artnet Analytics

artnet Indices White Paper

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1 artnet Index Methodology

One of the biggest challenges to developing an effective art index is the control of the underlying heterogeneity of artworks. Published literature on art index methodologies suggests two modeling approaches to control for heterogeneity: Repeat Sales Regression and Hedonic Regression.

Repeat Sales Regression (hereafter RSR)[1] uses repeat sales data of the same object, and calculates the index value using the price difference between the two selling points. RSR controls for some heterogeneity by considering the price change of the same object whose basic underlying characteristics, such as medium and size, do not change over time.

Hedonic Regression (hereafter HR)[2] generates index values based on artwork characteristics, such as artist, size, medium, and subject matter, and places less importance on the value change of a specific object over time. This separation of hedonic elements of an artwork allows HR to consider how different characteristics affect the value of an artwork.

The publication *On the Computation of Art Indices*[3] compares these two approaches in terms of number of observations, sample bias, specification bias, revision volatility, price inflation, and exchange rates. While the RSR method is criticized for sample bias due to availability of fewer repeat sales data, the HR method is criticized for its specification bias, as the functional form of the hedonic element of the artworks may lead to mis-specification problems, particularly when the form changes.

Concerns have been raised as to whether or not one can assume the coefficients of the hedonic variables to be constant over time.[4] These concerns have largely been addressed[5], and the HR approach has been refined for the purposes of art indexing. Nevertheless, if the purchase and the sales price of every object sold over a long period of time is known, RSR can be a more efficient measure of financial return for the art market.[6] Ginsburgh, Mei, and Moses[7] recommend the RSR method when the number of pairs is large, or when the time frame is greater than 20 years.

Expanding on the RSR approach to a wider dataset, by considering pairs of comparables in lieu of proper repeat sales, overcomes the largest criticism of the approach, and results in a more robust dataset to create indices. Auction lots from the industry's most comprehensive art database, the *artnet Price Database*, are used to identify comparable works by the same artist, thereby creating a unique dataset with the largest possible input.

artnet Indices include both repeat and single sales, only using information from items that can be grouped as *comparables* (hereafter Comparable Sets). Therefore, the artnet calculation structure incorporates aspects of repeat sales, in that it uses results from the sale of artworks that are homogenously grouped, and of hedonic sales, in that it considers each artwork individually during the estimation process.

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[1] Ginsburgh Victor, Jianping Mei, and Michael Moses. "On the Computation of Art Indices."*Handbook of the Economics of Art and Culture*. Amsterdam: Elsevier, 2006. 948-79. Print.
[2] Chanel, Olivier, Louis-André Gérard-Varet, and Victor Ginsburgh. "The Relevance of Hedonic Price Indices." *Journal of Cultural Economics* 20.1 (1996): 1-24. Print.
[3] Ginsburgh, Victor, Jianping Mei, and Michael Moses. "On the Computation of Art Indices." *Handbook of the Economics of Art and Culture*. Amsterdam: Elsevier, 2006. 948-79. Print.
[4] Ginsburgh, Victor, Jianping Mei, and Michael Moses. "On the Computation of Art Indices." *Handbook of the Economics of Art and Culture*. Amsterdam: Elsevier, 2006. 948-79. Print.
[5] Bocart Fabian Y.R.P., and Christian M. Hafner. "Econometric Analysis of Volatile Art Markets." *Computational Statistics & Data Analysis, 2012, 3091-3104.*
[6] Ginsburgh, Victor, Jianping Mei, and Michael Moses. "On the Computation of Art Indices."
[7] Ginsburgh, Victor, Jianping Mei, and Michael Moses. "On the Computation of Art Indices."

