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

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Table of contents

Abstract

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 (GDP) estimates at finer levels of geography. This demand is being met in different ways around the world, with, for instance, the European Union producing GDP estimates at the Nomenclature of Territorial Units for Statistics level and the United States producing GDP estimates at the county level. While Canada produces GDP 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 subprovincial and subterritorial grid square-based GDP using Yukon as a test case. 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. With this in mind, the paper has three objectives. First, it introduces and discusses the benefits a fixed grid for measurement. Second, it discusses how the measurement of fine-level aggregates relates to concepts within the System of National Accounts. Third, it identifies the types of data necessary to estimate GDP across a 1 km^2 grid and produces a set of grid-based GDP estimates that serve to describe the geography of economic output in Yukon.

1 Introduction

Greater geographic granularity improves analysts' and policy makers' ability to recognize issues, understand the nature of production and support regional economies. For over two decades, researchers have explored innovative methods for estimating gross domestic product (GDP) at fine geographies. These studies can broadly be 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. 2002) and studies based on population data (Murakami and Yamagata 2019, Kummu et al. 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 missing. Studies using night-based luminosity (Ghosh et al. 2010, Doll et al. 2006, Chen et al. 2002) 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 based on population (Murakami and Yamagata 2019, Nordhaus 2008, 2006) assume that GDP and population are synonymous. Therefore, they will also overestimate GDP of populated grid squares and underestimate GDP of unpopulated areas such as rural locations, industrial parks or ports. These concerns can be partially addressed by adding additional sensor data (on agriculture, airports and roads) (Ru et al. 2023, Murakami and Yamagata 2019, Yue et al. 2014), but this is only a partial adjustment because only specific industries and assets will be accounted for.

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 2022 a, b, c), while the United States produces county-level GDP estimates (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 does the European Union or the United States. These estimates geospatially locate GDP in a more production-consistent manner than sensor- or population-based allocation models and can potentially be used to produce industry estimates. But they lack the specificity of the small area fixed grids.

This paper spans the academic work and estimation strategies used in NSOs. It addresses the issue of producing fine, grid-level geography estimates for Canada by exploring the measurement of subprovincial and subterritorial GDP using Yukon as a test case. The goals of the paper are threefold. First, it introduces a fixed grid for measuring Canadian GDP. This grid is measured at a 1 km^2 resolution to improve granularity of subterritorial estimates. Second, the paper discusses how the measurement of fine-level aggregates relates to concepts within the System of National Accounts 2008 (SNA 2008) (United Nations et al., 2008). It illustrates how internal NSO datasets can be combined with allocation models to produce geospatially disaggregated values by industry. Third, the paper identifies the types of data necessary to estimate GDP at such a fine resolution and produces a set of estimates based on a 1 km^2 grid. These estimates are then shown on maps and used to produce urban–rural GDP estimates for Yukon.

Covering 472,345 km^2(Statistics Canada, n.d.), Yukon is larger than California (423,967 km^2) (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 $2.9 billion in GDP (in 2012 dollars) (Statistics Canada(n.d.). In many parts of the world, this population would be comparable to that of a moderately sized town. Despite its small population, Yukon was chosen as a test case 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.

Each of the paper's three goals is discussed within a separate section of the paper. The use of a fixed grid is discussed in Section 2, while the relationship between fine geographies and the notions of GDP in the SNA 2008 is explored in Section 3. Section 4 discusses how measurement is undertaken. Section 5 illustrates several sample outputs and examines issues for publishing fine-level data. Section 6 concludes.

2 Census geographies versus fixed grids for measuring gross domestic product

GDP is used to measure economic growth over time and compare the size of economies across space. Internationally, NSOs accomplish this by measuring GDP within national borders, while domestically this is done by using subnational administrative units like provinces, states or counties. Once the decision is made to measure GDP for finer-grained geographic areas, such as employment zones within a city or areas susceptible to flooding, 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 so that economic relationships, such as the relationship between infrastructure investment and economic growth, can be more effectively measured and tested.[1]

Within Canada, the traditional starting point for small area geographic information is the dissemination area (DA). A DA is defined as

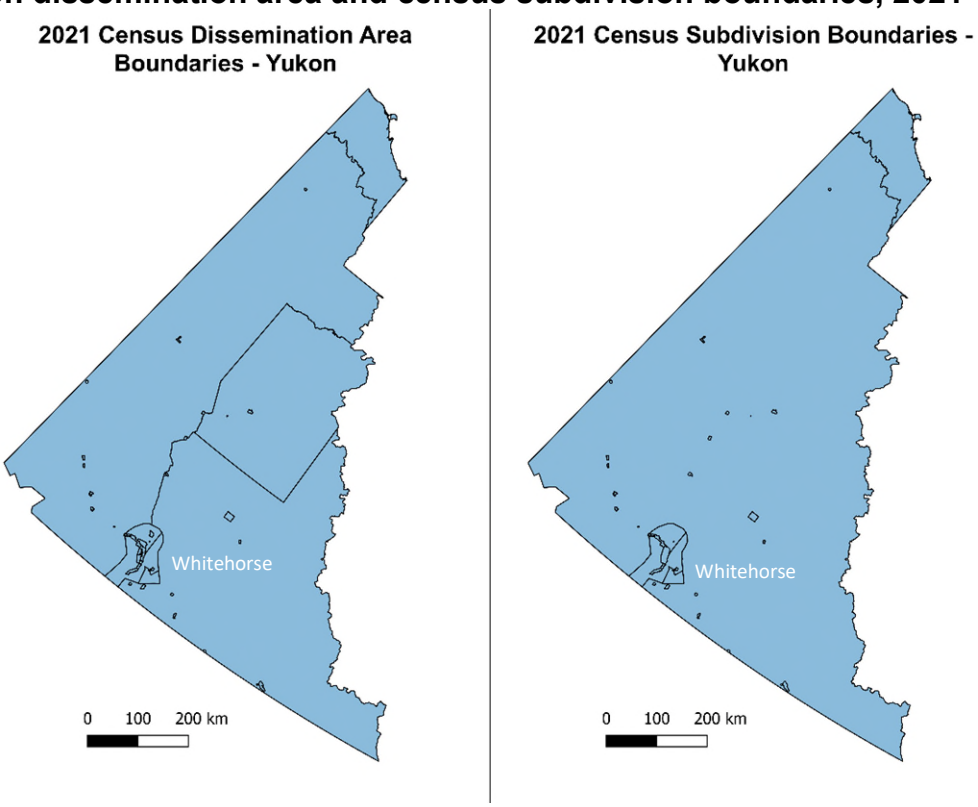
> … a small, relatively stable geographic unit composed of one or more adjacent dissemination blocks with an average population of 400 to 700 persons based on data from the previous Census of Population Program. It is the smallest standard geographic area for which all census data are disseminated. DAs cover all the territory of Canada (Statistics Canada 2021).

