that markedly evolved over the period. Roofs highlighted in the bottom rectangle degraded, while roofs within the top rectangle were upgraded in the same time frame" (Marx, Stoker, and Suri 2019, online appendix).
SOURCE: Marx, Stoker, and Suri (2019).

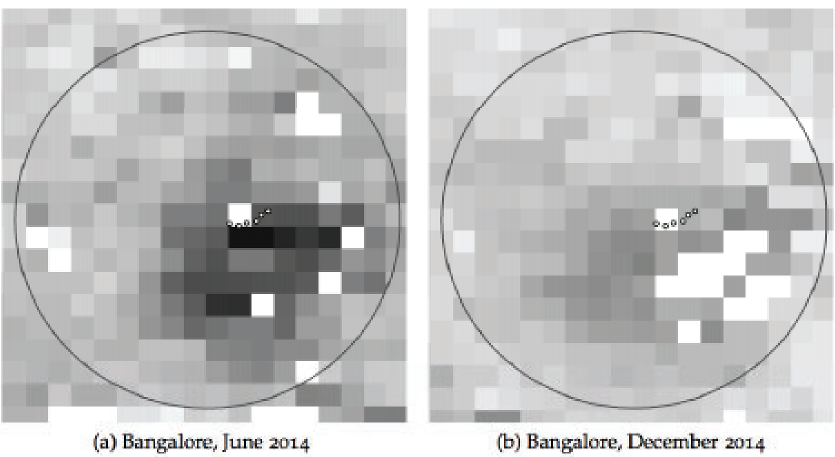
opened, as was the case for Bangalore in 2014 (Figure 7.5). But not many cities have seen subways open in the past 20 years.

Conveniently, satellite data on particulate matter are available for the whole world, so Gendron-Carrier et al. (2018) gathered administrative data on the opening of each subway stop in the 42 cities with new systems, which they were able to link to the pollution data. Without so many cities, they would not have had the statistical power for reliable inference.

Their results are quite striking. They find that subways substantially reduce particulates, and that the effect does not tend to decrease for as long as they can see in their sample, which is about eight years after the opening of the subway. This is somewhat surprising, as much other work, from Downs (1962) to Duranton and Turner (2011), predicts that new drivers will exploit any reduction in automobile traffic.

A feature related to the worldwide coverage is that satellites are measuring the same quantity everywhere. They don't turn off or change

Figure 7.5 Air Pollution before and after Inauguration of a New Subway Line in Bangalore



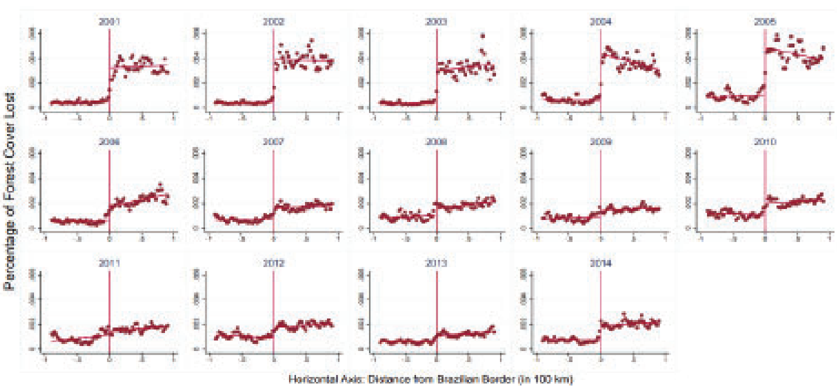
NOTE: Stations shown as small circles. Darker grid cells represent higher levels of particulates, and the large circle has a radius of 10 kilometers, centered on the central business district.

SOURCE: Gendron-Carrier et al. (2018).

methods when they cross a national border. This is different from even highly standardized surveys such as the Demographic and Health Surveys (DHS) carried out in many countries, because at a minimum, they must translate the same questions into different languages. Burgess, Costa, and Olken (2018) have exploited this idea of consistency across borders to consider the effect of a policy that Brazil introduced in 2006 to reduce deforestation. There are many reasons why deforestation rates change from year to year—including, for example, market prices of agricultural products farmers plan to grow on cleared land—so it's hard to distinguish the policy from other phenomena.