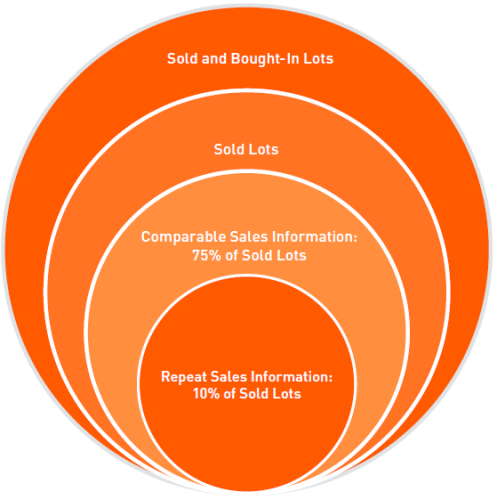


Figure 1: Data Coverage for artnet Indices

Figure 1 shows the quantity of art sales information included in the artnet index methodology. Of the 7 million lots in the *artnet Price Database*, approximately 75% can be grouped into Comparable Sets of artworks. All lots in this 75% are included in the artnet index calculation, and only 10% of them can be grouped into pure repeat sales, such as those found in the Mei Moses Index method. It should be noted that this is an upper bound of repeat sales, as it includes sales from all auction houses within the *artnet Price Database;* in contrast, the Mei Moses Index only includes those sales that occurred at Christie's or Sotheby's.

1.1 artnet Art Index Module

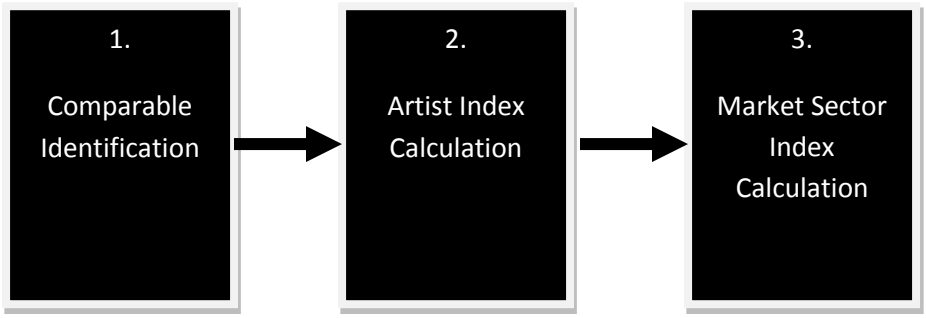


Figure 2: artnet Index Stages

At a macro level, the artnet index system consists of three stages of information processing. In the first stage, art experts examine, research, and group a single artist's sales data into Comparable Sets based on appraisal principles and art historical knowledge. Next, these groups are used to determine the artist index value for different time periods. In the last stage, those individual artist index values can be aggregated to create broader market indices, such as the **artnet C50™ Index**, a Contemporary Art index developed by artnet analysts. The artnet index tool allows for many report varieties, which track the performance of individual artists, market sectors, or Comparable Sets from an artist's career.

1.1.1 Stage 1: Comparable Identification

Identifying and organizing comparable artworks for individual artists plays a vital role in the development of artnet Indices. As outlined, it intends to expand the dataset examined when using a form of repeat sales. Increased heterogeneity could bias the model, making it imperative to ensure that all items in a Comparable Set display a high level of homogeneity, to pass both subjective tests by art scholars and objective tests by statistical analysts.

To determine the makeup of Comparable Set*s*, information on the artist and their historical significance is researched by artnet analysts. When necessary, outside experts are also consulted to determine what attributes of a particular artist most affect their market value. artnet then extracts the artist's auction records from the *artnet Price Database*, and the analysts organize and group the works. Initially, categorizing is done by major criteria, just as one would create a catalogue raisonné. The first step is to make distinctions between media, date ranges, subject matters, periods, and series. Analysts then examine core characteristics of the artwork, such as size, for each Comparable Set, and visually control for style, form, composition, color, and motif. Information from external sources, such as auction catalogues, is also used to refine the categorization judgments and spot aberrations or outliers. The Comparable Set*s* are controlled for quality via an internal review process, which includes another visual consistency check. The artnet Analytics team consists of certified appraisers and analysts with major auction house experience.

Below is an example of one of the Comparable Sets for Damien Hirst (British, b.1965):