While typically populated, DAs can have no population. Importantly, because they must cover the land mass of Canada and the population of Canada is not equally distributed, some units cover very large areas but have few (if any) people, while others may have a large number of individuals but a small area. As a general rule, urban geographies are fine grained. This can be seen in Figure 1 for Yukon, where very large areas are covered by one DA, with much smaller DAs encompassing or dividing up more populated areas like Whitehorse. In addition to varying in size, DAs also have irregular shapes. As Statistics Canada (2021) explains, "DA boundaries usually follow permanent and visible features on the ground, such as roads, railways, water features and power transmission lines. A small number of DA boundaries also follow imaginary lines, such as street extensions, utility or transportation easements, and property lines."

1. The development of grid-based GDP is hardly new. Ru et al. (2023), Ghosh et al. (2010), Murakami and Yamagata (2019), Yue et al. (2014), Doll et al. (2006), Nordhaus (2008, 2006), and Chen et al. (2002) have all produced such estimates, albeit usually using larger grids than those used in this work. Grid squares have also been successfully used to produce data in Finland and Sweden since the late 1990s (Tammilehto-Luode and Becker, 1999).

The highly varying sizes and shapes of DAs limit their capacity for analysis. First, the units have greatly differing shapes and areas that, while having a utility for population studies, are of limited use for integration with other data sources that are often finer grained (e.g., climate or land use data). Perhaps more important, geographically large DAs are of more limited analytical use beyond the Census of Population. This limitation occurs because the census geographic boundaries are conditional on the needs of the census rather than the information being analyzed. As Figure 1 illustrates, there are four DAs that cover most of Yukon's land mass, with many population centres stamped out of them. 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 is taking place. Consequently, it is not possible to consistently relate with geospatial precision events that may affect an economic activity (e.g., flooding or 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).

Figure 1
Yukon dissemination area and census subdivision boundaries, 2021



Source: Statistics Canada.

Current census geography aggregation structures use DA boundaries to build up to census subdivisions (CSDs) (see Figure 1), CMAs or economic regions (ERs) (Statistics Canada 2021). The higher-level aggregations have irregular boundaries that are subject to change across census cycles and can overlap (e.g., CMA and ER boundaries). The result is an analysis that must be conditioned on a census cycle; this can present considerable issues for residual disclosure when used with the business data that underlie GDP estimation.

The use of a fixed grid alleviates a majority of these problems and brings additional benefits. A fixed grid:

- allows for standardized and simplified analysis
- helps to mitigate (Arbia 1989) and test for sensitivity of results to the modifiable areal unit problem (see Bemrose et al. 2017)
- smooths out irregularities arising from population densities
- presents values that are truer to a real-world representation
- does not condition on the population when linking with other spatial data
- does not require conditioning on a census period (Lloyd et al. 2017).

The use of a fixed grid also supports the release of information that respects the confidentiality provisions of the *Statistics Act* while presenting consistent intertemporal and spatial information. The use of small areas presents challenges for preserving confidentiality, in particular for business data, where 1 km^2 grid squares often contain just a few businesses, especially in rural, sparsely populated areas. However, methods like random tabular adjustment and the use of open-source data can help to overcome these issues. Moreover, once in a publishable state, the grid values can be aggregated into any other geography or geometry that is desired. And, 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 Gross domestic product for fine geographies

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 and Yamagata 2019, Yue et al. 2014, Doll et al. 2006, Nordhaus 2008, 2006, Chen et al. 2002). In deciding to begin with institutional units, the approach used here builds on the datasets for estimating GDP housed within NSOs. These baseline concepts then align with the recommendations of the SNA 2008 and the sixth edition of the Balance of Payments and International Investment Position Manual (BPM6). These manuals, especially the latter, have recommendations that focus on methods for measuring institutional units that cross geographical boundaries and others for dealing with multiterritory units.

This alignment is important, because the credibility of the grid square GDP estimates presented in this paper rests on their consistency with national accounting concepts, without which they would not be accepted by the agency or the analysts and policy makers who use agency data. Therefore, some time is spent in this paper drawing out these connections. Readers more interested in the concrete steps taken to develop grid-based GDP and what these estimates look like can skip to the next section without any loss of continuity.

The SNA 2008 and BPM6 have largely been created with the goal of developing statistics based on resident institutional units that are active within nation-states or governed areas. For example, SNA 2008 section 4.12 states:

> Economic territory has the dimensions of physical location as well as legal jurisdiction. The concepts of economic territory and residence are designed to ensure that each institutional unit is a resident of a single economic territory. The use of an economic territory as the scope of economic statistics means that each member of a group of affiliated enterprises is resident in the economy in which it is located, rather than being attributed to the economy of location of the head office.