To address this, Burgess, Costa, and Olken (2018) use a spatial regression discontinuity design, as illustrated in Figure 7.6. Each point in each graph represents the share of forest in a 2.5-kilometer-wide swath of land parallel to Brazil's border cut down in a given year. This is equivalent to measuring deforestation along a transect crossing the border and then aggregating appropriately across all such transects. In the early years in the top row (2001–2005), when one moves from left to right into Brazil, rates of deforestation increase dramatically pre-

Figure 7.6 Deforestation Rates by Year and Distance to the Brazilian Border



NOTE: Average forest cover lost as a function of distance to the Brazilian border by year. Each point represents a 2.5-kilometer-wide band, indexed by distance into Brazil from the border, where negative values are in a neighboring country.
SOURCE: Burgess, Costa, and Olken (2018).

cisely at the border, represented by the vertical line in the middle. However, starting in 2006, that differential falls considerably, and by 2009 it is barely detectable. This is striking evidence that something important changed in Brazil relative to its neighbors in 2006, and the authors posit that this policy is the most likely candidate. Note that with coarser data, say at the district level, it would be more difficult to determine whether the jump happened precisely at the border.

The last advantage of satellites that I will highlight is their independence from typical reporting mechanisms. This is especially important when local officials might have incentives to underreport environmental damage, for example, but it has broader implications.

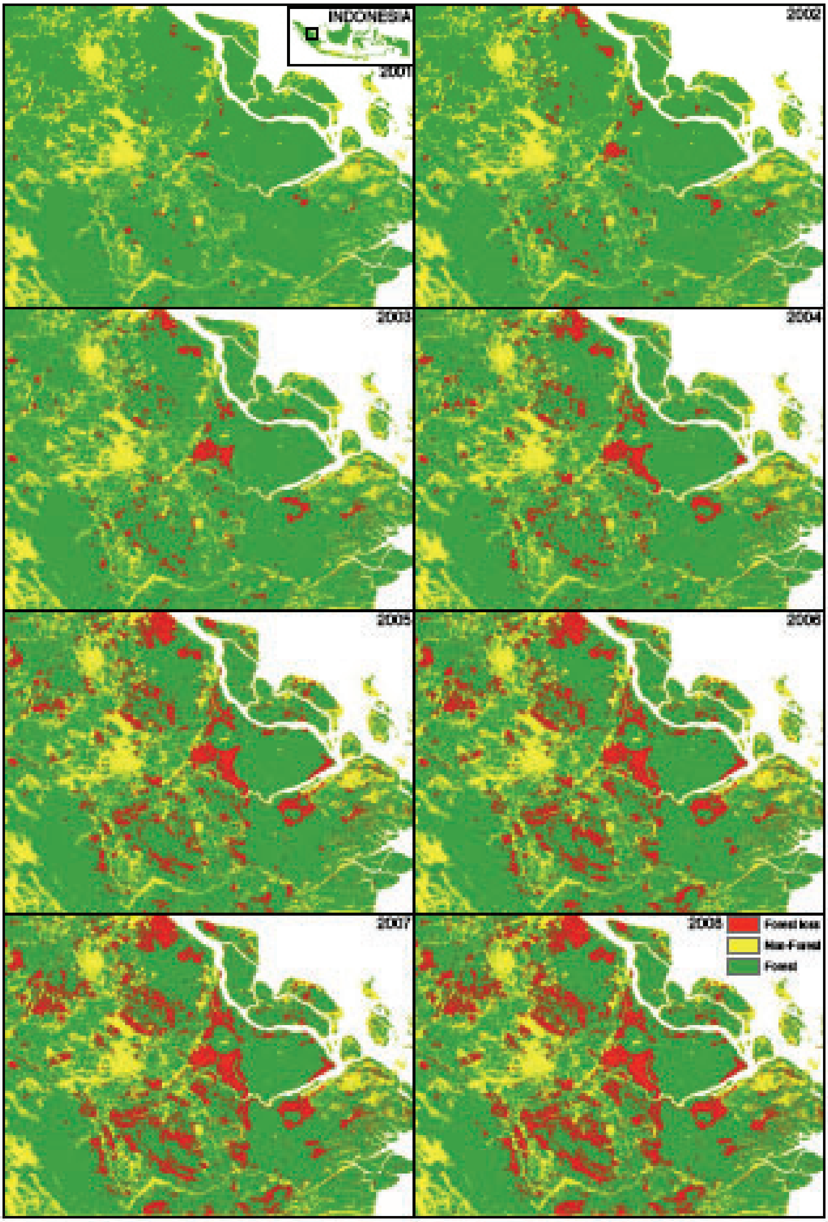
In an earlier paper, Burgess et al. (2012) look at how deforestation changed during rapid redistricting in Indonesia in the 2000s (Figure 7.7). By exploiting quirks in the timing of these changes, they show that redistricting led to more rapid deforestation. Their results are consistent with a model of Cournot competition in which the redistricting increased competition between districts for the revenue from legal and illegal logging.[2] A similar strategy has been used to investigate pollution in China, where the accuracy of official reporting has been called into question, with mixed results (Chen et al. 2012, 2013; Bombardini and Li 2019).