Date 2001 - 2001	**Date** 2001 - 2001	**Title** Untitled (Spin painting)	**Date** 2001 - 2001
Title Untitled	**Title** Mini spin painting	**Size** 17.7 x 17.7in. / 45 x 45cm.	**Title** Untitled
Size 18 x 18in. / 45.7 x 45.7cm.	**Size** 17.7 x 17.7in. / 45 x 45cm.	**Medium** Acrylic on Paper	**Size** 17.9 x 17.9in. / 45.5 x 45.5cm.
Medium Acrylic on Paper	**Medium** Acrylic on Paper	**Auction** Bonhams London, July 02, 2002, [Lot 205]	**Medium** Acrylic on Paper
Auction Christie's London, February 06, 2003, [Lot 735]	**Auction** Phillips, de Pury & Luxembourg New York, November 12, 2002, [Lot 194]	**Sales Title** Twentieth Century British Art, Post-War and Contemporary British Art	**Auction** Sotheby's London, June 27, 2002, [Lot 107]
Sales Title Post-War and Contemporary (Day Sale)	**Sales Title** Contemporary Art, Part II	**Estimated** US$ 12,260 - US$ 18,390	**Sales Title** Contemporary Art (Day Sale)
Estimated US$ 8,210 - US$ 11,494	**Estimated** US$ 10,000 - US$ 15,000	**Sale Price** US$ 11,034 HAMMER	**Estimated** US$ 10,669 - US$ 15,241
Sale Price US$ 7,848 PREMIUM	**Sale Price** US$ 11,950 PREMIUM		**Sale Price** US$ 12,749 PREMIUM

1.1.2 Stage 2: Artist Index Value Calculation

For a more in-depth understanding of how the index value calculations are computed, please refer to section 2 below, which outlines the various calculation methods used to generate the index values and other values necessary to maintain accuracy.

1.1.3 Stage 3: Market Index Value Calculation

Please see section 2.7 for an understanding of how artists are selected to represent a market index, such as the Contemporary or Latin American Index, and of how the market index values are generated.

1.2 Index Presentation

Once all the index values have been calculated, the resulting index is presented online in an interactive report that can be printed or downloaded as a pdf. To compare the performance of several indices with different base years, indices have been scaled to 100 in the earliest year all components were available. For financial indices that have been scaled, real values can be viewed on the right-hand Y axis.

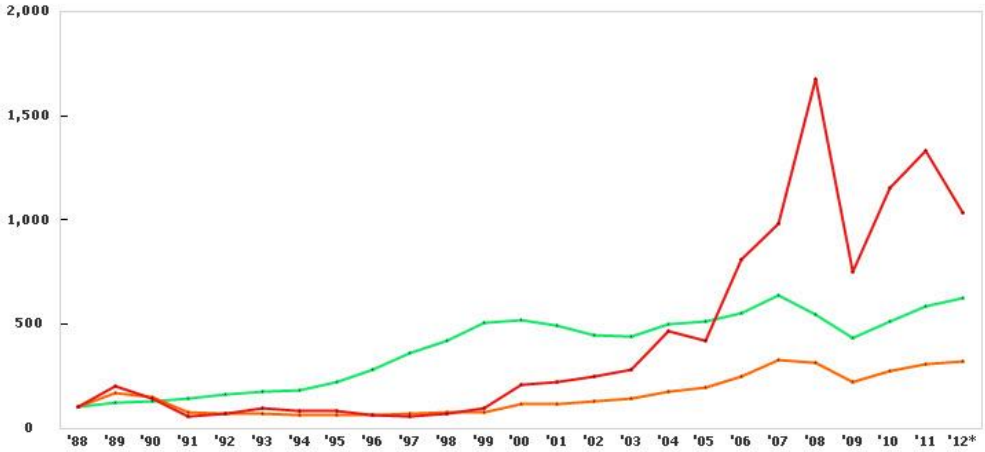
All indices can be viewed in either monthly or yearly segments, and users have the ability to customize the time frame for each index graph. By changing the time frame for each index, performance from a specific time onwards can be visualized.

Indices that represent a group of artists can also be customized to account for the distribution, or weight, of an artist's works within a collection. In creating an index line that represents a group of artists, users can change each artist's weight in the final combined index to reflect the exact composition of their particular collection. If custom weights are not applied, each artist will be given identical consideration in the final combined index.

In order to stay as up-to-date as possible, artist and market sector indices are updated on a monthly basis to reflect the addition of new data to Comparable Sets. Index values are subject to change as more information becomes available throughout the year.

For artists with sufficient sales history, users will be able to combine or compare Comparable Sets for a single artist. The resulting index will represent the performance of the chosen Comparable Sets, and will begin in the earliest year a sale is recorded within the selection, regardless of when the artist's overall index begins.

Example of Index



*Values as of 6/8/2012
Indices are scaled to earliest year with all components available.