This creates dual criteria for an economy that includes legal and geographic considerations. In discussing which institutional units to identify with an economy, the SNA 2008 (4.10) also notes:

> The residence of each institutional unit is the economic territory with which it has the strongest connection, in other words, its centre of predominant economic interest. The concept of economic territory in the SNA coincides with that of the BPM6. Some key features are as follows. In its broadest sense, an economic territory can be any geographic area or jurisdiction for which statistics are required. The connection of entities to a particular economic territory is determined from aspects such as physical presence and being subject to the jurisdiction of the government of the territory. The most commonly used concept of economic territory is the area under the effective economic control of a single government. However economic territory may be larger or smaller than this, as in a currency or economic union or a part of a country or the world.

While geared towards larger areas with a notion of political control, the SNA and BPM6 do note that statistics can be generated for any area of interest. The small, fixed grid squares discussed here therefore fall within their definition of economic territory, albeit towards its logical extreme. Nevertheless, the recommendations from the manuals still apply and the grid based economic area / economic territory can be used to determine which institutional units are active within it. The measurement is most clearcut for small businesses that are the institutional units in question and which have a single location that can be located within a grid square. However, it poses some challenges for the use of grids in cases where the production by an institutional unit occurs over a large area.

There are four cases where this occurs. The first is natural resource use and extraction, where production activity takes place over large and often remote areas. The second is production that occurs over networks (e.g., communications, railways, trucking or airlines). The third is production that occurs within large, complex firms. The fourth is public sector production, in particular public administration.

To implement measurement of production within the grid for these cases, the notion of a multiterritory institutional unit is adopted. The multiterritory unit is discussed in BPM6, which states:

> In the case of a multiterritory enterprise, it is preferable that separate institutional units be identified for each economy, as discussed in paragraphs 4.26–4.33. If that is not feasible because the operation is so seamless that separate accounts cannot be developed, it is necessary to prorate the total operations of the enterprise into the individual economic territories. The factor used for prorating should be based on available information that reflects the contributions to actual operations. For example, equity shares, equal splits, or splits based on operational factors such as tonnages or wages could be considered. Where taxation authorities have accepted the multiterritory arrangements, a prorating formula may have been determined, which should be the starting point for statistical purposes. Although the situation is somewhat different from the case of joint administration or sovereignty zones, discussed under economic territory in paragraph 4.10, the solution of prorating may be the same.
>
> The proration of the enterprise means that all transactions need to be split into each component economic territory. The treatment is quite complex to implement. This treatment has implications for other statistics and its implementation should always be coordinated for consistency. Compilers in each of the territories involved are encouraged to cooperate to develop consistent data, avoid gaps, and minimize respondent and compilation burden, as well as assist counterparties to report bilateral data on a consistent basis.

In the four cases, different methods of prorating (imputing or allocating) are employed depending on the type of production present. This allows each grid to be treated as a separate economy for which a GDP value can be computed.

4 Measuring spatial gross domestic product

This section discusses the methods used to determine GDP of a particular grid square at a 1 km^2 resolution for Yukon. The discussion blends methods and data sources because, depending on the type of production activity, a different form of measurement is used. The form of measurement is based on the way production occurs, and this dictates the type of data that is required. Because there are different approaches, the terms “prorate,” “impute” and “allocate” are used synonymously depending on the source or how they are commonly used for the models employed.

There are four forms of measurement for determining GDP by grid square:

1. direct measurement of business activity
2. imputations for remote workplaces and natural resources activity
3. imputations for production on networks
4. imputations for public sector activity.

The starting point for measurement is the supply and use tables produced by the Industry Accounts Division at Statistics Canada and the firm-level microdata compiled by the Economic Analysis Division. In all cases, GDP measurement is benchmarked to GDP at basic prices estimated by industry. For firm-level data, income-based GDP estimates formed by summing compensation of employees, gross operating surplus, taxes less subsidies on production and mixed income are compiled from administrative files and benchmarked to supply and use tables. They form the basis for the first approach. When this method is used, activity is geolocated to grid squares based on latitude and longitude from Statistics Canada’s Business Register (BR). For the second, third and fourth methods, different forms of spatial information (e.g., road networks, power grids, building footprints and school enrolments) are used to spread industry-level GDP estimates from the supply and use tables to the appropriate grid squares based on spatially appropriate allocation models determined by available data on that industry.

The subsequent subsections discuss the four different forms of measurement in greater detail. They explain why certain types of measurement are appropriate and why certain data sources are needed to facilitate this measurement. Table 1 reports the type of measurement used and the relevant data sources for a selected set of industries to illustrate the five forms of measurement. A full listing of industries is found in the appendix (see Appendix Table A.1).

Table 1
Data sources and imputation method by selected industry

NAICS code	Label	Measurement type	Source	Description	Vector	Approach
111	Crop production	Natural resources imputation	GeoYukon	Agricultural areas	Polygons	Allocate based on weight = area per grid cell/total area
21222	Gold and silver ore mining	Natural resources imputation	GeoYukon mining and exploration activities per	Hardrock mining locations Personal communication: Sydney.VanLoon@yukon.ca, Yukon Geological Survey	Points	Use points per grid cell/total points
2211	Electric power generation, transmission and distribution	Network imputation	Atlas of Canada Remote Communities Energy Database	Natural Resources Canada's Remote Communities Energy Database	Points	Use 0.75 × energy (kw) per grid cell/total kw
			GeoYukon Yukon Energy Corporation Power Lines	GeoYukon	Lines	Use 0.25 × length per grid cell/total length
			GeoYukon Yukon Energy Corporation Distribution Lines	GeoYukon	Lines	Use 0.25 × length per grid cell/total length
31	Manufacturing	Direct measurement/ firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
481	Air transportation	Network imputation	Our Airports	List of Yukon airports with their size and coordinates	Points	Use size of airport
484	Truck transportation	Network imputation	Census of Population	Road Network File	Lines	Use rank × length per grid cell/total length
6111	Elementary and secondary schools	Public sector imputation	Open government enrolment data	Enrolment by school and grade for all Yukon schools Combination of different Internet searches to find the school locations	Points Coordinates for schools	Use enrolment/total enrolment
622	Hospitals	Public sector imputation	Combination of different Internet searches to find the hospital locations	Coordinates for hospitals	Points	Use number of beds
911	Federal government public administration	Public sector imputation	Directory of Federal Real Property	Directory of Federal Real Property	Points or polygons	Use buildings per grid cell/total buildings
914	Aboriginal public administration	Public sector imputation	Open Data Canada First Nations Locations	Points	First Nations geographic locations	Use points per grid cell/total points

Notes: NAICS = North American Industry Classification System; GDP = gross domestic product.
Source: Statistics Canada.

