Reaching Regions RR

Mapping Production Activity in Yukon: Experimental Estimates of Grid Square-Based Gross Domestic Product

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In recognition that more geographically granular economic data improves our ability to understand the nature of production, support regional economies, and address emerging socio-economic and environmental problems, statistical agencies are increasingly asked to produce gross domestic product estimates at finer levels of geography. This demand is being met in different ways around the world, with, for instance, the European Union producing gross domestic product estimates at the Nomenclature of Territorial Units for Statistics and the United States producing gross domestic product estimates at the county level. While Canada produces gross domestic product estimates for census metropolitan areas, it does not currently produce the same level of coverage for smaller geographies as does the European Union or the United States. This paper addresses this gap by developing grid square-based gross domestic product using the Yukon as a test case in 2019. The Yukon was chosen because its small resource- and government-based economy provides a challenging but comprehendible test of these fine-grained measures. This choice will also support ongoing work measuring the economies of circumpolar regions.

Keywords
Gross Domestic Product, Grid Squares, Remote Regions, Yukon, Regional Economic Analysis

JEL Classification
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1. Introduction

Greater geographic granularity improves analysts' and policy makers' ability to recognize issues, understand the nature of production, and support regional economies. For instance, deciding where to allocate resources to mitigate the risks from climate change requires linking geographically detailed information on hazards (e.g., flooding) with similarly detailed information on potential economic impacts. Measuring the effects of economic shocks (e.g., a commodity price collapse) may require highly localized data. Similarly, investments in transportation infrastructure may have positive or negative effects on businesses depending on how it changes their relative access to local markets. One of the key measures that can be used as an economic metric is gross domestic product (GDP), which is a measure of economic production of goods and services.

For over two decades, researchers have explored innovative methods to estimate GDP at fine geographies. These studies can be broadly divided into studies using sensor-based data (Ru et al., 2023; Ghosh et al. 2010; Yue et al., 2014; Doll et al., 2006; Chen et al., 2022) and studies that rely on population data (Murakami & Yamagata, 2019; Kummu Taka, & Guillaume, 2018; Nordhaus, 2008, 2006). The goal has often been to produce a global map of how economic activity is distributed across regions to illustrate the utility of presenting GDP for small areal units.

The use of readily available sensor-based and population data is advantageous, because the geolocation of GDP can occur across the entire surface of the earth. The drawbacks are that the allocation models do not exactly align with the notion of GDP, and industrial information is often missing. For instance, studies using night-based luminosity (Ghosh et al., 2010; Doll et al., 2006; Chen et al., 2022) must assume that GDP occurs where lights are present. This method focuses attention on cities while limiting or omitting the production that occurs in rural areas (on farms, at hydro plants, at mines and in forests). Moreover, since these studies assume that GDP is dispersed per lumen, a downtown core or entertainment area with many lights will be accorded more GDP than an airport or manufacturing district that is more dimly lit. Similarly, studies that rely on population (Murakami & Yamagata, 2019; Nordhaus, 2006, 2008) assume that GDP and population are correlated. GDP, however, does not always follow population, particularly in more remote, resource producing regions (e.g., forest cuts or mine sites).[1]

Statistical agencies are also producing GDP estimates at finer and finer levels of geography. These estimates are made from the internal datasets of national statistics offices (NSOs) in different ways around the world and are based on political areas rather than fixed areal units. The European Union now produces GDP estimates based on the Nomenclature of Territorial Units for Statistics (Eurostat, 2022a, 2022b, 2022c), while the United States produces county-level GDP estimates (United States Bureau of Economic Analysis, 2022). Statistics Canada produces GDP estimates for census metropolitan areas (CMAs) (Statistics Canada, 2022a) but does not currently produce the same type of consistency for smaller geographies as do the European Union or the United States. These estimate GDP in a more production-

[1] These studies, such as Nordhaus (2006, 2008), often rely on more information than population to estimate GDP at a regional level (e.g., labour income by industry for US counties), bringing considerable information to bear on the problem. However, for sufficiently fine-grained grids, the use of population to allocated GDP can lead to biased estimates—that is, fine population grids (e.g., 1 km x 1 km) would tend to overestimate GDP of grid squares of residential areas with little economic activity and underestimate GDP of areas that are less populated such mining sites, industrial parks or ports within a region.

