How Much Would You Pay for a Satellite Image?

Lessons learned from French spatial-data infrastructure

CHADY JABBOUR, ANIS HOAYEK, PIERRE MAUREL, HÉLÈNE REY-VALETTE, AND JEAN-MICHEL SALLES

Satellite imagery is increasingly employed for land-use analysis and planning. In this article, we examine the economic value of high-resolution (HR) satellite images as perceived by direct users. Drawing on a French spatial-data infrastructure (SDI), the direct users of which are mostly from public bodies, we used a contingent-valuation method to evaluate their willingness to pay (WTP) for satellite imagery. A clear understanding of the value of these images is critical for justifying the large investments made in this sector and supporting policies that aim to develop and sustain these resources. We analyzed the differences in the stated values according to the various types of users. A survey of the registered users on the Geo Information for Sustainable Development (GEOSUD) platform found a mean value of €1,696 for a $60 \times 60\text{-km}^2$ HR image. Charging this amount leads to an acceptance rate of 43%, with 57% of users no longer acquiring the imagery. Furthermore, we noticed significant differences in values for images among the sectors. The results show that users are more willing to pay a fixed yearly amount to join an HR-image pooling system than to be charged per image. Hence, we recorded a mean membership value of €3,022, with 12% of users willing to pay up to €15,000 to join such a service. For the 7,500 HR images available on the platform, the total user benefits amount to €12.7 million.

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HIGH-RESOLUTION SATELLITE IMAGERY

Earth observation (EO) is used to monitor some of the world's most pressing issues: resource and land management, disasters, health risks, biodiversity and ecosystem services, and air quality, among others. [13], [24], [28], [44], [64]. The increasing number of satellites launched since the 1970s has led to a significant supply of satellite imagery [4], bringing countless benefits to societies and humankind such as the saving of many lives, improvements in environmental quality, enhanced regulatory and efficiency [7], [15]. In fact, the growing trend of free access to satellite images raises the question of valuation with particular acuity [45]. The valuation of EO is still in its infancy due to the difficulties it presents [30]. Valuing satellite images is not a simple process. Asking "How valuable is a satellite image?" should be followed by the question, "How valuable to whom?"

In recent literature, the social value of satellite images is assessed either qualitatively, as for *Landsat* and *Sentinel* images [36], [39], or quantitatively: some econometric modeling and estimation examples for the value of satellite information include analyses of agricultural productivity and vegetation dynamics [14], [63], land use and management [67], [68], air and water quality [9], [20], [53], and so on. Although most approaches are based on cost–benefit studies [21], other evaluations consist of statistical analyses [34]. In fact, a distinction must be made between the impacts of using satellite images, which can be determined through the number of lives saved, the time saved, reduction of uncertainty, and so on, and quantitatively measuring the value of the images, which is about estimating the value that users draw directly from the data [33]. Recently, Laxminarayan and Macauley [32] stated that the contingent-valuation method, which refers to consumers' WTP, can be the most important method for assessing the benefits derived from EO data. Thus, WTP could be a very useful tool for assessing the value of satellite images. Although this method has been cited in more than 2,000 works on diverse subjects [37], it was applied for the first time to satellite imagery in 2015 to evaluate the *Landsat* satellite images [34]. To our knowledge, our study is the first application of this method to HR satellite images.

This article explores the economic valuation of geospatial information as perceived by the direct users of a SDI. The study is based on HR satellite images provided by the GEOSUD (http://ids.equipex-geosud.fr/) Theia (http://www.theia-land.fr/ed) SDI, located in France. In general, satellite images can be distinguished on the basis of their spatial resolution or ground spatial distance (GSD). In the absence of an established standard, we use the following categories:

- medium resolution (MR), referring to greater than 5 m of GSD [e.g., *Landsat*, *Sentinel*, *Satellite pour l'observation de la Terre* (*SPOT*) *1–5*, *RapidEye*]
- HR, from 1 to 5 m of GSD (e.g., *SPOT 6/7*)
- very HR (VHR), indicating less than 1 m of GSD (e.g., *Pleiades*, *WorldView*).

Since 2011, the GEOSUD SDI has made it possible to acquire homogeneous coverage of the French national territory each year. From 2011 to 2013, this acquisition was based on MR images (from *RapidEye* and *SPOT 5*). Later, from 2014 to 2019, the HR *SPOT 6/7* images were used to produce the national map; the installation in 2014 of a direct receiving station with a *SPOT 6/7* telemetry contract for the period 2015–2019 made it possible to continue acquiring annual HR national-coverage maps and meet specific HR-image requests worldwide from GEOSUD SDI platform subscribers. From the very beginning of the project, all images were acquired with a single multiuser license for public and research purposes only. These images (raw and rectified images, annual national coverage, and so on) differ in terms of fitness for use and price versus those acquired directly from the basic image providers (i.e., Airbus Defense and Space [ADS]). For instance, at the end of 2018, if these images were not available through the pooling system developed by GEOSUD (an investment of €11 million), it would have cost €110 million for all SDI users to acquire them separately from the image providers at their preferential rates. Many users would have given up due to budget constraints.

The valuation shows the importance of satellite imagery in supporting territorial planning and development economics in a context of open and distributed innovation within networks, where information is considered a specific asset [25], [65]. In addition, it provides elements that allow the establishment of pricing scenarios to sustain the GEOSUD business model in the long run. In mid-2018, the launch date of the study, several debates on the question of the sustainability of GEOSUD beyond 2019 were taking place regarding the establishment of a national access mechanism for satellite imagery. In fact, the access that GEOSUD has been providing since 2011 for a wide range of images covering different themes is the result of an increasingly costly structure for the continuous development of new systems and maintenance of existing ones. At the current stage of GEOSUD's development, the first socioeconomic impacts are the costs avoided in the purchase of images by public actors and the scientific community due to pooling and the beneficial effects linked to user networking and training.

A first study was conducted concerning the direct impacts of the use of GEOSUD satellite imagery in the control of forest clear-cuts in France; an average ratio of €24 of productivity gains was obtained for every €1 invested in GEOSUD [26], [40]. An economic value assessment may address important policy questions and the way HR satellite images contribute to economic activity. Our study targets a multitude of users, most from public bodies, for whom current access to images through the SDI is free. In addition, it clarifies the sustainability issues of the HR-imaging system used since 2014, with the receiving station and *SPOT 6/7* terminal. Hence, by presenting elements to establish possible funding scenarios for the future, this study helps justify past and future investments to ensure the sustainability of this type of data.

METHODOLOGY

PARTICIPANTS AND DATA CHARACTERISTICS

In 2007, the first regional and European funding programs made it possible to initiate the GEOSUD project by financing a future extension of the Remote Sensing Center facilities in Montpellier, France. A SDI was created consisting of a satellite reception station, a *SPOT 6/7* satellite reception terminal, and a web portal for accessing images and associated services. The GEOSUD SDI is part of the broader framework of Theia, which aims to progressively build up an ecosystem of innovation in the field of satellite imagery for EO. In fact, the number of satellite-image direct users who have opened accounts through this SDI platform has reached approximately 1,000 members, with 517 entities having free access to satellite images:

- 162 research and education public organizations, composed mainly of experts in remote sensing and other research fields (e.g., archaeologists, economists, and geographers)
- 139 state services at the regional and departmental levels, mostly from ministries of agriculture and environment with staff trained in geographic information systems
- 105 local authorities at the regional, departmental, and local levels, mainly concerned with land-planning and sustainable-development projects, with staff having the same skill profiles as in the ministries
- 44 nonresearch public institutions, such as the state agencies in charge of natural-resources management (e.g., water and biodiversity), national or regional natural parks, and so on
- 67 nongovernmental organizations (NGOs) and associations.