4.1 Direct measurement

Direct measurement is the most common type of measurement and is typically applied to industries where business activity is attributable to specific locations (e.g., manufacturing [North American Industry Classification System (NAICS) 31 to 33], wholesale trade [NAICS 41] and retail trade [NAICS 44 to 45]). It relates business activity to a business location based on information from the BR, a comprehensive statistical frame that provides information on the size (e.g., employment) and structure of businesses, from the full enterprise down to individual statistical (operating) locations that are geocoded. In urban areas, geolocation data are accurate at the block-face level. However, for rural locations and many small towns, the postal code information employed to geolocate firms is less precise leading to less accuracy.

Based on these structures, two types of direct measurement are employed, both of which come from files designed to measure GDP by firm size that link to the BR. The first type is for small businesses. They are single-location firms that can be geolocated using latitude and longitude coordinates from the BR. In these cases, GDP of the firm is located in the grid square where it falls.

The second type is for complex businesses. They can be multilocation businesses in the BR that correspond with the notion of a multiterritory enterprise from the BPM6. The value added for these businesses is calculated at the ultimate parent level (highest level possible) and then allocated through the different levels recorded in the BR to reach the location level based on employment values or the number of business locations.

Allocation is performed for incorporated firms based on employment and the structure of the firm. Large firms have a structure on the BR that resembles an organization chart. Employment values can be recorded at any node but are typically recorded above production or service locations. In some cases, the BR provides estimates for employment by location. This information is used to help split values when it is present. When it is missing, an assumption that value added is equally split between locations is imposed. Non-employment variables such as profits are typically reported by a node that is high in the firm organization, such as a head office. These values are spread to locations based on employment and payroll values. In some cases, there may be missing values, and they are imputed at the location level using Markov chain imputation (Yuan, 2010). GDP values are then calculated and benchmarked to the industry-level values from the supply and use tables. Finally, the value of GDP for the location is located in the grid where it falls.

4.2 Remote workplace and natural resource imputations

GDP for remote workplaces and natural resources is predominantly reported where tax reporting locations are listed in Statistics Canada's data collection system. For major mining companies, reporting is likely to occur from their head office located in a major urban centre outside Yukon. For forestry companies, reporting does not occur in the timber harvest area. For agricultural activities, reporting occurs from farm or corporate head offices and not necessarily where agricultural production takes place.

To produce grid-based GDP estimates, it is therefore necessary to choose a method for allocating GDP to grid squares based on where an activity occurs.[2] Current data collection systems do not collect sufficiently detailed data to allow for this to be done at a firm level for all industries. Rather, allocations are made based on spatial data that coincide with the primary activity by NAICS code. In cases where point information can be obtained, it is used as a starting point. Points are production locations in remote areas, such as mine sites, where the latitude and longitude of the

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

location can be determined. Points are typically used when dealing with resource industries found in NAICS 21 (mining, quarrying, and oil and gas extraction). However, in some cases it is more appropriate to allocate GDP along lengths (lines) or within areas (polygons). Lengths are used, for example, when gold mining occurs along waterways, where the value is spread along the length of the rivers where the placer mining takes place. Finally, for some activities, polygons are used. Polygons represent enclosed areas such as farm fields (crop production [NAICS 111]) or pastures (animal production and aquaculture [NAICS 112]), as well as areas where there are forestry cuts (forestry and logging [NAICS 113]). For support activities, there is no indication for where the activities occur. These values are spread across the grid squares under the assumption that support activities for these industries occur where production of their associated industry takes place.

4.3 Network imputations

In several industries, production occurs on networks. This includes transportation networks, power generation and transmission networks, communication networks, and water and sewer networks. In these cases, spatial information related to network capital is used to allocate GDP values to grid squares. These allocation models use network-size, node and edge information to enrich the models. For example, the allocation model for truck transportation (NAICS 484) uses information on the road network in conjunction with information on road quality. In this way, paved highways are given a higher weighting than unpaved roads or lower-order surface streets. Similarly, airport capacity is used to spread air transportation (NAICS 481) GDP among Yukon airports and aerodromes.

4.4 Public sector imputations

Public sector GDP is composed of public administration (NAICS 91) and the public portions of educational services (NAICS 61) and health care and social assistance (NAICS 62). The latter two are predominantly composed of the public school system and hospitals.

Public sector activity in the BR is recorded at higher levels within organizations. For example, educational services activities are recorded by the school board or ministry of education, depending on the jurisdiction. As a result, using data based on tax filing locations will not cover public sector locations properly. To address this issue, public sector GDP is imputed to the locations where production occurs using geospatial information on building sizes (NAICS 91), data on enrolment in schools from open datasets published by the Government of Yukon (NAICS 61), and information on the number and location of hospital beds published by the Government of Yukon (NAICS 62).

Based on these four imputation methods, industry-level GDP from the provincial and territorial accounts is allocated to individual grid squares. This ensures that the grid-square estimates add up to published territorial GDP estimates. Across the four methods, 58.4% of GDP is allocated based on direct measurement, while imputations based on spatial allocation models are employed for the remaining share. Of these, the imputation for the public sector (35.1%) is the largest (see Table 2).

Table 2
Share of gross domestic product by allocation method

	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.