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consistent manner than sensor- or population-based allocation models and can potentially be used to produce industry statistics, but they lack the geographic precision of the small area fixed grids.

This paper spans the academic work and estimation strategies used in NSOs. It addresses the issue of producing geographically find-grained industry GDP estimates for Canada by exploring the measurement of subprovincial and subterritorial GDP using Yukon as a test case. Despite its small population and economy,[2] Yukon was chosen for several reasons. First, its small but broad-ranging resource- and government-based economy provides a challenging test requiring multiple sources and methods to allocate GDP to grid squares. Second, it is possible, given the small size of its economy, to use ground truth to assess whether the estimates make sense, and there are numerous secondary sources to do this. Lastly, Yukon was chosen to support ongoing work measuring the economies of circumpolar regions.

Once the decision is made to measure GDP for finer-grained geographic areas, such as employment zones within a city or areas affected by wildfires, administrative boundaries begin to make less sense. An ideal system of measurement would facilitate placing GDP where production occurs and use geometries that are sufficiently detailed and consistent through time so that economic relationships can be more effectively measured and tested. It is to satisfy these requirements that a 1 km x 1km fixed grid was chosen.

There are several specific benefits to grid squares worth noting. First, they allow users to build geographies that are customized to their specific question. For instance, questions of the level of output potentially affected by flooding often require fine-grained and customizable geographies. Second, by their nature they do not vary in size. Within Canada, a potential alternative to grid squares are dissemination areas (DA), which are the smallest geographic units for which census data are released (Statistics Canada, 2021). Importantly, because they must cover the land mass of Canada, some units cover very large areas but have few (if any) people. This can be seen in Figure 1 for the Yukon, where very large areas are covered by one DA, with much smaller DAs encompassing or dividing up more populated areas like Whitehorse. For economic activities that do not follow populations closely (e.g., resource extraction and infrastructure-driven GDP such as utilities), the geographic resolution of DAs is insufficient to meaningfully represent where economic activity takes place. Consequently, it is not possible to consistently relate with geospatial precision events that may affect an economic activity (e.g., forest fires) with production locations (e.g., road networks, industrial parks and logging sites) and the effect of the events (e.g., production disruptions or pollution of adjacent rivers). Finally, since the grids provide a standardized unit of measure that can be used to link data from multiple domains (e.g., weather or environment, topographical features, human activity, business activity, or health), the releasable estimates support the integration of GDP into the multidisciplinary examinations of phenomena that are increasingly required.[3]

[2] Covering 472,345 km^2 (Statistics Canada, n.d.), Yukon is larger than California (423,967 km^2) (United States Census Bureau, n.d.) and only marginally smaller than France (547,557 km^2) (World Bank, n.d.). Despite its size, in 2021, it had a population of just over 40,000 people (Statistics Canada 2022b) who produced $2.8 billion in GDP (in 2017 dollars) in 2019 (Statistics Canada, n.d.). In many parts of the world, this population would be comparable to that of a moderately sized town.

[3] There are several other benefits to fixed grids (and tessellations in general) that have been identified. They can help to mitigate (Arbia, 1989) and test for sensitivity of results to the modifiable areal unit problem (see Bemrose et al., 2017). They can also help to smooth out irregularities arising from population densities, present values that are truer to a real-world representation, do not condition on population when linking with other spatial data, and do not require conditioning on a census period (Lloyd et al., 2017). There also potential drawbacks to the use of grid

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Figure 1. Yukon 2021 dissemination area boundaries.
Source: Statistics Canada.

The remainder of the paper is organized as follows. The next section discusses how GDP measurement is undertaken. The following results section illustrates the geography of grid square GDP in the Yukon. This is followed by a brief conclusion.