From the beginning of the GEOSUD project until the end of 2018, GEOSUD members downloaded more than 15,000 images covering 55 million km^2, half of which are represented by the HR images (Figure 1). A brief analysis of the acquired data shows that old MR images continue to be downloaded (e.g., 1.4 million km^2 of *RapidEye* 2011 images were downloaded in 2017). However, it is recent HR images that are most downloaded, as shown by these values for *SPOT 6/7* images in 2017: 0.6 million km^2 of images in 2014, 1.2 million km^2 in 2015, 3.1 million km^2 in 2016, and 2.6 million km^2 in 2017). In addition to the annual national coverage (550,000 km^2), since 2015, the GEOSUD SDI has responded to more than 150 requests for *SPOT 6/7* images worldwide (single or multisite; single or multidate; single, bi-, or tri-stereo), covering an average of 1 million km^2/year.

SURVEY DESIGN AND DATA COLLECTION

The survey was performed online in early June 2018, targeting all HR-satellite-image users identified from the GEOSUD/Theia platform. To be able to download the images, users must be registered on Theia's web portal; this feature allowed us to access all of the 979 direct users of these images. Data were collected through a questionnaire survey that consisted of five sections:

1) the type of sector/usage category of the HR satellite images
2) the WTP for HR satellite images
3) the WTP for a membership to an HR-image pooling system/the number of images above which users are willing to pay for each additional image
4) preferences regarding payment terms
5) the impact of a price imposition on the requested number of images.

The respondents had several options for answering the questions in sections 1, 4, and 5. With respect to the usage category in section 1, respondents could choose more than one usage. An additional choice, "Other," was also included for free responses. However, in sections 2 and 3, with the assumption that users are limited to their current budgets (those of the project or their organization), respondents were asked to state their WTP for satellite images and a membership fee. Since GEOSUD data sampling captures the range of satellite-image users (research and education public organizations, state services, local authorities, nonresearch public institutions, NGOs, and others), integrating this assumption into the questionnaire emphasized the fact that the amount to be paid differs from a usual household budget constraint. The questions in these two sections (2 and 3) were as follows:

- *Question A, WTP for an HR satellite image*: "Would you be willing to pay an amount of x euros for an HR satellite image (60×60 km^2), which is equal to €$(x/3{,}600)$/km^2?"
- *Question B, WTP for a membership fee*: "Would you be willing to pay an amount of y euros to adhere to an HR-image pooling system?"
- *Question C, volume of images*: "After free acquisition of z images (60×60 km^2) at HR, are you ready to pay for each

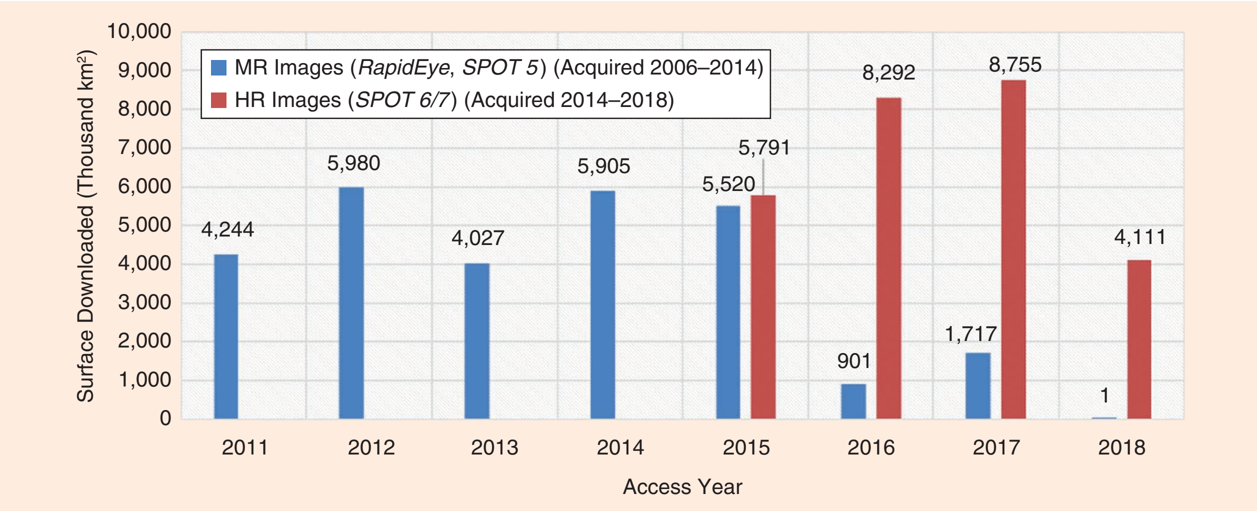

FIGURE 1. The MR and HR satellite images accessed from the GEOSUD archives.

additional image? (The price per each additional image is fixed at €750, i.e., €0.20/km^2.)"

The HR satellite images available through GEOSUD from the period 2014–2019 corresponds to *SPOT 6/7* images. In the survey, the requested image for which users' WTP was collected was fixed at a standard size of $60 \times 60\ \text{km}^2$. To simplify the process, the price for each square kilometer was integrated into the question.

In the economic valuation, according the U.S. National Oceanic and Atmospheric Administration (NOAA) panel's recommendations [1], [22], a double-bounded dichotomous choice was adopted. The dichotomous-choice format adopted in the GEOSUD data survey stimulates a market in which a respondent is given a price and asked about his/her WTP for that price. Additionally, this question format provides less opportunity for strategic behavior, as discussed in [11], thus giving an appropriate incentive questionnaire structure. The guiding principle behind the NOAA recommendations helps with designing surveys carefully to obtain accurate economic values and meaningful results. Having a large enough sample, as with the GEOSUD database, to be able to vary the image price amounts proposed to the respondents and get different valuation answers is also consistent with the NOAA recommendations.

The variables x, y, and z in questions A, B, and C were fixed, respectively, between €300 and €25,000, €500 and €15,000, and two and eight images as a result of several meetings between remote sensing experts and the steering committee of GEOSUD. For each question, a value generated randomly between the lower and upper bounds was proposed to each survey participant. Concerning WTP, questions A and B, due to the large range within the fixed lower and upper bounds, were each was asked in three stages for better precision. In the first stage, if an initial response was "yes," a follow-up question with a higher amount was asked, whereas a "no" response led to a lower amount. The same applies for the second stage. However, question C was asked in two stages due to the small range of proposed images. A "yes" response was followed by a lower volume of images.

The questionnaire was tested before the main survey. The focus was particularly on the WTP questions, to check if they were properly understood. Some 75 respondents among all of the database users were involved in the test. Two reminders were sent through mid-July 2018, the closing date of the survey. From the 979 users to whom the questionnaire was sent, 457 answers were received, of which 351 were complete; thus, we obtained a response rate of 36%. In addition, 106 partial responses were recorded. The respondents were assured of the anonymity of their answers and confidentiality in processing of the data and results. The statistical analyses were conducted with SPSS (Statistical Package for Social Sciences) and R (supported by the R Foundation for Statistical Computing). The representativeness of the data was found to be statistically relevant to the whole population.

In addition, the collected data throughout the survey's questions were coupled with the respondents' basic information registered via the GEOSUD SDI. These different aspects enriched our observations to push our analysis one step further and establish a comparative study while considering various parameters (i.e., price amount, sector typology, volume of images requested, and so on).