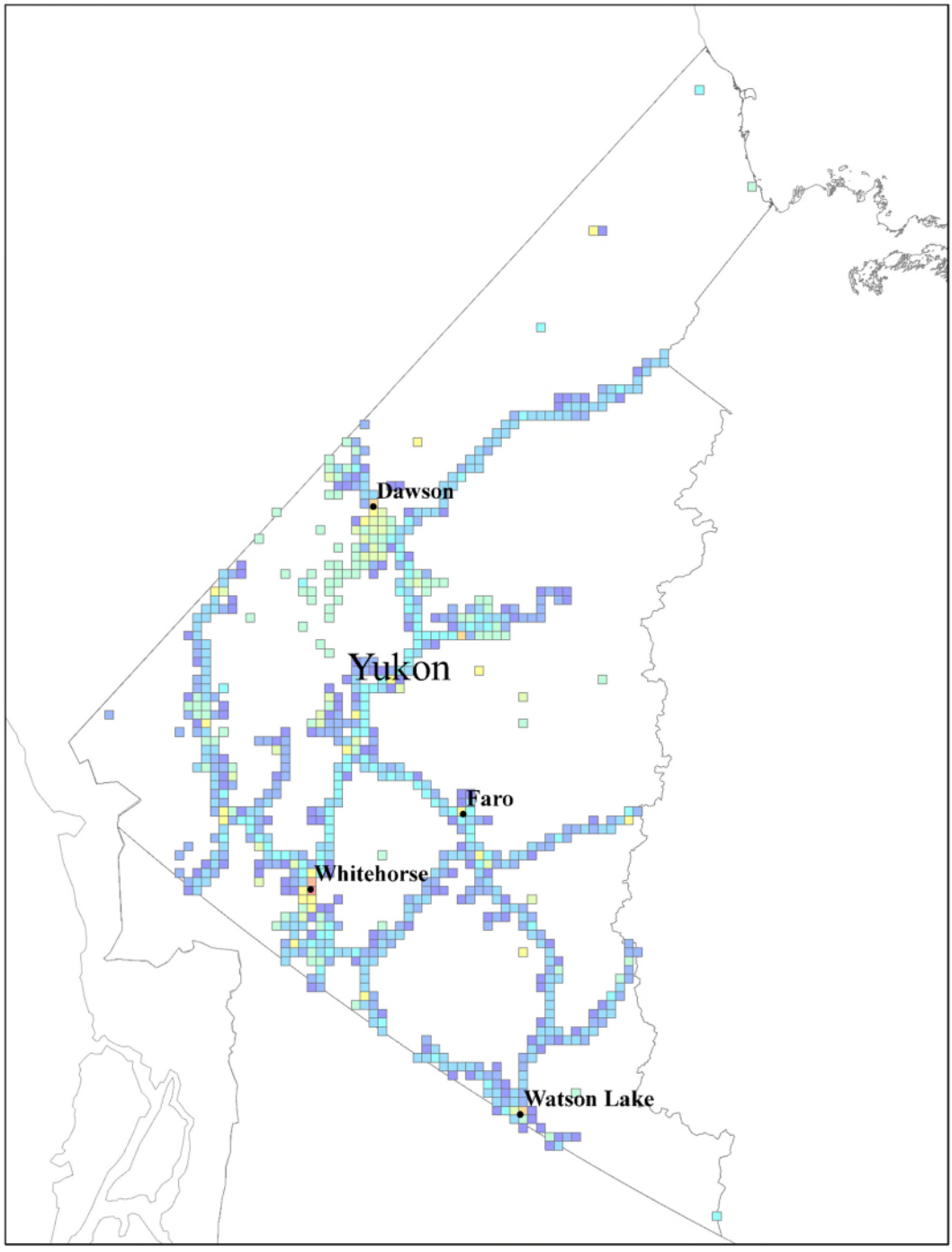
5 Results

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 coloured 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 is occurring and where it is most intense.

To provide an overview, Figure 2 presents the geographic distribution of Yukon's GDP aggregated to a 10 km^2 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 colour 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 coloured darker blue to indicate lower GDP levels. Similar to sensor- or population-based estimates, 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 place 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).