Active Indices

Line	Index Name	Equal / Cap Weight	More Options
	Lucio Fontana	Equal Weight Cap Weight	
	artnet Contemporary 50™(C50™) Remove		Right Y-Axis
	Dow Jones Industrial (^DJI) Remove		Right Y-Axis

2 Calculations

As explored in the above sections, the majority of published literature on art indices shows a preference for Hedonic Regression (HR) over the Repeat Sales Regression (RSR) used by financial indices. Many artists have limited data over time, diminishing the accuracy of a simple RSR approach. This data limitation has a severe effect on a traditional RSR model, leading to disruptive singularity issues when the amount of Comparable Sets is large with respect to the amount of data available within each Set. However, the HR approach still suffers from limitations, such as the presence of characteristics that may change over time and affect value. These changes, and effects on value, may not be recorded by HR.

artnet Indices combine the benefits of both RSR and HR in a more efficient, hybrid model, which treats RSR as a nested case of HR[8]. This new approach follows the same principles as a RSR model, but adopts the structure of a HR model; instead of considering price changes of comparable items by pairing sales, each sale is considered individually, identifying both the sale time (e.g., year) and Comparable Set membership as independent variables. The dependent variable is the log of the realized sale price minus the log average of sale prices for artworks in the same Comparable Set, unlike the log of price ratio used in traditional RSR models.

[8] See Appendix for the rationale

The artnet index is initially estimated using data available in Comparable Sets with more than one sale point. As new lots are added to the *artnet Price Database* (from recent or historical sales), future index estimation may generate a slightly different value for a previously published index year. In such a case, like other financial indices, artnet has developed an automated rectifier system, which first checks if the past value falls within the confidence interval of the most recent estimation. The presence of the past value in this interval indicates that there is no statistically significant difference between the previous value and the most recent one, and thus, no action is taken. If the previous value falls outside of the confidence interval, then the past index value is replaced with the more recent value. The artnet index methodology is capable of reacting quickly to this situation.

artnet computes two types of art indices: a cap-weighted index and an equal-weighted index. The cap-weighted index is similar to the S&P 500 Market Cap-Weighted Index, in which more weight is given to higher valued lots. The weights of each artwork in every index period are computed based on their performance in that period. The equal-weighted index is similar to the S&P 500 Equal-Weighted Index, as it gives equal importance to all the components constituting the index, irrespective of the difference in value.

2.1 Base Year Selection

In order to obtain a robust artist index in early years, when artists' data are limited, base years are selected for each artist based on data overlap. The base year of an artist index will be in the earliest year when there are both a subsequent sale in one Comparable Set and an initial sale in another Set. The index value in the base year will then be scaled to 100, and all index values in following years will be scaled to the base year.

2.2 Equal-Weighted Index

The index is constructed by assuming that the natural logarithm of the price of an artwork *i* (i=1,…,N, where N is the total amount of artworks), belonging to Comparable Set *s* (s=1,…,S) and sold in time *t* (t=1,…,T) follows the following linear relationship:

$$(1)\ \log(price)_{i,s,t} = C + \frac{1}{N_s}\sum_{t=1}^{T}\sum_{j=1}^{N_{st}}\log(price)_{j,s,t} + \sum_{t=1}^{T}\beta_t \times time_{i,t} + \sum_{s=1}^{S}\alpha_s \times Comparable\ Set_{i,s} + \varepsilon_{i,s,t}\ ,$$

where C is a constant and $time_{i,t}$ is a variable with a value of 1 when the artwork *i* has been sold in time *t* and 0 otherwise. Similarly, $Comparable\ Set_{i,s}$ is a variable taking the value 1 when the artwork *i* belongs to Comparable Set *s* and 0 otherwise. N_s is the total amount of artworks belonging to Comparable Set *s* and $N_{s,t}$ is the total amount of artworks belonging to Comparable Set *s* that were sold in time *t*. $\varepsilon_{i,s,t}$ is an error term and is assumed to be normally distributed with mean 0 and constant variance σ^2.