2. Gross Domestic Product for Fine Geographies

GDP is a measure of production that allows analysts to track variation in economic output over time and across space. GDP is a place-based statistic that reports on the production that occurs within a boundary. To measure GDP based on a fixed grid, it is assumed that each grid square constitutes a separate economy and that the productive activity of institutional units (e.g., firms and governments) can be measured or allocated by grid square. This creates a predominantly bottom-up approach based on firm-level data for most industries that differs from the existing literature, which uses a top-down approach to allocate industry or regional GDP estimates to a grid square (Ru et al., 2023; Ghosh et al., 2010; Murakami & Yamagata, 2019; Yue et al., 2014; Doll et al., 2006; Nordhaus, 2006, 2008; Chen et al., 2022).

squares, such as the need to split them when crossing administrative boundaries where GDP estimates are made (e.g., provincial or territorial borders). There may also generate spatial correlations in measurement error if less geographically granular information is being used to spread GDP from aggregate levels to grid squares.

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This section briefly discusses the methods used to determine GDP of a particular grid square at a 1 km^2 resolution for the Yukon (see Bemrose et al., 2023 for more detail). There are four forms of measurement for determining GDP by grid square:

- *Direct measurement of business activity.* GDP is estimated directly from firm-level tax data and (for multi-unit firms) allocated to geocoded firm operating locations. Direct measurement is the most common type and is typically applied to industries where business activity is attributable to specific locations such as a manufacturing plant or retail location.[4]
- *Imputations for remote workplaces (natural resource activity).* Information where activity is occurring such as mine sites, areas of agriculture production and forest cuts are used to allocate Yukon-wide industry-level GDP to grid squares.[5] This approach is taken because GDP for natural resource production is predominantly reported at tax reporting locations (e.g., a head office located in a major urban center outside Yukon) rather than where economic output is being produced.
- *Imputations for production on networks.* For industries where production occurs on networks (i.e., transportation networks, power generation and transmission networks, communication networks, and water and sewer networks), spatial information related to network capital is used to allocate GDP values to grid squares. For example, the allocation model for truck transportation uses information on the road network and its quality.
- *Imputations for public sector activity.* Public sector GDP is allocated to locations where production occurs using geospatial information on government building sizes, on enrolment in schools, and information on the number and location of hospital beds published by the Government of Yukon.

From a practical perspective, imputations that involve spreading GDP across grid squares will tend to result in spatially autocorrelated measurement error, which will not be the case with direct measurement.

Regardless of the method, grid square GDP is benchmarked to add to Yukon industry totals for 2019. Across the four methods, 58.4% of GDP in 2019 is allocated based on direct measurement of business activity, while imputations based on spatial allocation models are employed for the remaining shares. Of these, the imputation for the public sector (35.1%) is the largest (see Table 1).

Table 1. Share of Gross Domestic Product by Allocation Method, 2019

	Remote workplaces	Networks	Direct observation	Public sector
Percent of GDP	3.6	2.9	58.4	35.1

Note: GDP = gross domestic product. *Source*: Statistics Canada.

[4] For industries like construction, economic activity is allocated to the operating location, which is where the firm is located rather than where construction is taking place.

[5] This follows a similar approach to Ru et al. (2023), where satellite image data are used to allocate agriculture, forestry, fishing and hunting GDP.

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3. Results

Presented below is a set of figures aimed at illustrating the geography of Yukon's GDP distributed by grid square. Presenting grid square estimates raises the problem of meeting confidentiality guidelines, as many will have only a few businesses. To address this problem, the levels of grid square GDP are not reported. Instead, grid squares are shaded to indicate relative intensity of production or simply colored black to indicate the presence of activity. While this approach is unsatisfactory if the estimates are to be compared with grid square GDP estimates elsewhere or over time, it does provide the reader with a clear sense of where production occurs and where it is most intense.

3.1 *Geography of economic activity in the Yukon*

To provide an overview, Figure 2 presents the geographic distribution of Yukon's GDP aggregated to a 10 km x 10 km nested grid square resolution. These larger grid squares are used because the sheer size of Yukon makes presenting the data with smaller grid squares difficult, in particular when using color to indicate intensity of economic output. Unlike sensor-based or population-based estimates for the spatial distribution of economic activity, Yukon's spatial GDP pattern closely follows the road network and production in mining areas around Dawson City, which are shaded blue to indicate lower GDP levels. Populated areas, such as Whitehorse and Dawson City, are orange to indicate higher GDP levels. These patterns come from the imputation methods used for network values that link GDP to the locations where the productive activity is occurring. They reflect the way in which economic dispersion is closely tied to society's ability to move goods around and highlight the importance that infrastructure networks have for supporting the economy. These patterns also reflect the stylized fact that density of population and density of networks are associated with higher GDP (the road, water, sewer, electrical and telecommunications grids are all densest in more heavily populated areas).