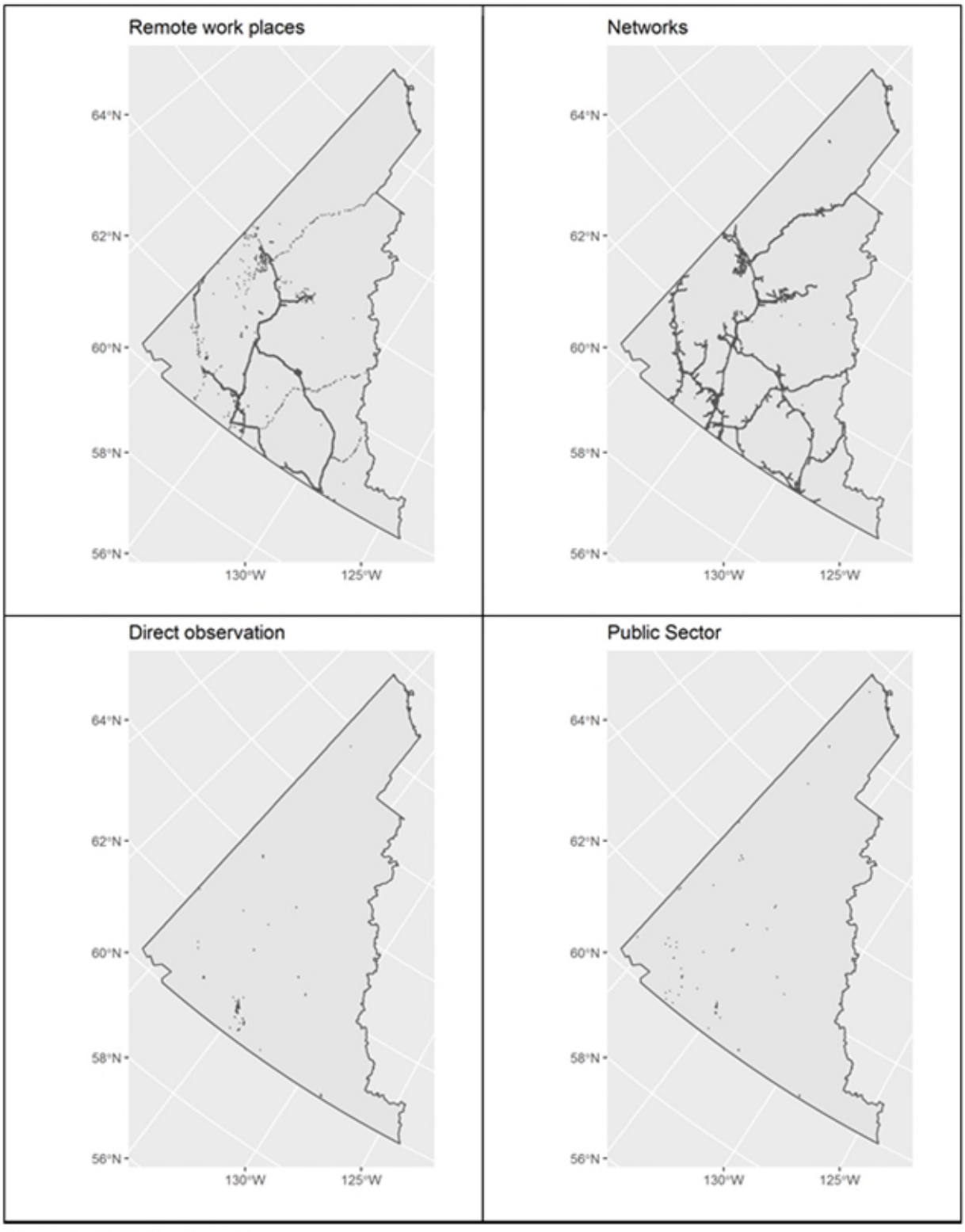
The highest GDP values occur in and around Whitehorse and Dawson City. They are two of the most populated centres in the territory and contain the largest number of businesses and important public sector entities. Much of the placer gold mining in Yukon occurs in the rivers around Dawson City. Public 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 centres, which generate GDP.

Figure 2
Total gross domestic product, 10 km^2 resolution



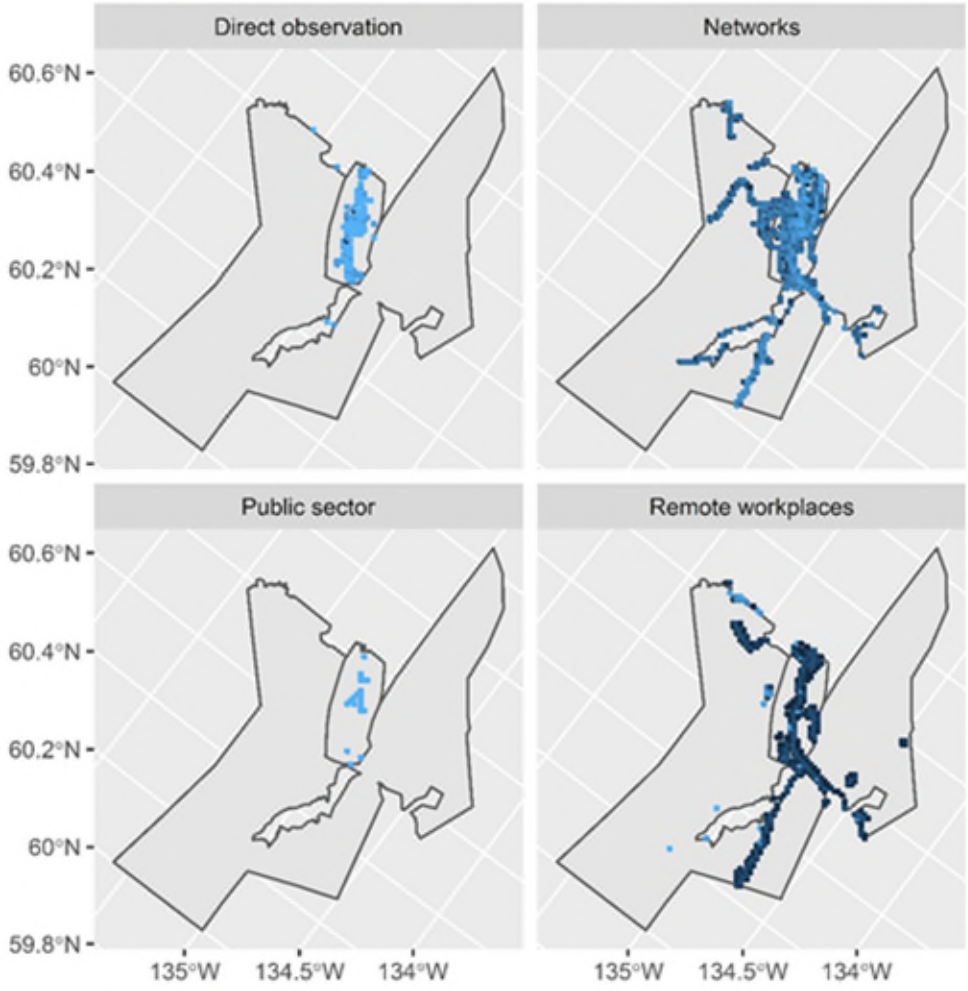
Source: Statistics Canada.

Figure 3
Gross domestic product by measurement approach, 1 km² resolution



Source: Statistics Canada.

Figure 4
Gross domestic product for Whitehorse, 1 km² resolution



Source: Statistics Canada.

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.

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 CSDs for Yukon 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 instance, flooding or forest fires.