MODEL ESTIMATION

Based on the responses to the WTP questions, the probabilistic distribution of the WTP amounts was evaluated through a generalized multilinear model with a binary dependent variable, defined by

$$Y_i = F(\beta' X_i) + \varepsilon_i; i \in \{1, 2, \ldots, N\},$$

where N is the number of observation, $F(\cdot)$ is the cumulative distribution function (CDF), ε_i is the residual term with $\mathbb{E}[\varepsilon_i] = 0$, and Y_i follows a Bernoulli distribution of parameters:

$$\pi_i = \mathbb{E}[Y_i] = \mathbb{P}[Y_i = 1 | X_i] = F(\beta' X_i),$$

then,

$$Y_i = \begin{cases} 1 & \text{when individual } i \text{ is willing to pay a particular price} \\ 0 & \text{otherwise.} \end{cases}$$

The vector $X_i = (X_{1i}, X_{2i}, \ldots, X_{pi})$ represents the p independent variables for the ith individual. Finally, $\beta = (\beta_1, \beta_2, \ldots, \beta_p)$ is the vector of coefficients to be estimated. Therefore, the problem consists of estimating π_i based on the X_i observations.

In the context of this study (a qualitative dependent variable with binary outcomes), the most commonly used CDF is logistic distribution [69], defined as

$$F(u) = \frac{e^u}{1 + e^u}.$$

Thus, in this particular situation, the regression is described by the binary logistic model [16], whereby the probability of individual i's WTP a price is estimated by

$$\pi_i = \frac{e^{\beta' X_i}}{1 + e^{\beta' X_i}}. \tag{1}$$

However, (1) is not usable unless the β parameters are estimated. To do this, we referred to the classical principle of maximum likelihood. In our case, the likelihood function is given by

$$\begin{aligned} L(y_1, \ldots, y_N) &= \prod_{i=1}^{N} \mathbb{P}[Y_i = 1 | x_i]^{y_i} (1 - \mathbb{P}[Y_i = 1 | x_i])^{1 - y_i}, \\ &= \prod_{i=1}^{N} \pi_i^{y_i} (1 - \pi_i)^{1 - y_i}, \end{aligned} \tag{2}$$

where y_i and x_i are the observed values of the Y_i and X_i variables.

By applying the logarithmic function, we obtained the log-likelihood function:

$$l(y_1, \ldots, y_N) = \sum_{i=1}^{N} [y_i \ln \pi_i + (1 - y_i) \ln(1 - \pi_i)].$$

Thus, the estimation of β was performed by maximizing the log-likelihood through solving the system of partial derivatives:

$$\frac{\partial l}{\partial \beta_j} = 0; \quad j \in \{1, 2, \ldots, p\}. \tag{3}$$

The solution to (3) is obtained by the iterative method of Newton–Raphson [29]. The estimated parameters are denoted by $\hat{\beta} = (\hat{\beta}_1, \hat{\beta}_2, \ldots, \hat{\beta}_p)$.

APPLICATION TO THE GEOSUD SPATIAL DATA INFRASTRUCTURE

To apply this approach to the survey's observations, we created four dummy variables for the five different activity sectors of users: $D_1 =$ NGOs and various organizations, $D_2 =$ local authorities, $D_3 =$ state services, and $D_4 =$ nonscientific public institutions; we considered research and education organizations as the reference level. The choice of the reference level had no impact on the quality of the model, and the effect of this sector is implicit within the intercept coefficient. In addition, we considered the variables $B =$ the proposed price amount, $V =$ the annual average volume of requested images, and the four created dummy variables as independent variables. On the other hand, the response to the WTP question was considered as a dependent variable. The annual average volume of requested images represents an additional variable resulting from the information registered for every respondent via the GEOSUD SDI: the global volume of images requested by each group divided by the overall period during which that group was a member of GEOSUD. This variable was chosen instead of the global volume of images requested because it represents the reality of satellite-image demand. We noticed several gaps in the demand of some adherent groups, which may request a many images in one year but none in the next several years. Hence, we chose to use the average volume, which gives a better representation of the images requested since the registration date.

Therefore, an explicit expression of the logistic model is

$$Y_i = F(\beta_0 + \beta_1 B_i + \beta_2 V_i + \beta_3 D_{1i} + \beta_4 D_{2i} + \beta_5 D_{3i} + \beta_6 D_{4i}) + \varepsilon_i; \quad i \in \{1, \ldots, N\},$$

where β_0 represents the intercept coefficient. After estimating all of the coefficients of the model and considering the statistically significant ones, we could compute the probability that a particular user would agree to pay a proposed charge. In addition, by varying the amounts and applying (1), we could also generate, for every sector, a probabilistic demand function for the imagery and, therefore, a global demand function that respects the weights of each sector. Furthermore, to generate the demand function for each sector, the variable V was fixed and represented by the mean of all V_i users within the considered sector.

With demand functions, it was straightforward to find the precise amount that a predefined percentage, p, of users is willing to pay for an image. Analytically, the amount that corresponds to a probability of acceptance p is given by

$$p = \frac{e^{\beta_0 + \beta_1 B_i + \beta_2 V_i + \sum_{k=1}^{4} \beta_{k+2} D_{ki}}}{1 + e^{\beta_0 + \beta_1 B_i + \beta_2 V_i + \sum_{k=1}^{4} \beta_{k+2} D_{ki}}}.$$

Then,

$$p\text{-level WTP} = \frac{1}{\beta_1}\left[\ln\left(\frac{p}{1-p}\right) - \left(\beta_0 + \beta_2 V_i + \sum_{k=1}^{4} \beta_{k+2} D_{ki}\right)\right]. \tag{4}$$

Therefore, at the p-level WTP, when charged, p% of the users are expected to accept paying, and $(1-p)$% will turn down the proposed amount.

Based on the WTP probabilistic distribution, the expected WTP value was computed by applying a classical result for continuous random variables:

$$\mathbb{E}[\text{WTP}] = \int_0^{\infty} [1 - F(\text{WTP} < x)]\, dx, \tag{5}$$

where $F(\cdot)$ is the CDF of the WTP distribution. Finally, to solve the integral in (5), we applied numerical integration methods [22], in which we considered the lowest and highest proposed prices as the lower and the upper boundaries, respectively, of the integral.

RESULTS

DESCRIPTIVE RESULTS

The majority of respondents were from the research and education sector, with 179 responses (51% of 351 fully recorded answers), followed by local authorities, with 60 responses (17.1%). With respect to the usage category of HR satellite images, we accounted for five different main uses. Two additional uses were recorded for the "Other" option. We can see that the observation activity accounts for the highest percentage of use and that almost half of users acquire the images for research activity (Table 1). The choice of the segmentation between operational (e.g., monitoring) and nonoperational (e.g., R&D) use was guided by the fact that scientists and operational public users do not have the same needs and do not evaluate the satellite imagery on the same criteria due to the nature of their jobs. The researchers—direct users of GEOSUD, the majority of whom are remote sensing experts—rely on the usefulness of images to generate new knowledge and develop transferable methods. They are also used to benefit from support programs for partial or total free access to images [e.g., through the French Centre National d'Etudes Spatiales (CNES) Incitation à l'utilisation Scientifique des images SPOT program, European Space Agency (ESA), and so on]. On the other hand, the operational users—often nonspecialists in the remote sensing domain—react differently to satellite images or image-based products (manufactured themselves or by expert providers) in their professional fields.