Even in the absence of outright falsification, the availability of a measure independent of traditional data sources is useful to reduce measurement error. Henderson, Storeygard, and Weil (2012) show this in combining data on lights growth with traditional GDP growth data. In essence, both lights and traditional GDP are subject to measurement error, but since the sources of their measurement error are very different, they are likely to be uncorrelated, and thus the two measures can be combined to form better estimates.[3] Pinkovskiy and Sala-i-Martin (2016) invoke a similar method in using lights to determine whether national accounts or household survey data provide more reliable estimates of national incomes.

CONCLUDING THOUGHTS

To highlight these six advantages of spatial data, I have described examples related to deforestation, pollution, urban growth, transporta-

Figure 7.7 Forest Cover in Riau Province, Indonesia, 2001–2008



SOURCE: Burgess et al. (2012), by permission of Oxford University Press.

tion, and political economy. There are many more in economics, on topics as varied as tourism (Faber and Gaubert 2019) and economic history (Pascali 2017), not to mention a much longer tradition in other fields, especially environmental science.

Another area that holds particular promise for the future is agriculture, especially in the developing world. It is not easy to learn a lot about crop choice or yield from a single satellite image. But once multiple images per growing season are available—or, even better, images every day—it starts becoming possible to learn an enormous amount about the agricultural economy. And with higher frequency high-resolution images, I expect that we will be able to learn about the choices of individual farmers at increasingly low cost.[4]

While I believe that this technology holds great promise, I do not want to give the impression that it can replace traditional data sources, or that it is without problems. The view from above is a powerful one, but it is not a complete one, and traditional administrative or survey data are critical to have in nearly all of the examples described above. Any given satellite image is a snapshot at one instant in time, not a summary of a day or a month that one could get, for example, from a pollution monitoring station. The most recent night-lights sensors,[5] for another example, provide data from two o'clock in the morning—as opposed to the early evening, as earlier satellites did—and so researchers will have to study whether that changes their relationship with economic activity. Satellites do not last forever, so repeat measurements over long periods require launching new satellites and adapting measurement techniques to them. It is still difficult to delineate objects like building footprints from a satellite image. Computers are getting better at that, but it's not yet routine, so it often requires lots of human labor. And while it is true that satellites generally operate the same way regardless of their location, context still matters. For example, an algorithm that is good at distinguishing a city from a surrounding forest does not always work as well in distinguishing a city from a surrounding desert. So, as in everything, it is important to know one's data well before attempting to interpret it.

To briefly summarize, satellites provide data for data-poor contexts, often at high resolution, with frequent repeat measurement, for the whole world, consistently across borders, in a way that is difficult to falsify because they are generally independent from traditional data providers. They are not magic, but as the price of data and processing power goes down and algorithms for analyzing them get better, they hold enormous potential for learning about economics and policy.

Notes

This chapter is based on the opening keynote address of the World Bank Land and Poverty Conference 2019, drawing on material from the Sichel Lecture delivered at Western Michigan University on October 10, 2018, and on Donaldson and Storeygard (2016). As Donaldson and Storeygard make clear, the economics literature using satellite data relies heavily on a much larger and older (but still rapidly developing) technical literature on the engineering and science of remote sensing.

1. For more details on satellite data and their use in economics, see Donaldson and Storeygard (2016), especially the references therein.
2. Note that redistricting could cause more mundane difficulties in reporting as well, as new district governments come into being, even in the absence of illegal motives.
3. This is slightly complicated by the fact that the units of the lights-based estimate are unknown. By analogy, if one weighs oneself with two different scales, both using kilograms as their unit of account, a simple mean of the two measurements is the optimal combination (unless one knows something about their relative precision). However, if one of the scales has an unknown unit of account, then its relationship to kilograms must be measured using the same data.
4. See Lobell (2013) and, for a recent developing-world example, Burke and Lobell (2017).
5. Visible Infrared Imaging Radiometer Suite (VIIRS).

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