The highest GDP values occur in and around Whitehorse and Dawson City. They are two of the most populated centers in the territory and contain the largest number of businesses and important public sector entities. Much of the placer gold mining in Yukon occurs in the rivers around Dawson City. Public sector entities in the territory, including the territorial government, the hospital and Yukon University are all located in Whitehorse. Smaller communities have fewer businesses, often in the service sector (e.g., hotels, service stations, and retail stores) and also include public sector activity, such as police detachments, schools and health centers, which generate GDP.

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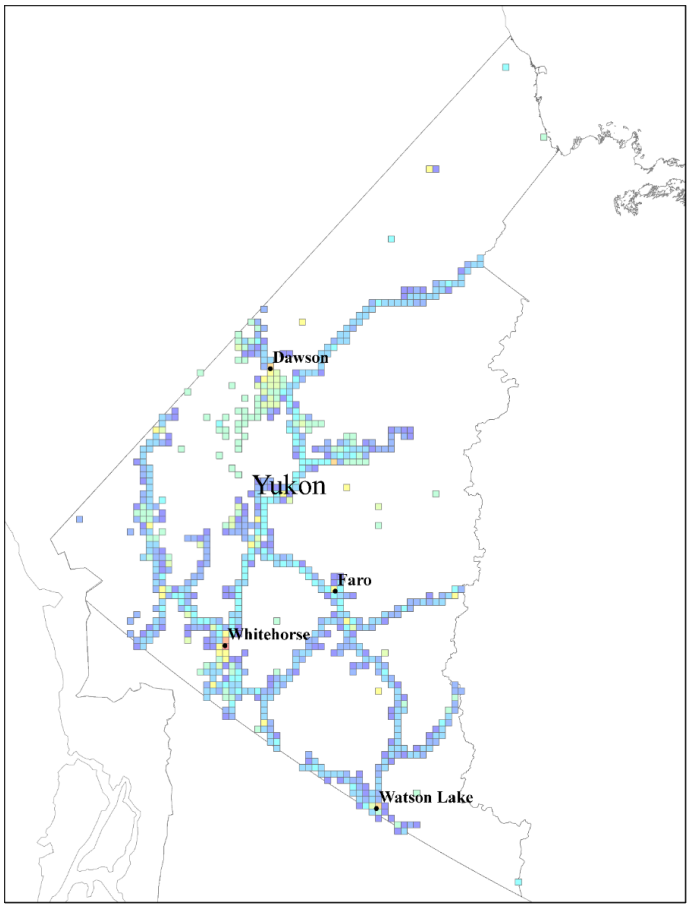

Figure 2. Total gross domestic product, 10 km x 10 km resolution, 2019.
Source: Statistics Canada.

3.2 Geographic patterns of economic activity by measurement type

The geography of grid square GDP can be further illustrated by mapping out GDP by measurement approach. Across the territory, as expected, industries that rely more on remote workplaces to produce GDP and network-based GDP are widely dispersed (Figure 3). Much of Yukon's rural GDP is attributable to these industries. Activities that are measured based on direct observation, such as manufacturing, wholesale trade, retail trade, and accommodation and food services, as well as public sector activities, are concentrated in and around populated areas that are, in comparison, few and far between.