β_t and α_s are coefficients. β_t can be interpreted as the marginal impacts of time on the log price. By construction, the coefficient corresponding to the base period (t=0) is set to zero. Coefficients of all other periods are constructed with respect to this given base period. The

price level of the base period is later set arbitrarily to 100, and the price level of other periods is adjusted accordingly.

$$(2)\ \log(price)_{i,s,t} - \frac{1}{N_s}\sum_{t=1}^{T}\sum_{j=1}^{N_{st}}\log(price)_{j,s,t} = C + \sum_{t=1}^{T}\beta_t \times time_{i,t} + \sum_{s=1}^{S}\alpha_s \times Comparable\ Set_{i,s} + \varepsilon_{i,s,t}\ ,$$

Defining the corrected log price $Y_{i,s,t}$:

$$(3)\ Y_{i,s,t} = \log(price)_{i,s,t} - \frac{1}{N_s}\sum_{t=1}^{T}\sum_{j=1}^{N_{st}}\log(price)_{j,s,t}\ ,$$

where $Y_{i,s,t}$ stands for the log price of each artwork corrected by the overall log price level of the set to which it belongs.

All differences between artworks are comprehensively caught by the time dummy variable $time_{i,t}$ and the variable $string_{i,s}$ as comparable artworks are grouped in the same Set.

$$(4)\ E(Y_{i,s,t}) = E\left(C + \sum_{t=1}^{T}\beta_t \times time_{i,t} + \sum_{s=1}^{S}\alpha_s \times string_{i,s}\right)$$

In matrix form:

$$(5)\ E(Y) = E(XB)$$

Under the Gauss-Markov assumptions, the Ordinary Least Squares (OLS) estimator of the β parameter is:

$$(6)\ B = \left(X'X\right)^{-1}\left(X'Y\right).$$

A price index with base value 100 is defined as:

$$(7)\ Price_t = 100 \times e^{\beta_t}$$

Or, alternatively as:

$$(8)\ Price_t = Price_{t-1} \times e^{(\beta_t - \beta_{t-1})}$$

Example:

Price	**Time**	**Set**	$\log(price)_{i,s,t}$	$Y_{i,s,t}$
2000	**0 (Base period)**	**1**	7.60	- 0.56
5000	**1**	**1**	8.52	0.35
5050	**1**	**1**	8.53	0.36
6000	**1**	**2**	8.70	0.20
3000	**2**	**1**	8.01	- 0.16
4000	**2**	**2**	8.29	- 0.20

In this example, the matrices Y and X are:

$$Y = \begin{matrix} Y_{i,s,t} \\ -0.56 \\ 0.35 \\ 0.36 \\ 0.20 \\ -0.16 \\ -0.2 \end{matrix} \qquad X = \begin{matrix} & time_1 & time_2 & Comparable\ Set_1 \\ 1 & 0 & 0 & 1 \\ 1 & 1 & 0 & 1 \\ 1 & 1 & 0 & 1 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 \\ 1 & 0 & 1 & 0 \end{matrix}$$

Result of the OLS estimation procedure: $B = (X'X)^{-1}(X'Y)$.

$$B = \begin{matrix} C & -0.67 \\ \beta_1 & 0.90 \\ \beta_2 & 0.43 \\ \alpha_1 & 0.11 \end{matrix}$$

The index is then computed as:

$$Index_{t=0} = 100$$

$$Index_{t=1} = exp(0.90) \times 100 = 245.96$$

$$Index_{t=2} = exp(0.43) \times 100 = 153.73$$

2.3 Cap-Weighted Index

The artnet index methodology can be adapted to use a diagonal weight matrix allowing for more weight to be given to high valued works. An artwork *i* that belongs to Comparable Set *s* sold in time *t* is weighted by a ratio with a numerator representing the average price of all artworks from set *s* sold in time *t*. The denominator is the sum of prices of all artworks sold in time *t*:

$$(9)\ \Omega_{i,s,t} = \frac{\frac{1}{N_{s,t}}\sum_{j=1}^{N_{s,t}} price_{j,s,t}}{\sum_{s=1}^{S_t}\sum_{j=1}^{N_{s,t}} price_{j,s,t}} \times time_{i,t} \times string_{i,s}\ ,$$

$$(10)\ W = diag\left(\Omega_{1,1,1}, \dots, \Omega_{\mathrm{i,s,t}}, \dots, \Omega_{N,S,T}\right)\ ,$$

$$(11)\ B = \left(X'WX\right)^{-1}\left(X'WY\right).$$

The cap-weighted index uses the equal-weighted index procedure until the index calculation stage, at which point the price index is constructed with a weight matrix.