In sections 4 and 5, respondents were limited to a single choice. In terms of payment, we noticed that a relatively high percentage of users preferred to pay a membership fee for a pool that allowed them free access to HR satellite images. The offer of a number of images for free before the imposition of price came second, with 35% of users choosing this option. (Our discussion of the answers to the section 3 question provides more details and elements of the analysis of

TABLE 1. THE DESCRIPTIVE RESULTS.

SECTION 1

SECTOR	%	HR SATELLITE IMAGERY USAGE	%
Research and education organizations	50.99	Observation and monitoring (of territory, specific areas, coastlines, forests, and so on)	69.36
Local authorities	17.09	R&D (research and development)	44.57
State services	13.67	Monitoring for control	17.94
Nonscientific public institutions	13.10	Management and planning	17.50
NGOs	5	Other: personal interest	1.8
		No use	1.4

SECTION 4		SECTION 5	
PREFERENCES FOR PAYMENT TERMS	%	IMPACT OF A PRICE IMPOSITION ON THE REQUESTED VOLUME OF IMAGES	%
Paying a membership fee for the pooling service	38.46	0% (The volume of requested images will not change.)	9.68
Paying for requests over a certain number of free images	35.04	25%	6.55
Combination: membership to the pooling service and payment for some images	14.51	50%	18.23
Other	10.25	75%	24.21
Paying for the first image	1.42	100% (The organization will not require more images.)	41.31

this option). In section 5, although many respondents (41%) believed that their organization would not request more images in the case of a price imposition, 9.7% responded that the number of images needed would not be affected. In addition, a list of recorded answers in the "Other" category are presented here:

- "No payment seems to be justified for a scientific use."
- "The structure will acquire a drone instead of paying for satellite images."
- "Researchers must have access to public data without any specific conditions of payment."
- "Payment should be for added-value products, not for the satellite images."
- "Communities have declining budgets, and the priority is not for image acquisition."
- "Funding must be done through ministries."

STATISTICAL RESULTS

The respondents' answers revealed rich information, which we extracted through statistical analysis. We began by applying the maximum-likelihood principle to compute the estimators for the different parameters (Table 2). In addition, all of the sector coefficients are measured relative to the reference level. The demand curve (Figure 2) indicates the global probability of acceptance for different proposed price amounts. To represent the global demand probabilities, we considered V as fixed and represented by the mean of all V_i of the significant sectors' users.

To evaluate the global performance of a logistic regression, we used the receiver operating characteristic curve [49]. The area under the curve is approximately 86.8%, indicating a good model performance with a high global prediction accuracy. To be able to perform a graphical WTP analysis, we used a zoomed version of the global model to clearly visualize the demand curve (Figure 3).

Based on Figure 3 and applying (4) and (5), several interesting results can be derived. As expected, the percentage of individuals who are ready to accept a proposed price decreases as the price increases. On the other hand, the global median amount (corresponding to 50% WTP) is approximately €1,209, which means that 50% of individuals are expected to agree to pay more than this sum and 50% to refuse. By charging €1,209 per image, GEOSUD could lose half of its subscribers. By applying (4), one can specify a p-level WTP for any value of p. For example, approximately 63% of users are not willing to pay more than €300 per image; however, approximately 10% of users are willing to pay €4,969 or more for an HR satellite image. Another important statistical result obtained by numerical integration of (5) is the mean value per image, which is globally approximately €1,696 per image. Charging this amount to GEOSUD users should lead to an acceptance rate of 43%, with 57% of users no longer acquiring imagery.

SECTOR-BY-SECTOR ANALYSIS

Based on the results in Table 2, sectors D_2 = local authorities, D_3 = state services, and D_4 = nonscientific public institutions

TABLE 2. THE ESTIMATORS' ANALYSIS.

COEFFICIENTS	ESTIMATE	STANDARD ERROR	Z VALUE	P VALUE (>|Z|)
B = Price(β_1)	-5.843×10^{-4}	4.717×10^{-5}	−12.386	$<2\times10^{-16}$****
V = Volume(β_2)	1.785×10^{-2}	8.062×10^{-3}	2.214	0.0268**
$D_2(\beta_4)$	5.236×10^{-1}	3.086×10^{-1}	1.697	0.0898*
$D_3(\beta_5)$	6.193×10^{-1}	2.656×10^{-1}	2.332	0.0197**
$D_4(\beta_6)$	9.642×10^{-1}	4.642×10^{-1}	2.077	0.0378**

Asterisks indicate statistical significance at the *10%, **5%, ***1%, and ****0.1% asymptotic levels, respectively, and apply to subsequent tables.

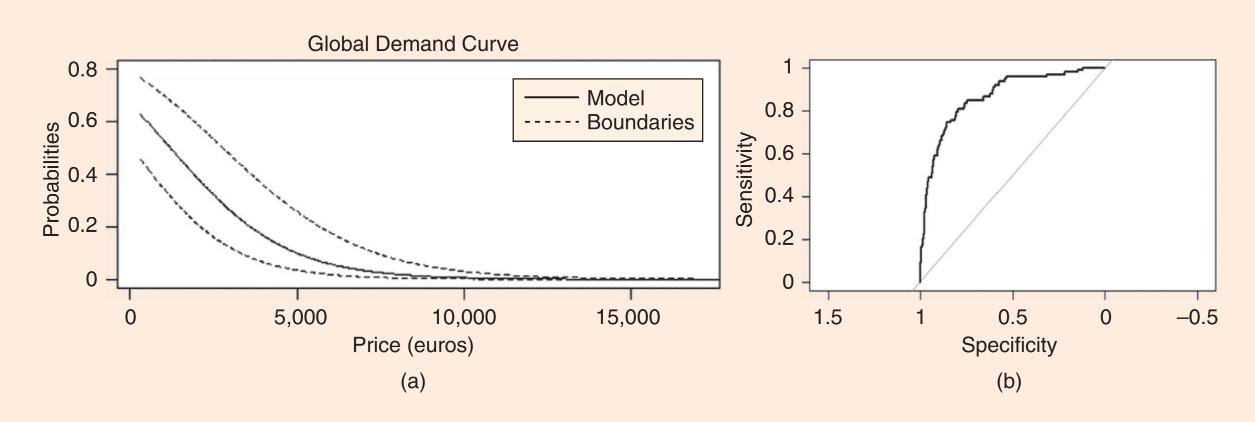

FIGURE 2. The (a) demand curve and (b) receiver operating characteristic curve model performance.

are statistically significant, with positive estimated coefficients. An individual belonging to one of these sectors has a greater probability of accepting a certain price value compared to an individual in the reference sector (i.e., research and education organizations). By considering an individual in a significant class, fixing V, which represents the mean of all V_i of the users within this class, and varying the price amounts, one can generate a sector-by-sector probabilistic demand function. Figure 4 illustrates the demand functions of the D_2, D_3, and D_4 sectors. Using these demand functions, it is easy to identify a sector-by-sector p-level WTP to which p% of users in the corresponding sector will agree. Finally, recall that the global demand curve is based on sector-by-sector probabilities and respects the weight of each significant sector. The results concerning global and sector-by-sector means and medians (in euros) are presented in Table 3. The highest WTP value recorded among the three significant sectors was for nonscientific public institutions, with a mean value of €2,126.

MEMBERSHIP ANALYSIS

For membership value analysis, the independent variables introduced are M = the membership proposed price amount; V = the annual average volume of requested images; and the four dummy variables representing the sectors D_1, D_2, D_3, and D_4, with the research and education organizations as the reference sector. Based on information from the survey regarding the membership amount that each user is willing to pay and by closely following the steps described, the estimators' analysis is presented (Table 4).