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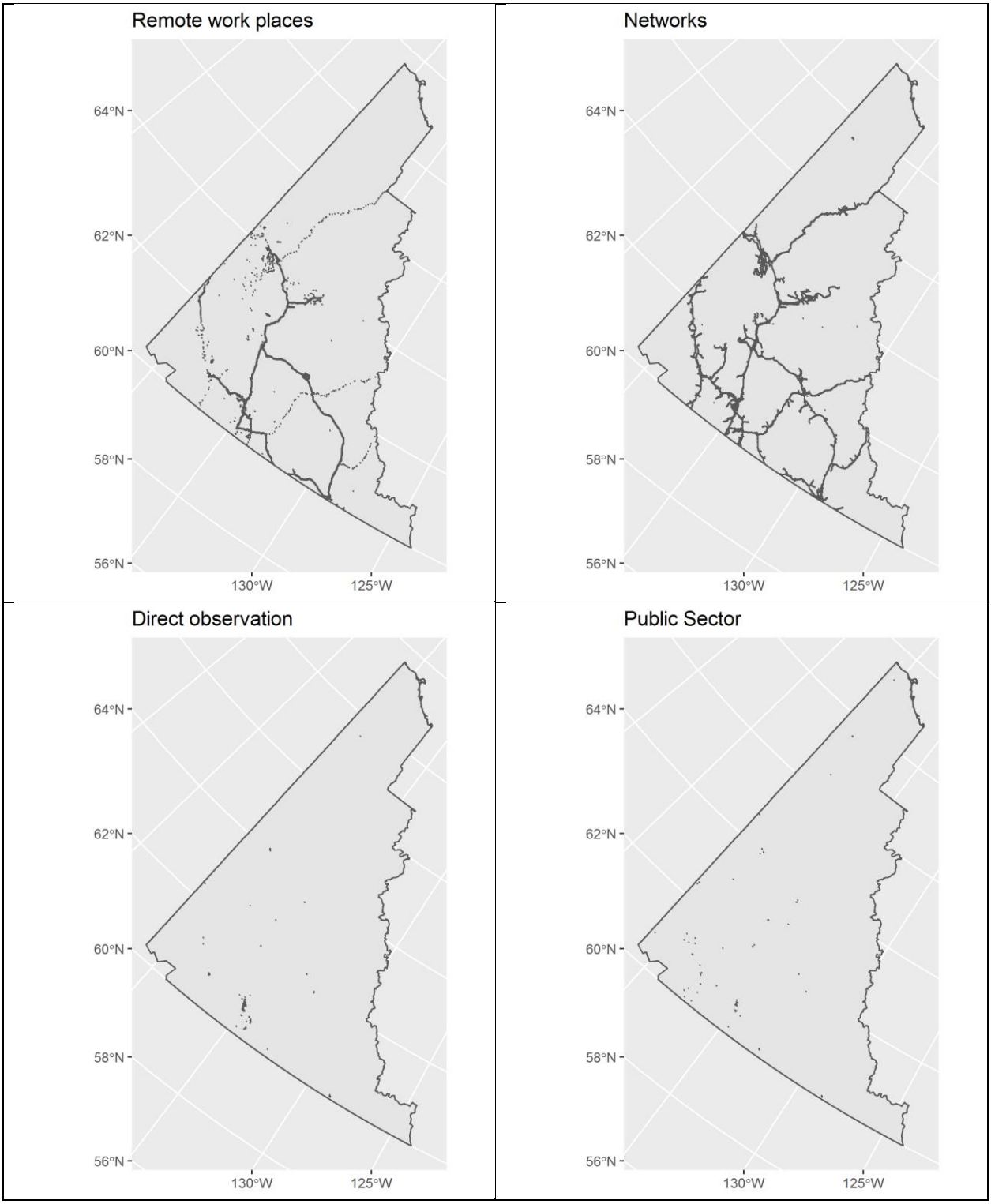

Figure 3. Gross domestic product by measurement approach, 1 km^2 resolution.
Source: Statistics Canada.

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The grids used as the basis for measurement can be spatially joined to other geographic features to illustrate the level and source of GDP in these areas. Grid values are joined with the Census Subdivisions (CSDs), which can be broadly thought of as municipalities, such that any grid square that overlaps with a CSD is considered to be associated with the CSD. To illustrate, Figure 4 provides an example for how this works for grid squares associated with the Whitehorse CSD and the Whitehorse, unorganized CSD. Even within the Whitehorse area, there are distinct patterns to the production of output. As a practical matter, this means municipalities, which often have limited information on their economic output, have a detailed picture of their economies and the consequences of disruption to them from, for example, flooding or forest fires.

