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Valuing the Numismatic Legacy of Alexander the Great

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Abstract

The conquests of Alexander III ("The Great") transformed the economic as well as political landscape of ancient Greece and Persia. It produced a prolific coinage, part of which survives today. This paper uses a hedonic price modeling approach to analyze auction prices of the major coin type of Alexander the Great. The findings make it possible to identify the effects of specific coin characteristics on realized auction prices, sellers' reservation prices (auction price estimates), discrepancies between realized and estimated prices, and the variability of auction prices around predicted prices, or auction price surprise. The findings reveal that similar considerations shape estimated and realized prices, but bidders consistently value positive coin characteristics more highly than do sellers. Realized auction prices, the difference between realized and estimated prices, and auction price surprise are increasing over time, particularly for the highest grade coins.

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Valuing the Numismatic Legacy of Alexander the Great

Recognizing the economic and political importance of having a uniform coinage, Alexander III ("The Great") quickly took over existing mints in the places he conquered and produced a prolific coinage. For example, Price (1991, p. 369) writes:

> *"When Alexander arrived in Cilicia he found a well established Persian coinage produced from Tarsus by the satraps. The silver staters displayed the figure of Baal of Tarsus, seated and holding his flowering sceptre...the same engravers clearly turned from cutting dies for the Persians to producing those of the imperial Macedonian coinage. Details of the throne, drapery, and figure can be closely compared in the two series, and it is certain that the mint began to strike the Alexander series without any serious break in production...immediately after Alexander's arrival in summer 333 BC."*

At other sites, most notably Alexandria, new mints were established where none had existed before. During Alexander's reign from 336 to 323 BC, a huge volume of three coin types were struck at no fewer than 26 mints, from Amphipolis in what is now Macedonia to Alexandria and Babylon, with silver and gold bouillon principally from treasures captured from the Persians. After Alexander's death, Greek rulers and cities throughout the former empire produced the same coin types at new mints. In all, about 114 different mints produced Alexander coins over a period of 250 years, including many imitative issues. The last "Alexanders" were minted at Mesembria (Thrace) around 65 B.C.

A large but unknown number of these coins have been discovered in hoards scattered throughout the Mediterranean region, evidence of both the abundance and geographic scope of the trade they facilitated.[1] Today there is a lively trade in Alexander coins via on-line auctions, from eBay to numismatic auction houses in the United States and Europe.

From an economic valuation perspective, these coins are of interest for several reasons. First, they are of uniform weights and *typoi* (designs), carefully chosen by the ruler for economic and political purposes (see below). This makes the coins of Alexander comparable in ways that other, more diverse ancient coinages (or, indeed, most items sold at art and antiquities auctions) are not. Second, the volume of contemporary sales of Alexander coins exceeds that of any other ancient coin variety, ensuring a sufficient sample size with which to study the factors determining the value of these coins today. Third and most importantly, despite their basic uniformity, these coins exhibit substantial diversity in terms of the times and mints at which they were struck, the artistry and quality of the dies that shaped them, and their degree of

[1] The basic reference on ancient Greek coin hoards remains Thompson, Morkholm and Kraay, 1973.

preservation. Because of this, auction prices of the same basic Alexander coin type can vary by a factor of 40 or more.

These large price disparities tell us that people do not demand ancient coins; they demand coins with particular characteristics, for which they are sometimes willing to pay a high price at auction. The view in economics that individuals receive satisfaction from, and thus value, specific characteristics of goods is called "hedonic price theory," named after the Greek word for pleasure. The interplay of a particular coin characteristic's supply and demand in the market determines the price that people are willing to pay for the characteristic, that is, the characteristic's hedonic price. Characteristics that are in great demand but short supply (like "superb-grade struck during the king's lifetime") fetch a high price, while characteristics that are more common or not in demand ("low-grade, posthumous") command a lower price.