Because the intercept coefficient is significant, in the context of membership WTP, the impact of the reference sector (i.e., research and education organizations) on the probability of acceptance should be considered. In addition, sector

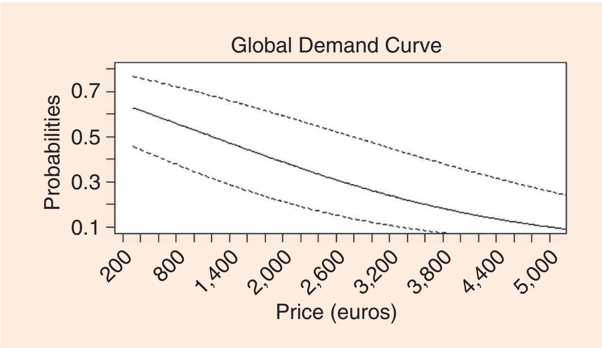

FIGURE 3. The zoomed global-demand function.

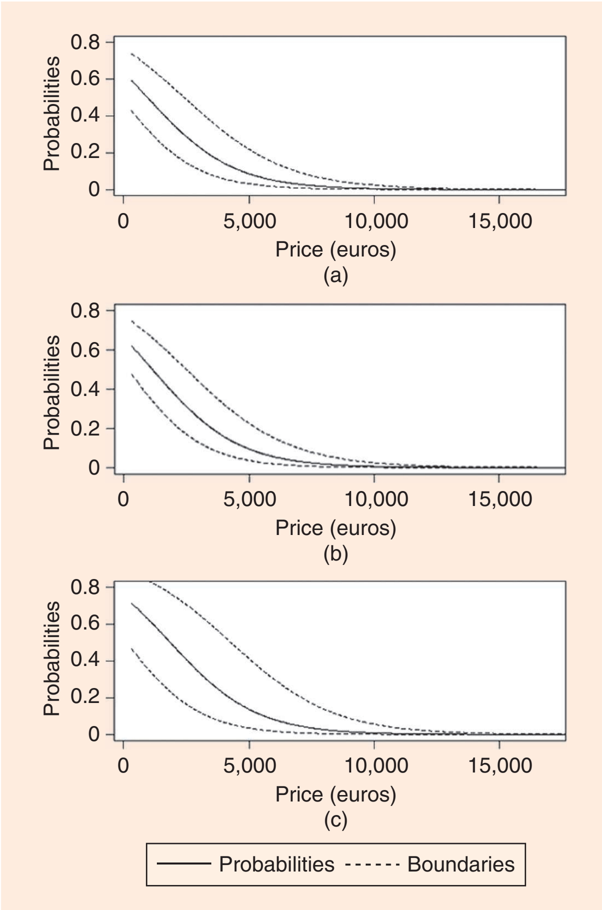

FIGURE 4. The demand curves of the significant sectors: (a) local authorities, (b) state services, and (c) nonscientific public institutions.

D_3 = state services and, obviously, the membership proposed price amounts are also significant. However, the variable V = the annual average volume of requested images is not significant here. By applying (5), the means of each significant sector are, respectively, €2,782 (research and education organizations), €3,428 (state services), and €3,022 (global sector). In this case, the median cannot be defined because the decreasing probabilities curve starts with a probability of 0.32 (<0.5), corresponding to the least proposed membership price amount of €500. The global membership WTP mean (€3,022) is clearly higher than that of the global WTP per image (€1,696). This means that, in general, users tend to be willing to pay more for a fixed yearly amount than when being charged per image. State services represent the sector that is willing to pay the most for a membership fee, with a mean of €3,428. In fact, almost 12% of users agreed to pay a €15,000 membership fee. This percentage of users increased up to 20% for a fee of €8,000.

VOLUME ANALYSIS

Proceeding in the same way, we applied the binary logistic model to fit the answers to the two proposed threshold volumes. The responses to the threshold-volume questions are considered binary dependent variables. On the other hand, the independent variables are V_{proposed} = the proposed threshold volume; V = the annual average volume of requested mages; and the four dummy variables representing the D_1, D_2, D_3 and D_4 sectors, with the research and education organizations as the reference level. The estimators' characteristics are presented in Table 5.

As in the membership WTP model, the intercept coefficient is significant. Therefore, the reference sector (i.e., research and education organizations) should be considered. In addition, sector D_2 = local authorities and the proposed threshold volume are significant. We found an average volume threshold of eight images, above which subscribers are ready to pay €750 for each additional image (Table 6).

In fact, a simple cross-comparison between the descriptive results of survey sections 4 and 5 and the results obtained from the three main questions of sections 2 and 3 shows the following: although 9.7% of users responded that the requested volume of images would not be affected in the case of a price imposition, 10% were ready to pay €5,000 for an image, and 11.8% would accept a membership fee of €15,000 for an HR-image pooling system. However, 41% of users believed that their organizations would not use any more images in the case of a price imposition, 38% of users were not willing to pay even €300 per image, and 67% refused to pay more than €500 as a membership fee.

To have a global view, we combined the survey's results with the GEOSUD database. A direct way to compute the total economic benefits of the HR satellite images is by multiplying the total number of HR satellite images available on the platform by the global mean value per image. This may result in a total economic benefit of €12.7 million perceived only by the direct users. Since the global demand WTP curve represents the relationship between the price of the image and the quantity demanded, the area below this curve can be presented as the net consumer surplus, the benefits that users obtain for their use of HR satellite images. These €12.7 million represent the economic gain of consumers at zero cost per image. So far, the operating costs of GEOSUD amount to €11 million. Second, when the results based on the mean membership WTP (€3,022) are generalized, GEOSUD, through the 500 entities registered on the platform, could account for some €1.5 million in the case of a membership-fee imposition.

DISCUSSION

The approach chosen is based on the current users of a club good [57] that can be accessed only by organizations, mostly public entities, already registered on the GEOSUD platform. The GEOSUD SDI, to which we had privileged access, has been used as an example to illustrate the potential of these images in a wide and growing range of uses. Although the respondents were not totally in a position to make tradeoffs between different agencies' budget priorities, the survey endeavored to frame their answers as if they could make these decisions themselves. Hence, the study was not merely a simple opinion-gathering vehicle but a more substantive

TABLE 3. THE MEANS AND MEDIANS IN EUROS OF THE DIFFERENT SIGNIFICANT SECTORS OF USERS.

SIGNIFICANT SECTORS	MEAN (EUROS)	MEDIAN (EUROS)
D_2 = local authorities	1,531	950
D_3 = state services	1,645	1,139
D_4 = nonscientific public institutions	2,126	1,860
Global	1,696	1,209

Means and medians represent WTP price per image.

TABLE 4. THE MEMBERSHIP-WTP ESTIMATORS' ANALYSIS.

COEFFICIENTS	ESTIMATE	STANDARD ERROR	Z VALUE	P VALUE (>|Z|)
β_0 = intercept	-7.987×10^{-1}	1.410×10^{-1}	-5.665	1.47×10^{-8}****
M = membership price (β_1)	-8.752×10^{-5}	2.106×10^{-5}	-4.156	3.24×10^{-5}****
D_3(β_5)	2.713×10^{-1}	1.643×10^{-1}	1.652	0.0986

TABLE 5. THE THRESHOLD-VOLUME ESTIMATORS' ANALYSIS.