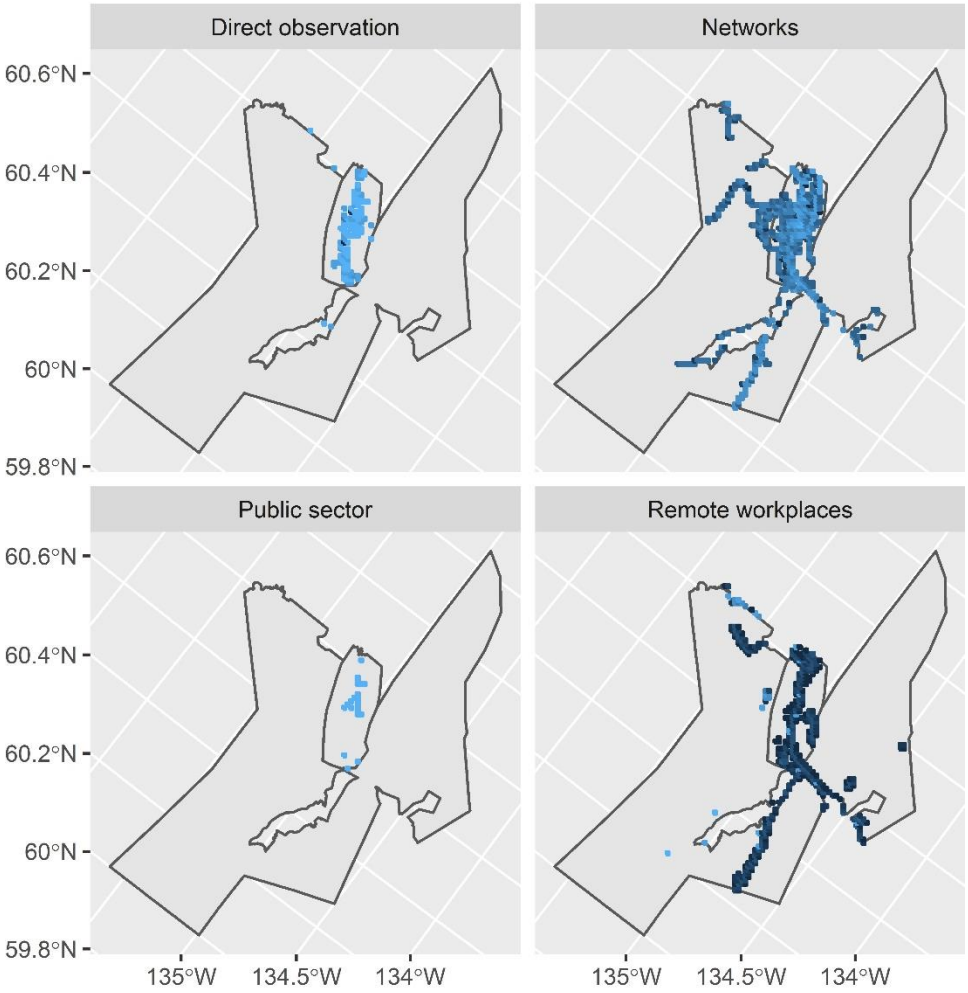

Figure 4. Gross domestic product for Whitehorse, 1 km^2 resolution.
Source: Statistics Canada.

3.3 *Geographic footprint of GDP*

Grid square GDP can also be summed to produce estimates for total GDP based on whether a grid square is associated with a CSD that is, in turn, associated with a populated place; a rural grid square that is used to produce GDP; and a rural grid square that is not used to produce GDP.

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When this is done, the land use patterns with respect to GDP creation can be visualized. This is shown in Figure 5, which illustrates the composition based on 100% of Yukon's 472,345 km^2 land mass fitting into a 687.3 km-sided square. The black square in the southwest corner shows the proportion of the land mass associated with populated areas that is used to produce GDP, while the addition of the red strip around the black square adds the area associated with GDP production in rural areas. The sum of the black square and the red strip equals the total land mass used for GDP, which sums to 9.1%. The majority of the land mass is not used for production. Across areas producing GDP, the majority is associated with populated areas that account for 2.8% of the land mass but 84% of GDP. The other 6.3% of the land mass used for GDP in rural areas occurs along road systems, electrical grids and the rivers outside Dawson accounts for 16% of GDP. From the perspective of GDP measurement, the remaining 89.9% of Yukon's territory is "not there."