Price	Time	Set	Weights	log(Price)	Y
2000	**0 (Base period)**	**1**	2000/2000=100%	7.60	- 0.56
5000	**1**	**1**	((5000+5050)/2)/16050=31.3%	8.52	0.35
5050	**1**	**1**	((5000+5050)/2)/16050=31.3%	8.53	0.36
6000	**1**	**2**	6000/16050=37.4%	8.70	0.20
3000	**2**	**1**	3000/7000=42.9%	8.01	- 0.16
4000	**2**	**2**	4000/7000=57.1%	8.29	- 0.20

In this example, the matrices Y, X, and W are:

$$Y = \begin{matrix} Y_{i,s,t} \\ -0.56 \\ 0.35 \\ 0.36 \\ 0.20 \\ -0.16 \\ -0.2 \end{matrix} \qquad X = \begin{matrix} & time_1 & time_2 & Comparable\ Set_1 \\ 1 & 0 & 0 & 1 \\ 1 & 1 & 0 & 1 \\ 1 & 1 & 0 & 1 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 \\ 1 & 0 & 1 & 0 \end{matrix}$$

$$W = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.313 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.313 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.374 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.429 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.571 \end{bmatrix}$$

Result of the OLS estimation procedure: $B = \left(X'WX\right)^{-1}\left(X'WY\right)$.

$B = \begin{matrix} C & -0.66 \\ \beta_1 & 0.89 \\ \beta_2 & 0.43 \\ \alpha_1 & 0.10 \end{matrix}$, the index is then computed as:

$$Index_{t=0} = 100$$

$$Index_{t=1} = exp(0.89) \times 100 = 243.51$$

$$Index_{t=2} = exp(0.43) \times 100 = 153.73$$

2.4 Monthly Calculation Method

The linear model used to estimate the index is based on a discrete function of time. As a consequence, the index estimation depends on the frequency of new data entering the dataset. The model extension presented employs a common data-based procedure in order to provide more useful monthly updates of price levels.

This methodology is based on a standard approach that consists of forwarding the most recent value of an artist's individual price level in the composition of the index. Duplicating the most recent past prices in certain conditions is a procedure commonly deployed by composite financial index providers (e.g., Nasdaq-100 Index).

In the case of artnet, data completion occurs at the base level: the time discretization of equation (1) contracts to a monthly level to provide an estimation of monthly returns of each artist. In the absence of new data, past observations from the previous time period are forwarded up to a logical threshold, at which point the new observations take over. In practice, this yields a zero-return at the artist's level but allows for computation of a monthly composite index.

In the following example, a composite index is made for two artists. Artist 1 did not appear on the auction market in month 2, while artist 2 did not appear in month 3:

Artists	**Month**	**β**	**N**
1	*1*	*0.12*	*30*
2	*1*	*0.23*	*40*
2	*2*	*0.22*	*50*
1	*3*	*0.13*	*20*

For each artist, their last prices are forwarded in their respective datasets. Completion eventually produces the following results:

Artists	**Month**	**β**	**N**
1	*1*	*0.12*	*30*
2	*1*	*0.23*	*40*
1	**2**	**0.12**	**30**
2	*2*	*0.22*	*50*
1	*3*	*0.13*	*20*
2	**3**	**0.22**	**50**

Subsequently, the monthly index is computed:

$$Index_{t=0,\{artist1,artist2\}=100}$$

$$Index_{t=1,\{artist1,artist2\}=\frac{(\exp(0.12-0)\times 30+\exp(0.23-0)\times 40)\times 100}{70}=120.24}$$

$$Index_{t=2,\{artist1,artist2\}=\frac{(\exp(0.12-0.12)\times 30+\exp(0.22-0.23)\times 50)\times 120.24}{80}=119.42}$$

$$Index_{t=3,\{artist1,artist2\}=\frac{(\exp(0.13-0.12)\times 20+\exp(0.22-0.22)\times 50)\times 119.42}{70}=119.76}$$

2.5 Confidence Interval

The confidence interval provides vital information regarding the effectiveness of the indices. It also plays a significant role in determining whether or not past index values need to be revised[9]. The methodology requires the confidence interval to be calculated.

