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Using Satellite Imagery to Revolutionize the Creation of Tax Maps

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Globally, cities rely on property taxes as a key source of revenues to finance the services that enhance its long-term competitiveness and counter the negative aspects of density. In developing countries, the technical complexity of ensuring that tax rolls are complete and valuations current is often perceived as a major barrier to bringing in more property tax revenues. This policy paper shows how high-resolution satellite imagery makes it possible to assess the completeness of existing tax maps by estimating built-up areas based on building heights and footprints. Together with information on sales prices from the land registry, targeted surveys, and routine statistical data, this makes it possible to use mass valuation procedures to generate tax maps. The example of Kigali illustrates the reliability of the method and the potentially far-reaching revenue impacts. Estimates based on modelling show that heightened tax compliance and a move to a 1% ad valorem tax would yield a tenfold increase in revenue from public land.

Surface Model Derived Entirely from Satellite Imagery. | © Generated by GAF AG

Municipalities need property taxes to finance service delivery

The ability for cities to raise revenues in a non-distortionary way for effective urban service delivery and infrastructure is essential to realizing the potential of urbanization. As most benefits from these investments will be capitalized in surging land values, recurrent taxes on land and other real property can be an incentive-compatible financing method. In developing countries, taxes on land and property are still far below those of developed countries, even in relative terms. Instead, cities often rely heavily on land transaction taxes, but these impose frictions on land market operations, push transactions into informality, and create incentives for fraudulent under-declaration of sales values.

The technical complexity and high fixed costs of ensuring that tax rolls are complete and valuations current are perceived as major barriers to bringing in more property tax revenues. Often, less than 50% of taxable properties are on the tax roll, because maps to identify these are incomplete, out of date, or access to them is fragmented between government units. Using the example of Kigali, in our latest working paper, we demonstrate how high-resolution satellite imagery makes it possible to assess the completeness of existing tax maps, enhances their distributional fairness and facilitates the use of spatial mass valuation models or CAMA to impute the potential yield from tax policy changes.

Municipalities can use this approach to improve tax maps and build scenarios for identifying policies that best meet their needs. Using spatial imagery for updating tax maps is also useful for places with rapidly expanding urban growth not yet captured in official data, even although tax revenues could be quite buoyant. With a per km^2 cost of US$34 for imagery and $112 for processing of footprints and building heights the total cost for our study area of 340 km^2 was about US$40,000, with ample scope for further reductions.

Using land registration to enhance property tax collection in Rwanda

Rwanda stands out among African countries for having established a complete and fully digital registry of rights in 2012. This nationwide first-registration program recorded spatial and textual data for each of the 11.6 million parcels, assigned a Unique Parcel Identifier (UPI) to each, with all data captured in the Land Administration

Information System (LAIS). This UPI that is also used for the mortgage register and also the Rwanda Revenue Authority (RRA) uses the same UPI and can access the LAIS. The land registry is, somewhat surprisingly, not used for fiscal purposes and setting lease fees—the equivalent of property taxes—to identify properties, automatically bill owners for land lease fees owed or to send reminders. Moreover, the lease fees charged are still based on self-declaration and fail to consider changes in land values, albeit, reliable price data are available in the LAIS for some 85,000 recently transacted properties.

Tax collection efficiency

Overlaying tax and registry data made it possible to assess the tax collection gap. To compare potential to actual revenue from land lease fees, and estimate the potential for a more effective tax collection, we draw on 2015 parcel-level data for land tax revenue from the RRA, while using the UPI to link RRA tax collection and the LAIS data. Our analysis shows that collection rates are below a potential of $6.74 million, as only 30% of taxable residential parcels in urban Kigali paid lease fees in 2015. Thus, in Kigali alone, closing the tax collection gap could more than triple revenue. Efforts to reduce costs of tax compliance (e.g., automated billing, reminders, mobile payment, applying peer pressure) may thus have high returns.

Modeling changes in tax fee structures

To assess the effects of changing the fee structure from self-declaration to market values, we estimate hedonic property values by combining remote sensing and administrative data. As the property registry in Rwanda does not contain data on building characteristics needed for a mass valuation exercise, we drew on satellite imagery to generate information on built-up area. A spatial hedonic regression model was subsequently developed to estimate property values for urban Kigali. Our analysis of property values displayed that neighborhood characteristics and building volume affect residential property prices that, in fact, are not accounted for in the computation of current lease fees which is highly regressive and hence fails to maximize property tax revenue.

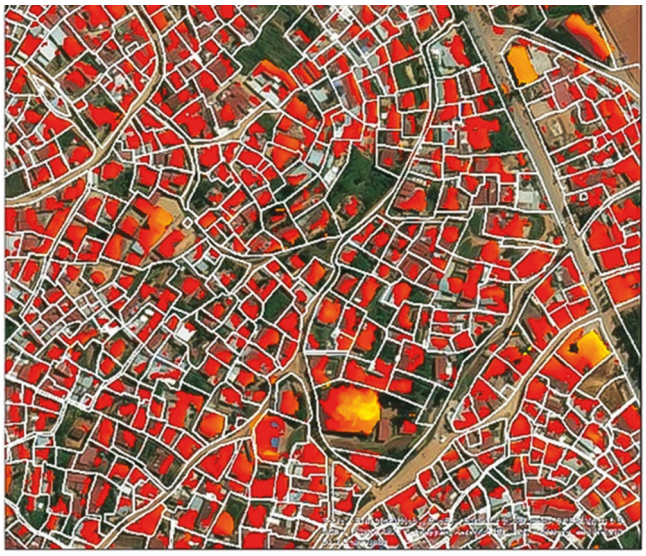
Data on building heights and the volume of built-up area were generated from processing high-resolution satellite imagery (see Figure 1). We overlaid the result, with boundaries of cadastral parcels obtained from LAIS to estimate building footprint and compute building volume. Together with information on sales prices for 85,000 properties from the land registry, targeted surveys, and routine statistical data, this makes it possible to develop spatial hedonic regression analysis for property prices for use in mass valuation models to generate tax maps and impute the potential yield from changes in tax fees and exemptions, thus laying the foundation for better-informed policy.