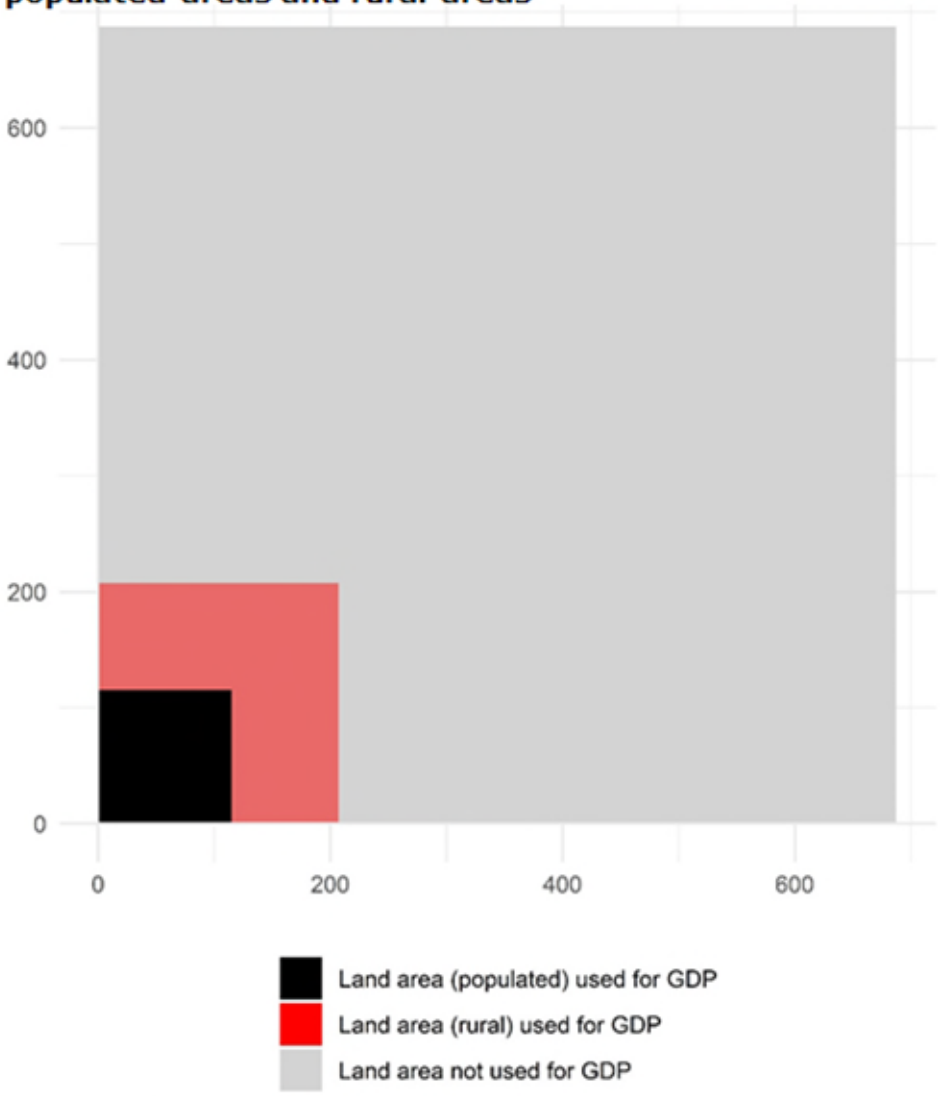
Grid square GDP can also be summed to produce estimates for total GDP based on whether a grid square is

1. associated with a CSD that is associated with a populated place
2. a rural grid square that is used to produce GDP
3. a rural grid square that is not used to produce GDP.

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. The majority of the land mass is not used for production—9.1% of the land mass at a 1 km^2 resolution is associated with activities contributing to GDP. Across these areas, the majority of GDP 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. 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 the national accounting system 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 (GDP), populated areas and rural areas



Source: Statistics Canada.

6 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. In doing so, it illustrates how GDP measured within a grid aligns with concepts from official manuals for calculating economic statistics (SNA 2008 and BPM6) and provides different methods for measuring GDP by grid depending on the type of activity.

Census geographies are not uniform, are subject to change over time and can have overlapping aggregations. This produces several problems, with one of the most important being maintaining confidentiality. Census aggregations produce considerable risk for residual disclosure, limiting the amount of data that can be released. Fixed grids, once rendered anonymous, provide a remedy for this issue because the values within a grid can be aggregated into other geographies. Deciding on a method for creating confidentiality-conformant grid squares is presently a work in progress. Nevertheless, grid-based values can be placed in research data centres for use by academic researchers in their current form.

The methodologies presented in this paper for using a fixed grid align with concepts used to produce official statistics using the SNA 2008 and BPM6. In effect, each grid square is treated as a separate economy in which capital and labour are combined to produce GDP. 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 and construction). 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.