There are some recent precedents using statistical techniques to study the auction prices of ancient coins. Charles Shahar's (2006) fascinating study of the facing-head drachms of Larissa used one-way analysis of variance (ANOVA) to compare the mean estimated and realized prices of coins of different grades, artistic quality, scarcity of reverse types, defects, and year and currency of auction. It does not provide estimates of the effects of specific traits or combinations of traits on the price, though, controlling for other factors. A less formal but similar approach was used by Terrence W. Faulkner (2004) to compare the prices of Elagabalus imperial coins sold by major auction houses and on e-Bay. David Chiszar, et al. (2004) and Chiszar and Hobart M. Smith (2000) tested the correspondence between estimated and realized prices at the Triton IV and III auctions, respectively. Their regression approach allows us to see how an increase in the estimated price affects the realized price; however, it does not control for characteristics of the coins, which are likely to affect both. The approach most similar to the one used here is that of John G. Matsusaka's study of how selected characteristics affect the market price of the "Tribute Penny" of Tiberius. Although not characterized as such, it can be called a type of hedonic price analysis.

In contrast to ancient numismatics, numerous studies have used the hedonic method to value the traits of other heterogeneous goods. Perhaps the most common and well-known uses of hedonic price analysis are in real estate, to answer such questions as "What is a view worth? A good school district? A remodeled kitchen? A third bedroom or second bath?" These studies recognize that house prices are heterogeneous and shaped by the supply and demand of a complex array of housing characteristics. A Golden Gate Bridge view can add hundreds of thousands of dollars to the price of a Berkeley hills home, and the relocation of a corporate headquarters in a small town can drive up the prices not simply of houses but, disproportionately, of houses with characteristics that are demanded by executives' families.

Recently, hedonic price models have been used to study wine prices. What does a Napa or Bordeaux appellation add to the price of a bottle of wine? An additional year of aging? A high score from Wine Spectator magazine? Understanding how the characteristics of wines affect prices, of course, is critical to a vintner's success,

because in many cases these characteristics can be altered during the wine-making process.

Coin dealers are forever confronted by the challenges of placing values on coin traits, asking such questions as "What is the added value of a superb extra-fine versus fine grade? A rare mint? A strike from a particularly artistic die? A signature of the famous diemaker Kimon? Provenance from a well-known collection?" On the negative side, by what amount does a flaw (weak strike, double strike, porous coin surface, or test cut) detract from the value of a coin? Not uncommonly, combinations of characteristics must be considered, for example, a superb lifetime issue or a coin well struck from an artistic die but with minor porosity or die rust.

A fundamental difference between ancient coins, on one hand, and houses and wines, on the other, is that the characteristics of ancient coins are fixed, changing only as new hoards are discovered.[2]

The combination of uniformity and diversity makes hedonic price analysis an ideal tool to identify "what's in the price" of ancient coins and how buyers and sellers value specific coin traits.[3] This article reports the findings of a hedonic price analysis of all specimens of the Alexander the Great *tetradrachm* (silver 4-drachm piece) sold at the Classical Numismatics Group (CNG) auctions between 2001 and 2006, a total of 805 transactions with realized prices ranging from US$95 to $5,750.

I

The Coinage of Alexander

Alexander III carried out a numismatic as well as political conquest of the ancient Mediterranean and points east. It is clear that both conquests were carefully planned in advance. In 336 BC, when Alexander assumed power after the assassination of his father, Philip II, local coinages flourished in hundreds of Greek city-states and colonies around the Mediterranean. Various weight standards were used, and each locale had its own design or *typoi*, for example, Athena and the owl in Athens; the Pegasos in Corinth and her colonies in *Magna Graecia* (Italy and Sicily); the wheat ear in Metapontum; a boy riding a dolphin in Taras; a rose in Rhodes; a nymph carried off by a naked satyr on the island of Thasos; horses in Larissa; the nymph Arethusa and chariot of Syracuse; the hare of Messana. These images conveyed the authority of the local state and facilitated trade within city-states' zones of economic influence. They

[2] Forgeries, retooling, and over-cleaning are sad testimony to the extent to which some people are willing to forego ethical considerations in an effort to alter this inherent fact.