COEFFICIENTS	ESTIMATE	STANDARD ERROR	Z VALUE	P VALUE (>|Z|)
β_0 = intercept	0.31157	0.14780	2.108	0.03502**
V_{proposed} (β_1)	0.05716	0.02687	2.128	0.03338**
D_2(β_4)	0.69706	0.23847	2.923	0.00347***

valuation exercise; it aimed to clarify the users' interest in this type of information and, more generally, through their public representativeness, to contribute to the improvement of governance systems. Although the users' WTP depends mainly on their interest in HR satellite images, the values may be coupled with other reasons for mobilizing necessary resources to assume these possible new expenses, which are constrained by the mandatory public call for tender.

WILLINGNESS TO PAY FOR SATELLITE IMAGERY

Since 2014, the images downloaded by the survey respondents from the GEOSUD archives consist mainly of HR *SPOT 6/7* images. Likewise, a study conducted by Loomis et al. [34] presented a detailed valuation for geospatial information concerning the MR *Landsat* satellite imagery. The national aspect of Loomis's study paved the way to consider several types of users, for whom a mean value of US$912 is recorded for a *Landsat* image (scene). For the total of 2.38 million scenes downloaded, a total user benefit of US$1.8 billion resulted. The HR imagery provides highly sensitive information, and its characteristics differ greatly from those of the *Landsat* images in terms of precision, volume of acquired surface, resolution, available bands, latency, automatic processing, application scenarios, and so on [18]. This may explain the higher valuation in our study for an HR satellite image (€1,696).

In addition, the fact that the annual average volume requested was significant fits with the logically expected results that the probability of a user accepting a proposed price increases with the requested volume of images. This may result from the nature of the respondents, who are generally well informed and concerned about the nature of the good they are evaluating. The efforts that GEOSUD is making toward lowering the barriers that hamper the use of satellite images reinforce valuation in that direction. In addition to the images, the added-value products and services available through the GEOSUD SDI contribute to the benefits for users. On the other hand, the results of the survey show that the prices users are willing to pay for *SPOT 6/7* images are significantly less than the current ADS commercial rates. In general, the commercial price of a $60 \times 60\,\mathrm{km}^2$ *SPOT 6/7* image varies between €13,500 and €16,500, respectively, for an archived ADS image and a programming request. (A 50% discount is applied within the GEOSUD SDI if the intended use is for research purposes.) Thus, when considering the research case as an example, a simple comparison between the commercial price of a satellite image resulting from a programming request (€6,750; therefore, €1.875/1 km^2) and the mean WTP recorded by the GEOSUD SDI respondents for such an image (€1,696; therefore, €0.47/1 km^2), reveals a ratio of four. This ratio rises to 10 if the comparison involves the mean WTP value and the commercial price excluding the research discount (€13,500).

Compared to a purely commercial model, the GEOSUD SDI made it possible to progressively build a database of reusable satellite images for researchers and public actors. In a more concrete way, the annual national coverage produced by GEOSUD completes the Institut National de l'Information Géographique et Forestière's (IGN's) aerial coverage, which is renewed once every three years. The national coverage product is in accordance with French public policy of maintaining map coverage of the entire territory for the many uses that could emerge. Consequently, the GEOSUD pooling system is bringing together an entire ecosystem of innovation, including researchers, public actors, and private service providers, in addition to the HR imagery. Thus, by promoting innovation in various sectors, it is allowing the community of users to become much broader and more diverse than it would have been if only a purely commercial model were used.

TABLE 6. THE PERCENTAGE OF USERS WILLING TO PAY ABOVE A NUMBER OF FREE IMAGES ACQUIRED.

	USERS WILLING TO PAY €750 ABOVE THE NUMBER OF FREE IMAGES (%)		
NUMBER OF FREE IMAGES	RESEARCH AND EDUCATION ORGANIZATIONS	LOCAL AUTHORITIES	GLOBAL
1	59	74	63
2	60	75	64
3	62	76	66
4	63	78	67
5	65	78	68
6	66	79	69
7	67	80	70
8	68	81	72
10	71	83	74
12	73	84	76
14	75	86	78
16	77	87	80

The row shaded in gray indicates the average volume of eight images, above which the percentage of users (classified by category) is ready to pay €750 per image.

WILLINGNESS TO PAY AMONG SECTORS

When examining the WTP for satellite images, we noticed significant differences among the various sectors. As an example, the nonscientific public institutions (such as the Office National des Fôrets; Centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement; IGN; CNES; and natural park managers, water agencies, the National Office for Hunting and Wild Fauna, and so on) make up the sector with the highest WTP, and half of its users are ready to pay €1,860 per image. By fixing an acceptance rate of 60%, the WTP amount for this sector is about five times that of the local authorities, which has the lowest WTP. This might be explained by their need for images at the local territory scale and, therefore, of smaller size. We fixed 3,600 km^2 as the image size because it was necessary to have a standard valuation framework; however, this presented some inconvenience according to the users' different expectations and requirements. In some situations, these differences result from inconsistency between end users' needs for products based on satellite imagery and the solutions available, due to the recent adoption of satellite images in certain sectors [30], [51].

In fact, the increasing availability of data and rapidly evolving analysis techniques in some particular domains enhance the value that these data could have for direct users. As a consequence, some categories of users translate their uses of HR satellite images into greater benefits. As an example, nonscientific public institutions are considered macrostructures, with management covering a wide perimeter and having strict efficiency requirements with dedicated public funds. Being more effective through their missions while responding to the needs and ambitions of the various components of society can be rewarded back by society itself. Thus, this process can be translated into a budget increase within these entities: a greater value granted for improved control and organization [46]. Hence, given the contribution and the benefits in terms of efficiency that these HR images can provide, these organizations are ready to pay large amounts to acquire them. In addition, as part of recent reforms to the administration in France, these organizations aim to reduce their staff while relying more on automated processes.

The 60% threshold used earlier as an example refers to the acceptance rate of users (*U*) related to a certain payment generated (*P*): *U*% of users will agree to pay *P* euros. The payment could be either for the satellite images themselves or for membership fees to join the SDI platform. There could also be a policy combining the two options, which, until now, was not established at the level of the GEOSUD SDI platform. The GEOSUD management and steering committee must choose whether to keep this threshold (which could vary depending on its policy), and various price values could be enacted for each separate sector. The same analysis and comparisons among sectors can be performed by fixing the WTP amounts and analyzing the acceptance rates. The SDI, knowing the budget necessary for the ongoing supply of its imagery service, should make a compromise between the service cost and a sufficient number of members willing to pay this cost so that it fulfills its goals. The policy of setting the WTP amounts and the acceptance rate of users represents a compromise for the SDI regarding several criteria (economic, strategic, managerial, and so on) that must be considered. For example, by imposing a high tariff, the SDI could cover its costs by collecting the necessary amount from the small proportion of users who are willing to pay these high prices. However, if viewed strategically as a platform-exchange service, the SDI would then be confined to a small community of satellite-image users for whom networking is of less importance.

WILLINGNESS TO PAY MEMBERSHIP FEES

Many GEOSUD SDI users would prefer to pay a membership fee for a pooling service rather than to pay per image. The global membership WTP mean (€3,022), which is substantially higher than the global WTP per image (€1,696), clearly illustrates this argument. Despite some minor differences between these membership values among the sectors, the logic remains the same and can be explained in terms of several issues. First, by joining a pooling structure, public bodies avoid needing to get financial approval to buy images. Their need for images to support projects and wide diagnostic processes cannot be known in advance. Paying a membership fee allows access to a larger selection of images, which better fits their users' needs.