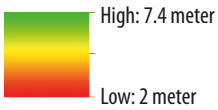
Using the current tax system, potential lease fees based on land value from all residential properties in urban Kigali sold in 2013–16, and for which the prices are available, would be US$ 552,923. A 1% flat rate of land value could raise some US$2.6 million—more than four times the current property tax yield (see Figure 1). Extrapolating this to all urban residential properties in Kigali suggests that a move from the current lease fee based on self-declaration at the time of registration, to a 1% updated value-based tax could increase revenue to between US$ 16 and US$ 19.3 million—almost 10 times what is currently collected, and would also spread the tax burden more equally.

Figure 1. Estimated building height

a. Central Kigali

b. Higher-Density Neighborhood





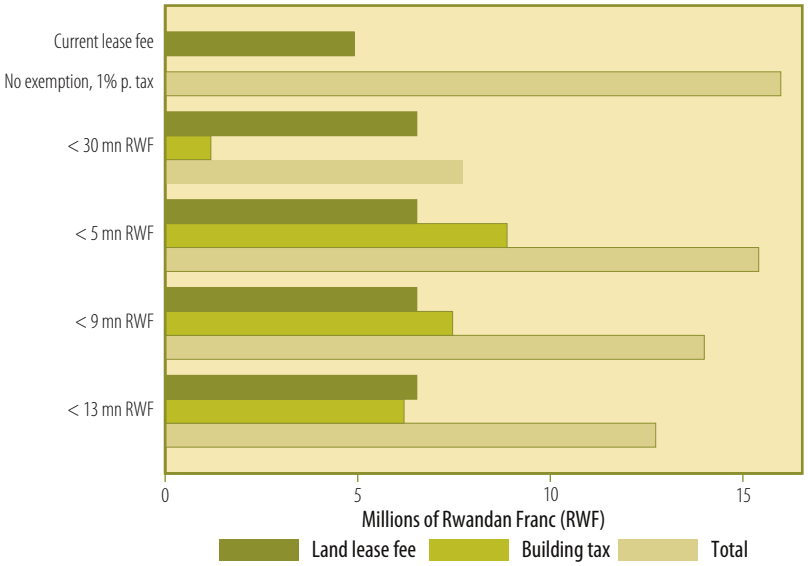
Costs of tax exemptions

Exemptions significantly reduce tax yield. For example, in Kigali city 60% (67,000) of all residential parcels and 99% of agricultural parcels are exempted from paying lease fees. A proposal being discussed in government circles is to levy separate fees on land and on buildings and adjust exemptions. The hedonic regression model developed allows to explore what would happen if taxes were levied only on land or if certain exemptions were adopted. Figure 2 projects the tax revenues for the various exemption options that are being considered by government. The model shows that while there may be scope for exempting those at the very bottom, those currently being discussed for 'low-cost housing' (i.e., less than RWF 30 million) are too generous: they would leave only 5% of properties with any building tax obligation.

Policy implications

The case of Kigali illustrates that high resolution remotely sensed imagery can be used to prepare a property inventory or "tax map", and reliably check the completeness of valuation rolls and generate data on property values that are needed to run automated mass valuation models at a fraction of the time and resources required by more traditional technologies. The imputed values on land and property, together with administrative records on taxes collected, allows us to provide information on (i) potential revenue gains from the full collection of current property taxes fees; (ii) likely yields from alternative rates, in the case of Rwanda a uniformly applied 1% valuation tax; and (iii) the implicit cost of exemptions. This approach can enable cities in developing countries to not only augment the financial resources at their disposal but also realize ancillary benefits in terms of ownership documentation and planning. Using such imagery, together with information on land prices, could reduce the cost of preparing tax maps and ground the debate on tax reform by providing more reliable data on which to base scenarios.

Figure 2. Predictions for estimated tax revenue in Millions of Rwanda Franc (RWF) from a 1% property tax with various exemptions on building tax levels and control areas before and during the project



Note: Results are based on the spatial error model and apply to our study area.

1. Current lease fee rates imply that 0.45% pay RWF 5/m2, 0.16% pay 10/m2, 14% pay RWF 30/m2, and 86% pay RWF 70/m2.
2. Building tax is 1% of building value exempting all structures with values less than the exemption threshold.
3. Threshold values: RWF 30 mn ((US$ 38,120), RWF 5 mn (US$ 4,927) is first quartile, RWF 9 mn (US$ 8,277) is median value, and RWF 13 mn (US$ 11,055) is mean value.
4. Land tax is RWF 70/m2 for area < 300 m2 plus RWF 105/m2 for area > 300m2.

This policy brief is based on Ali, Daniel Ayalew; Deininger, Klaus W.; Wild, Michael. 2018. Using Satellite Imagery to Revolutionize Creation of Tax Maps and Local Revenue Collection. Policy Research Working Paper; No. 8437. World Bank, Washington, DC. https://bit.ly/2GfXsXH.

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