The use of the grid squares illustrates how the boundaries of GDP measurement in more remote places in the north can skew how economic activity is viewed and is a potential means to integrate GDP measurement with other types of land use. It is important to keep in mind that for many people living in Yukon, the unpopulated, wild areas are used for hunting, fishing, gathering and participating in traditional practices. For Indigenous people, who make up just under one-quarter of the population in Yukon (Statistics Canada, 2022b), hunting and fishing are an important source of food. These activities constitute the land-based economy that can be an important source of nutrition and community well-being in remote places (Natcher, 2009). Moreover, they may in the longer run provide measures that could supplement current GDP measures for understanding geo-spatial land use patterns.

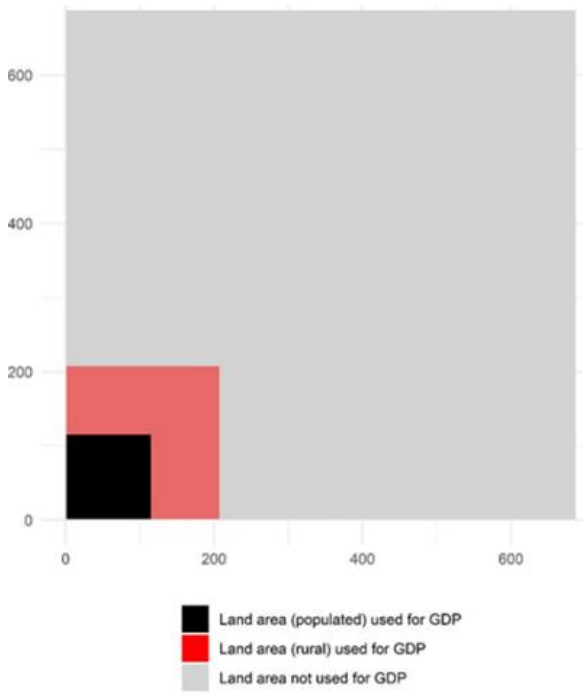

Figure 5. Land use shares for creation of gross domestic product, populated areas and rural areas.

Source: Statistics Canada.

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4. Conclusion

This project provides a first look at how grid-based GDP estimates can be constructed for Canada. It makes the argument that fine-level geographies for business statistics are better produced using a fixed grid system than census geographies. Fixed grids, once rendered anonymous, provide a remedy for this issue because the values within a grid can be aggregated into other geographies and followed consistently through time.

For cases where production occurs at a business location, firm activity can be geolocated based on latitude and longitude. However, there are cases where business activity does not occur at a business office. They include activities carried out on networks (e.g., transportation and utilities) and at job sites (e.g., extractive activities). For the former, imputation models are used to combine the infrastructure that undergirds the network with GDP values. The models used provide estimates that are sufficient for examining the distribution of activity in Yukon on an experimental basis. They can be improved upon in a number of ways, including refining the data and methods to allocate GDP to grid square locations and, in the context of Yukon, considering extending the current boundaries of GDP to other forms of production that require imputation, such as hunting and fishing for personal consumption.

More broadly, this work speaks to the potential power of combining confidential data that reside in NSOs with publicly available information to provide geographically fine-grained measures of economic production. Policy makers are often confronted with questions that require very detailed geographic information to understand and, if need be, address. How are resources to be allocated to mitigate the potential effects of climate change? What are the potential impacts of infrastructure investments on business populations? How far and wide do economic shocks (both positive and negative) propagate and what are their long-term economic and social effects on communities. Moreover, answering these questions often entails combining data that cross domains, requiring the integration of economic, social, and/or environmental data. A common, fixed grid provides a potentially efficient and effective means to combine measures across space and time.

From a North American perspective, the Yukon is a geographically large but remote place with a small population and economy. It serves as a test case for researchers interested in improving measures of remote economies, especially in the north. It also serves as a point of departure for future work. The increasing availability of precisely geocoded information on businesses from both public and private sources provides an opportunity to expand these measures to larger economies.

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