Unlike some traditional management processes, in which basic technological support tools evolve slowly over time, some specific high-tech contexts depend on a large number of images due the nature of the research and, mainly, the time factor—that is, once the project is over, this demand may slow down. For this, several entities, despite their low demand for satellite images, are willing to pay large amounts for what the pooling service may offer them in terms of the number of images and added-value services. This also explains the nonsignificance of the annual-average-volume-requested variable in the context of membership analysis. When estimating their WTP to join an HR-image pooling system, users dissociate their past consumption of images. Hence, these organizations prefer a membership fee because of uncertainty about the number of images they will be requesting. This opportunity represents security compared to paying for each image requested.

HIGH-RESOLUTION SATELLITE IMAGES

There is enormous expected global growth of large satellite-image pooling services that cover a wide range of image resolutions (MR, HR, VHR, and so on). Internationally, the *Copernicus 8* program in Europe is heading toward its future in the Data Information and Access Service (DIAS). Multinationally, we see Google with Google Earth and its platform Google Earth Engine, Amazon with its platform AWS9, and others. In this context, the introduction of these devices at larger scales raises the question of the specific value of HR *SPOT 6/7* imagery compared to commercial VHR images (e.g., *Pleiades, WorldView*) and free MR images (e.g., *Sentinel-2*, *Landsat*). In fact, there is an interest in HR images in terms of technical complementarity. Despite the lower technical properties and characteristics compared to *Pleiades* images, HR images are considered additional sources to complement the *Sentinel* program, with the possibility of covering complete territories with finely exploitable elements.

This point was taken into account by the GEOSUD SDI when selecting the *SPOT 6/7* satellite acquisition in 2014. The *SPOT 6/7* images were chosen for several technical characteristics (spatial resolution, coverage capabilities, and programming agility) that appeared to be complementary to *Pleiades* (inframetric resolution but insufficient satellite resources to cover large territories) and *Sentinel* (free and very high repeatability but with low spatial resolution limited to 10 m). The *Pleiades* and *Sentinel* programs represent a constellation of satellites, entirely financed by public funds with an entrusted exploitation by space industrial actors.

This phenomenon illustrates various mechanisms: the DIAS for pooling the *Sentinel* images and digital signal processing (DSP) for a public-use delegation of those from *Pleiades*. Through the DIAS pooling mechanism for the *Sentinel* images, three usage levels are present. First, open access to the satellite images is provided via the DIAS platform. Second, processing tools can be found to extract added value and allow product and service development. Finally, a third level groups these elements following a marketplace logic. The DIAS infrastructure, the result of an industrial consortium with European grants, raises several questions about its sustainability and long-term economic model. On the other hand, access to *Pleiades* images for public use is conditioned on the establishment of a DSP agreement between the CNES and ADS. Therefore, it seems necessary to think about the place occupied by HR satellite images, that is, between the free MR *Sentinel* and the VHR *Pleiades* images.

Furthermore, recent research confirms the benefits of having shared access to a multisensor and multiresolution image bundle to cover a variety of application domains. For example, advances in artificial intelligence and machine learning illustrate the use of VHR and HR imaging as a massive learning base for processing MR *Sentinel-2* images [5], [6]. In fact, the results of our study serve to highlight this issue through examining the usefulness of this type of data, whose complementarity to MR and VHR images needs to be justified.

POOLING MECHANISMS

In general, the differences among satellite-imagery resolutions are not trivial and can manifest as stark shifts, such as in land-cover classifications, image sharpness, patch-level metrics, pattern analyses, and so on. The data continuity, increased affordability, and improved access conditions are essential elements in the supply of HR satellite images, whose benefits are numerous and could be found in several forms and applications (e.g., see [38] for tropical biodiversity studies, [10] for biodiversity conservation, [35] for land-use classification, [66] for geology, and [58] for precision farming). Furthermore, the cost of satellite imagery has a large impact on its use and the resulting societal benefits [34]; if too expensive, it will not be used extensively as originally intended.

In fact, efficient satellite-image pooling mechanisms, such as the GEOSUD SDI, reinforce these facts. The access to and use of a large library of HR satellite imagery play a role in supporting the institutional services in the implementation of their territorial planning missions, through the assistance and integration of image-based space technologies into public policy systems [19], [61]. Furthermore, although satellite-image users are increasingly close to their local and territorial issues, the availability of a free HR satellite database allows them to manage their day-to-day tasks in a more precise way. In complementarity with MR and VHR images, HR images offer a good compromise between spatial resolution and high coverage capabilities. Thus, the GEOSUD SDI is allowing many users who could not afford the price of the images to be present in the satellite-imagery field. By adopting an upstream financing strategy through public authorities and open access downstream, the GEOSUD SDI is conserving a large base of its subscribed users, despite their unwillingness to pay for the images and services provided. Similarly, Amazon, Google, and the ESA, with their new strategies for providing *Landsat* and *Sentinel* satellite images on their platforms, are also heading toward expanding the use of and access to such data. While pooling access to satellite imagery, they are creating a networked community whose coordination and collaboration drives more innovation processes and the development of added-value services and products.

Although free access and use provide great opportunities for the community of satellite-imagery users, the lack of financial resources calls into question the sustainability of the SDIs if this service continues to be offered at no cost. Hence, the outcomes of this study could be used to secure public funds for SDIs by providing to public bodies all of the impacts of and justifications for pooling-mechanism strategies. The study could also be used to develop appropriate business models to respond to the free supply of HR satellite data. The WTP results make it possible to build economic models based on the practices of the SDI's direct users. Moreover, they allow refinement of the existent economic scenarios with the least negative impact on direct users of the satellite imagery. Although the GEOSUD SDI is evolving toward the Data Terra National Research Infrastructure, which will include the Dispositif Institutionnel National d'Approvisionnement Mutualisé en Imagerie Satellitaire (DINAMIS) pooling mechanism, it will maintain elements to guide and situate discussions with its partners about current funding opportunities (annual membership, price per image, premium beyond a certain number of free images provided, and so on), thus allowing for better future strategic choices based on factual bases. To cover the full costs of DINAMIS, estimated at €3.5 million/year (including the access to HR *SPOT 6/7* and VHR *Pleiades* imagery for noncommercial use), the targeted economic model is based on upstream financing provided by a consortium of six public bodies carrying DINAMIS. It will be complemented by a financial contribution from the direct users of the service with a differentiated pricing policy. The financial commitments made at the beginning of 2019 by DINAMIS holders and the simulations of contributions from direct users shape the business model implemented in 2020.

ORGANIZATIONAL-ROUTINE CONCEPT

The GEOSUD/Theia initiatives have profoundly changed the landscape in France for the supply and access of commercial HR satellite imagery to public and academic institutions by bringing major innovations, such as the logic of sharing and pooling through an all-public actor, licensing strategy, and archive of images. These images and, more generally, the remote sensing technology produce savings beyond their direct use [54]. Integrating them into processes that include other added-value products and are capable of generating resources [51] explains users' WTP despite the lack of budget. This issue meets the organizational-routine concept [3], [47], which states that a service becomes fully valuable only once its use is completely integrated into the regular operating process so that, consequently, resources will be mobilized in the same direction. In addition, the images carry a kind of proof due to the visual nature of the data itself, meeting the evidence-based-planning approach [17]. Their value to their organizations relies on the fact that they sustain and secure their existence.