7 Appendix

Appendix Table A.1
Data sources and imputation method by industry

NAICS code	Label	Measurement type	Source	Description	Vector	Approach
111	Crop production	Natural resources imputation	GeoYukon	Agricultural areas	Polygons	Allocate based on weight = area per grid cell/total area
112	Animal production and aquaculture	Natural resources imputation	GeoYukon	Agricultural areas	Polygons	Allocate based on weight = area per grid cell/total area
113	Forestry and logging	Natural resources imputation	GeoYukon cutting permits	Forest cut permits	Polygons	Allocate based on weight = area per grid cell/total area
114	Fishing, hunting and trapping	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Polygons	Use location of firm
115	Support activities for agriculture and forestry	Natural resources imputation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Polygons	Allocate values equally across grid squares for NAICS 111, 112 and 113
211	Oil and gas extraction	…	Zero value added in 2018	…	…	…
21221	Iron ore mining	…	Zero value added in 2018	…	…	…
21222	Gold and silver ore mining	Natural resources imputation	GeoYukon mining and exploration activities	Hardrock mining locations Personal communication: Sydney.VanLoon@yukon.ca, Yukon Geological Survey	Points	Use points per grid cell/total points
21223	Copper, nickel, lead and zinc ore mining	Natural resources imputation	GeoYukon mining and exploration activities	Hardrock mining locations	Points	Use points per grid cell/total points
21229	Other metal ore mining	…	Zero value added in 2018	…	…	…
21231	Stone mining and quarrying	…	Zero value added in 2018	…	…	…
21232	Sand, gravel, clay, and ceramic and refractory minerals mining and quarrying	Natural resources imputation	GeoYukon gravel pits	Gravel pits, maintenance, quarries and stockpiles	Points	Use points per grid cell/total points
21239	Other non-metallic mineral mining and quarrying	…	…	…	…	…
213	Support activities for mining, and oil and gas extraction	Natural resources imputation	Files for NAICS: 21222 and 21223	…	Points	Use points per grid cell/total points
2211	Electric power generation, transmission and distribution	Network imputation	Atlas of Canada Remote Communities Energy Database	Natural Resources Canada's Remote Communities Energy Database	Points	Use 0.75 × energy (kw) per grid cell/total kw
			…	GeoYukon	Lines	Use 0.25 × length per grid cell/total length
			GeoYukon Yukon Energy Corporation Distribution Lines	GeoYukon	Lines	Use 0.25 × length per grid cell/total length
2212	Natural gas distribution	…	Zero value added in 2018	…	…	…
2213	Water, sewage and other systems	Network imputation	Canadian Building Footprints	Building footprint clustered around infrastructure	Polygons	Use area per grid cell/total area
23	Construction	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Place value in location where tax file is located; data are not sufficient to allocate to building sites
31	Manufacturing	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
32	Manufacturing	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
33	Manufacturing	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid

… not applicable

Notes: NAICS = North American Industry Classification System; GDP = gross domestic product; and N/A = not available.

Source: Statistics Canada.

Appendix Table A.1
Data sources and imputation method by industry (continued)

NAICS code	Label	Measurement type	Source	Description	Vector	Approach
41	Wholesale trade	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
44	Retail trade	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
45	Retail trade	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
481	Air transportation	Network imputation	Our Airports	List of Yukon airport sizes with coordinates	Points	Use size of airport
482	Rail transportation	…	Zero value added in 2018	…	…	…
483	Water transportation	…	Zero value added in 2018	…	…	…
484	Truck transportation	Network imputation	Census of Population	Road Network File	Lines	Use rank × length per grid cell/total length
485	Transit and ground passenger transportation	Network imputation	Census of Population	Road Network File	Lines	Use length per grid cell/total length
486	Pipeline transportation	…	Zero value added in 2018	…	…	…
487	Scenic and sightseeing transportation	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
488	Support activities for transportation	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
491	Postal service	Network imputation	Combination of different Internet searches to find the post office locations and population from 2016 Census	List of post office locations with coordinates	Points	Use population
492	Couriers and messengers	Network imputation	Census of Population	Road Network File	Lines	Use rank × length per grid cell/total length
493	Warehousing and storage	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
511	Publishing industries	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation modelnit locations	Points	Allocate based on unit values in grid
512	Motion picture and sound recording industries	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
515	Broadcasting (except Internet)	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
517	Telecommunications	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
518	Data processing, hosting, and related services	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
519	Other information services	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
52	Finance and insurance	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
53	Real estate and rental and leasing	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
54	Professional, scientific and technical services	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid

… not applicable

Notes: NAICS = North American Industry Classification System; GDP = gross domestic product; and N/A = not available.

Source: Statistics Canada.

Appendix Table A.1
Data sources and imputation method by industry (continued)

NAICS code	Label	Measurement type	Source	Description	Vector	Approach
55	Management of companies and enterprises	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
56	Administrative and support, waste management and remediation services	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
6111	Elementary and secondary schools	Public sector imputation	Open government enrolment data	Enrolment by school and grade for all Yukon schools Combination of different Internet searches to find the school locations	Points Coordinates for schools	Use enrolment/total enrolment
6112	Community colleges and C.E.G.E.P.s	Public sector imputation	Yukon University	Yukon University community locations	Points	Use points per grid cell/total points
6113	Universities	Public sector imputation	Yukon University	Yukon University community locations	Points	Use points per grid cell/total points
6114	Business schools and computer and management training	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
6115	Technical and trade schools	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
6116	Other schools and instruction	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
6117	Educational support services	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
621	Ambulatory health care services	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
622	Hospitals	Public sector imputation	Combination of different Internet searches to find the hospital locations	Coordinates for hospitals	Points	Use number of beds
623	Nursing and residential care facilities	Public sector imputation	Combination of different Internet searches to find locations	Coordinates for buildings	Points	Use points per grid cell/total points
624	Social assistance	Public sector imputation	Combination of different Internet searches to find locations	Coordinates for buildings	Points	Use points per grid cell/total points
71	Arts, entertainment and recreation	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
72	Accommodation and food services	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
81	Other services (except public administration)	Direct measurement / firm allocation	GDP by firm size file	Small firms: Unit locations Complex firms: Allocation model	Points	Allocate based on unit values in grid
911	Federal government public administration	Public sector imputation	Directory of Federal Real Property	Directory of Federal Real Property	Points or polygons	Use buildings per grid cell/total buildings
912	Provincial and territorial public administration	Public sector imputation	Combination of different Internet searches to find the school locations	Points	Coordinates for buildings	Use size of building
913	Local, municipal and regional public administration	Public sector imputation	Combination of different Internet searches to find the municipal buildings	Points	Coordinates for buildings	Use size of building
914	Aboriginal public administration	Public sector imputation	Open Data Canada First Nations Locations	Points	First Nations geographic locations	Use points per grid cell/total points
919	International and other extra-territorial public administration	…	…	…	…	…

… not applicable

Notes: NAICS = North American Industry Classification System; GDP = gross domestic product; and N/A = not available.

Source: Statistics Canada.

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