To calculate an asymptotic confidence interval for equal-weighted index, the error matrix is first computed using the following equation:

$$(12)\ e = Y - \hat{Y} = Y - X\left(X'X\right)^{-1}X'$$

Next, the sum of squared errors (SSE) and mean square error (MSE) are calculated using the elements from the error vector *e* using:

$(13)\ SSE = \sum_{i=1}^{N} \varepsilon_i^2$ where ε_i are the elements of vector e.

$(14) MSE = \frac{SSE}{N-p}$ where p is the amount of columns in matrix X.

Defining the variance-covariance:

$$(15)(X'X)^{-1}MSE$$

This is a p by p matrix with diagonal elements indicating the square of the standard errors of the estimated regression parameters. Finally, the confidence interval for any parameter β_t is calculated using:

$(16)\ CI_{\beta_t} = \widehat{\beta_t} \pm t^* \times s(\beta_t)$,

where $s(\beta_t)$ is the standard error of the β_t parameter and where t^* is the critical value of *t-distribution* with *N-p* degrees of freedom.

In the case of the cap-weighted index, equation (14) must be adjusted as follows:

$(17)\ MSE = \frac{Y'(W - WX((X'WX)^{-1})X'W)Y}{N-p}$

Equation (15) becomes: $(18)\ (X'WX)^{-1}MSE$

2.6 artnet Market Indices

In addition to artist specific indices, artnet also calculates broader indices for various markets.

artnet has created a growing number of market indices by examining, though not bound to, the categorization methods used by auction houses.

The first market index to be released by artnet analysts was the **artnet C50™ Index**. This index is tracked based on the performance of the 50 top-ranked artists within the Contemporary Art market each year. Other indices, such as the Impressionist Art Index and the Modern Art Index, are also based on the performance of the top-ranked artists within their respective category each year.

[9] See Appendix for reasons index values may be revised

2.7 Selection of Artists for artnet Market Sector Indices

artnet developed a robust approach in which artists are ranked based on their yearly performance. The rank for each artist in a given year is used in an exponential decay formula that goes back five years; the resulting rank value generated is used to determine the final ranking for all artists.

More specifically, artists are ranked using the following steps:

a. Determine universe of artists in the market sector, based on their style, birth and death years, and art movements associated with them

b. Compute total lots sold and median price for each artist per year, excluding prints

c. Multiply median price by sold lots; the result will be hereafter referred to as *m*

d. Generate the overall rank for year *x* by using the value *m* in an exponential decay going back five years. For example:
Overall Rank in year x= $[(m_{x-1} * \exp^{0}) + (m_{x-2} * \exp^{-1}) + (m_{x-3} * \exp^{-2}) + (m_{x-4} * \exp^{-3}) + (m_{x-5} * \exp^{-4}) + (m_{x-6} * \exp^{-5})]$

e. After the decay is performed, the artists with the highest overall rank in year *x* are included in the computation of the sector index for year *x*

2.8 Composite Index Calculations

Composite indices (i.e., one comprised of multiple artists) are calculated in a single step, based on equation (1), by merging all comparable sets of artists. An equal-weight index is derived thanks to a weight matrix that forces the model to give each artist the exact same importance:

$$(19)\xi_{a,t} = \frac{\mathrm{N}_t}{n_{a,t} \times A_t},$$

where N_t is the total amount of artworks sold at time *t* and $n_{a,t}$ is the amount of artworks from artist *a* sold at time *t*. $\mathrm{A_t}$ is the total amount of artists for whom at least one transaction was observed at time *t*. The equal-weight matrix is:

$$(20)\Xi = diag(\xi_{a,t})_{N \times N}$$

The parameters are then estimated using OLS:

$$(21)\mathrm{B} = (\mathrm{X}'\Xi\mathrm{X})^{-1}(\mathrm{X}'\Xi\mathrm{Y})$$

By extension, a cap-weighted composite index is obtained in a similar way:

$$(22)\mathrm{B} = (\mathrm{X}'\Xi\Omega\mathrm{X})^{-1}(\mathrm{X}'\Xi\Omega\mathrm{Y}).$$

2.9 Composite Index Yearly Adjustment

At the end of every calendar year, a new group of artists is selected for the composite indices based on their performance in the previous year. Once this ranking process is complete, the composite index will be recalculated on the first business day in January to reflect the new group of artists. The composite index values generated in early January will then be scaled to the closing value for December of the previous year. This adjustment will ensure that composite indices remain stable, even after the artists included in the index change. All subsequent months will follow this scaling logic.