In situations where there is no direct financial gain, providing symbolic gains of popularity and social legitimacy offers a higher level of influence to the territories, paving the way to think, for instance, of the urbanization phenomenon and the synergies that may arise among different types of urban, suburban, and rural areas [23]. In fact, their existence and availability require responses to new obligations in terms of monitoring and evaluating emerging activities as soon as the technology becomes available. As a particular example, a satellite-implementation plan was effectively put in place in the state services of the French Ministry of Ecology. Additionally, to face operational difficulties related to forest control, the systematic mapping of clear-cuts, based on HR satellite imagery and developed by GEOSUD, has been used operationally since 2013 by the regional and local services of the French Ministry of Agriculture. The labeling of the mapping method and the training sessions as well as the accompaniment tools (user manual and online technical assistance) has been set as a support for the appropriation of these images. However, for local authorities, the geomatics benefits can be found mainly in large organizations due to a culture based on cadastral plots and aerial images, which are always present.

Thus, the satellite remote sensing technology should demonstrate its complementarity, and even its superiority, to aerial images with the arrival of new VHR and large-coverage constellations, such as *Pleiades NEO*. This progression takes into account the knowledge of both the technicians in charge of using these tools and elected officials and policy makers. The decision to invest in this technology within different public administrations is not just necessarily political; there are institutional ministerial decisions related to public policies. Unlike ministries, which have a central administration to put a strategy in place and diffuse it throughout all of the decentralized services, the political power of local authorities makes the labeling and recommendation mechanism more difficult, given the need to reproduce these tasks in each of the communities. Hence, the weight of politics is much stronger at a community scale. Technicians must convince the political power, such as intercommunity and municipal councils, to invest in this technology. Thus, it will be important to understand, with respect to each specific context, to what extent the images have made it possible to change practices and identify the opportunities gained by their use in the entity's organization.

SATELLITE IMAGERY AS AN INFORMATIONAL ASSET

In the context of SDIs, the value attributed to satellite information reflects the creation of a common resource by the infrastructure, characterized as an *informational asset*. With an economy increasingly focused on intangible resources [31], [59], behavioral economics [12], and platform paradigms [43], the informational asset is becoming an essential factor, whether at the macroeconomic dynamic level or for behavior studies of consumers and agents. It is somewhat linked to the notion of information management at the territory level [2]. Territories, seen as geographical units of the economic system, have complex economic development processes [60]. Finding the right information, with sufficient quality and at the right scale, highlights the organization setup needed to acquire this information, manage it, and exploit it within a sphere of the territorial decision, thus modernizing the territorial economy and implementation effectiveness [8], [50]. Smart cities are one recent example of how this technology can support the emergence of innovation within the management of smart territories [62]. In this context, the informational asset according to the geographical scale contributes to the economic development of territories [55] and reduces the disparities between rural and urban areas [56]. At the economic level, these institutional changes may generate employment opportunities within governance systems and digital companies for developers of new information products, according to the logic of a two-sided market [26].

FROM IMAGE-BASED TO DATA-STREAM MODELS

Finally, it remains important to highlight the general evolution from a traditional satellite-image-based market strategy (the $60 \times 60\,\text{km}^2$ acquisition attempts) to new data-stream models (i.e., what you use determines what you pay). In the basic model, the surface covered may be larger but with a lower price, whereas payment in a data-stream model relies on the "useful square kilometers" acquired, depending on the area defined as useful for the user. However, the price in the second case is higher, and the covered surface is limited to a defined area.

Despite this evolution, pooling mechanisms could be still applicable. All of the pixels purchased through a data-stream flow could also be integrated into a pooling service, allowing collective use of the data stream already bought from the initial suppliers. Similarly, commercial prices for collective data flow may be applied, as in the case of individual data-stream pooling logic. These new models have yet to prove their usefulness economically and their ability to meet users' needs. In any case, it is likely that these new models will be more effective with the public if, in the context of an ecosystem of innovation, they succeed in shaping a structured community where members pool their budgetary resources and competences, rather than having a set of isolated users accompanied individually [52]. Hence, new models of public–private cooperation are also likely to emerge as value chains become increasingly reorganized around added-value products and services. Such models, developed at the European and international levels, will constitute a new opportunity in the satellite-imagery field.

CONCLUSIONS

Direct users constitute the first link between the SDI and the wider community of beneficiaries of satellite-image-based products and services. Therefore, by estimating the value that these users draw directly from the satellite images, this research fills part of the gap that exists between users' needs for justification materials and investors' exigencies for the availability of this technology in the market. The novelty of our work results from applying the widely used contingent-valuation method within the framework of a SDI to value specific geospatial data and their benefits. The results obtained could be used to inform the design of a future pricing model for satellite imagery aimed at sustaining the financing of these services. In addition, our findings may also stimulate public awareness about future decision making related to the EO field and, more particularly, satellite images.

Although the development of the HR and VHR satellite markets was initiated with various satellites, including the French *SPOT* 6/7 and *Pleiades*, competition with other spatial and aerial data sources (e.g., high-altitude pseudosatellites and unmanned aerial vehicles) or in situ data (e.g., networks of terrestrial sensors, the Internet of Things, and crowdsourcing) could also be present. With some restrictions still existing in the commercial use of HR and VHR satellite images, the access conditions already mentioned affect global satellite-imagery prices through the redistribution of costs across the value chain. The new space actors with small, low-cost satellites, coming from IT sectors or newly active nations, such as China or South Korea, will have a large presence with their new commercial offerings [18]; with all of the recent satellites launched, the future seems promising. In addition, satellite constellations such as *Planet* and *Terra Bella*, among others, offer several interesting features. With higher revisit rates, less expensive services, and an ability to make more timely decisions, the new space actors are promoting information freshness, applications, and data-analytics tools through their development of new platforms. These constellations, through their new business models, will provide benefits to many fields through appropriated data analytics, establishing more efficient connection nodes, and networking systems across the globe [41], [42], [48]. Although they have the opportunity to claim a place among competing players already present in the market, the new space actors are opening the way to revisit the traditional business models of SDIs. Their influence on the satellite-imagery market call into question the financial capabilities deployed and reorients them toward new solutions for financing space technology and, more particularly, the satellite-imagery domain. For this, valuation approaches should evolve to be more extensive, comprehensive, user oriented, and closely tied to explicit targets. Therefore, in the absence of standardized practices for measuring the contribution of geospatial information to society [30], this study sets a cornerstone for future valuation works.

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AUTHOR INFORMATION

Chady Jabbour (chadyjabbour@gmail.com) has been with Centre d'Economie de l'Environnement–Montpellier; the University of Montpellier, France; Conseil National de la Recherche Scientifique; Institut national de la recherche agronomique; and Montpellier SupAgro and has served on the faculty of the Economic Science and Business Administration department, France/Lebanese University, Beirut, Lebanon.

Anis Hoayek (anisshoayek@hotmail.com) is with the Alexander Grothendieck Institute, University of Montpellier, France.

Pierre Maurel (pierre.maurel@irstea.fr) has been with Territoires et environnement par la télédétection et l'information spatiale, Irstea, AgroParisTech, Centre de coopération internationale en recherche agronomique pour le développement, Conseil National de la Recherche Scientifique, and the University of Montpellier, France.

Hélène Rey-Valette (helene.rey-valette@umontpellier.fr) has been with Centre d'Economie de l'Environnement–Montpellier; the University of Montpellier, France; Conseil National de la Recherche Scientifique; and Institut national de la recherche agronomique.

Jean-Michel Salles (jean-michel.salles@supagro.fr) has been with Centre d'Economie de l'Environnement–Montpellier; the University of Montpellier, France; Conseil National de la Recherche Scientifique; Institut national de la recherche agronomique; and Montpellier SupAgro.

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