2.10 Conclusion

artnet Indices are held to the highest possible standards of data integrity, and artnet believes its index methodology to be the most accurate, testable, and transparent art index commercially available. The methodology successfully incorporates the unique characteristics of art, while maintaining the accuracy of repeat sales. Multiple variations of the final index creation process were tested against one another to determine the best and most accurate calculation method. These tests confirmed that the artnet index methodology performs extremely well. In addition, safeguards have been developed and put in place to ensure that the indices are dynamic enough to accommodate additional data from any time period. The information artnet Indices makes available to users are more powerful than any other art analysis tool currently available.

3 Appendix

3.1 Repeat Sales as Nested Case of Hedonic Regression

Consider a sale of item *i* at time t_1 at price p_{i,t_1}. Given that the item has *h* characteristics, a hedonic regression for this item can be written as:

$$\log(p_{i,t_1}) = \sum_{k=1}^{K} \alpha_k h_{i,k} + \sum_{\tau=0}^{T-1} \beta_\tau d_{i,\tau} + \eta_{i,t_1}$$

where $h_{(.),k}$ is the kth characteristics of the item *i* and $d_{(.),\tau}$ is the indicator variable which takes the value of 1 if the item is sold in the time period τ, else 0.

Consider another item *j* which is sold in time t_2 (where $t_1 > t_2$) and at price p_{j,t_2}. With the item having *h* characteristics, the hedonic regression model for item *j* is as follows:

$$\log(p_{j,t_2}) = \sum_{k=1}^{K} \alpha_k h_{j,k} + \sum_{\tau=0}^{T-1} \beta_\tau d_{j,\tau} + \eta_{j,t_2}$$

Considering a repeat sales model, where both *i* and *j* are same items, and their price difference is the parameter of interest, the hedonic regression form of this repeat sales model is:

$$\log(p_{i,t_1}) - \log(p_{j,t_2}) = \left(\sum_{k=1}^{K} \alpha_k h_{i,k} + \sum_{\tau=0}^{T-1} \beta_\tau d_{i,\tau} + \eta_{i,t_1} \right) - \left(\sum_{k=1}^{K} \alpha_k h_{j,k} + \sum_{\tau=0}^{T-1} \beta_\tau d_{j,\tau} + \eta_{j,t_2} \right)$$

Since the characteristics *h* are common across both items, the above model is reduced to:

$$\log\left(\frac{p_{i,t_1}}{p_{j,t_2}}\right) = \left(\sum_{\tau=0}^{T-1} \beta_\tau d_{i,\tau} \right) - \left(\sum_{\tau=0}^{T-1} \beta_\tau d_{j,\tau} \right) + \zeta$$

where the indicator variable $d_{(.),\tau}$ is -1 for time t_2 and +1 for time t_1. The above equation is the same form as the traditional repeat sales model, and thus proof shows that the repeat sale is a form of hedonic regression.

3.2 Data standardization

artnet Indices are based on Comparable Sets that use public auction sales data extracted from the *artnet Price Database*. Although most auction houses report transaction prices that include a buyer's premium, some auction houses only report hammer prices. Based on an analysis of historical auction catalogs, artnet applies a formula to all records with hammer prices, only to estimate the effect of a buyer's premium. All prices in the artnet Analytics Reports are therefore either reported as, or equated to, the hammer price plus a buyer's premium.

3.3 Index Revisions

artnet adheres to the same strict data revision logic as the S&P Case Schiller methodology[10]. The revising of index data is based on new information not previously recorded or submitted. For example, as a new-to-artnet auction house has sales results added to the *artnet Price Database*, sales data for as far back as the new auction house can provide is added to the database, and in turn to the indices. When the new data is entered, a comparison is made between the index values prior to and after the addition. If the index values move outside of the first index confidence interval, then the new index values replace the prior values. In the event that the index stays within the confidence interval, no change is made. This in-house data management system allows for a constant monitoring of data to maximize accuracy.

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[10] "S&P/Case-Shiller Home Price Indices." *Index Methodology*. S&P/Case-Shiller, Nov.-Dec. 2009. Web. 30 Jan. 2012. <http://www.standardandpoors.com/indices/sp-case-shiller-home-price-indices/en/us/>. Page 33.