[3] This study adds to a growing body of empirical literature related to the economics of art and art auctions; for example, see Ashenfelter and Graddy, 2006.

also reflected the identities of Greek city-states and their people. Since the beginning of coinage in the 7th Century BC, rulers recognized the political as well as economic importance of coins. For example, the idea of putting Athena and the owl on the coins of Athens is attributed to Peisistratos, the popular despot who took control of Athens from a ruling oligarchy in the late 6th Century BC. His displacement of the *typoi* of the oligarch families with Athena, the deity of Athens, was a critical part of his appeal to the populace.

Confronted by the need to economically unify his future empire, facilitate transactions, and pay his armies, Alexander invented two universal coin types based on a common weight standard (the Attic standard used by Athens), and in three denominations—two in silver, one in gold. The types and weight standard were carefully chosen to consolidate political support from Greek city states, particularly Athens, which was to be critical for the success of Alexander's conquests, while at the same time paving the way for the acceptance of the new coinage in the soon-to-be conquered lands to the east, then under Persian control. The three major Alexander coins include a 1-drachm (approx. 4.25 grams in weight) and tetradrachm (4 drachm, approximately 17 grams) denomination in silver and a gold stater (approximately 8.6 grams). At the time of their issue, these coins were demanded for their bouillon value, and the exchange rate of gold to silver was approximately 10:1. Gold staters were not struck at all of Alexander's mints, and the bulk of the coinage as we know it consists of silver tetradrachms.

The two silver denominations share the common type of Herakles wearing a lion scalp on the obverse and, on the reverse, Zeus seated on a throne, holding a scepter in his left hand and an eagle, his symbol, in his right (see Figures 1a and 1b). The wide appeal of Herakles and Zeus as symbols on the new coinage is evident. Herakles was a legendary hero to all Greeks and recognized ancestor to the Macedonian royal house. The representation of Zeus, the principal Greek god, on the reverse of these coins is remarkably similar to the Baal (deity) on Persian coins of the same period. The type chosen for the gold coin was of a helmeted Athena on the obverse and a winged Nike on the back. Athena was the principal deity of Athens, but the design of the helmet she wears is from Corinth. Nike, goddess of victory, holds out a wreath and stylus, an emblem of naval victory, likely recalling Athens' defeat of the Persians under Xerxes at Salamis 150 years earlier. The coins bear the inscription "of Alexander" (ΑΛΕΞΑΝΔΡΟΥ) on their reverse.

The Alexander silver tetradrachm is the focus of this study because it is the denomination for which there are a sufficient number of transactions with the necessary information to estimate a hedonic price model with multiple coin characteristics at a reasonable level of precision.

Ancient Coin Supply Today

The number and qualities of ancient coins in existence at any given time is fixed, the result of past hoard discoveries. Nevertheless, new coin hoards occasionally

are discovered, so the long-term supply is less inelastic, random but influenced to some degree by new search technologies. According to Paul Rynearson[4]

> *Coins that are found tend to come as single finds, family caches or large treasury hoards. Single finds are often of low grade and usually bronzes. Family hoards tend to be groups of coins of precious metals, which families entrusted to the eldest male; they were selected specimens of coins circulating at the time. There were no banks at the time, so wealthy families hoarded money in the most precious metal possible. Their coins often were placed in a container, such as a metal box or pottery vessel. Treasury hoards have the largest number of coins in them, at times many thousands. Usually of silver, but sometimes of gold, they are often found in metal boxes. In this type of hoard the coins are usually in the highest state of preservation, as they had not yet been given out in payment to mercenary soldiers, magistrates, etc.*

Some hoards are unearthed by archeological digs, but most are found by accident, unearthed in farmers' fields or at construction sites. Archeological evidence accompanying discovered hoards can provide clues about the coins. Groupings of coins in the same hoard provide information on the directions in which coins circulated (often from distant mints; for a fascinating illustration see Price and Waggoner's 1975 analysis of the Asyut Hoard unearthed in Egypt in 1969). The presence of one or more datable specimens in a hoard can assist in dating other specimens, at least placing a late boundary on their year of issue. Usually this information is lost, however. Laws establishing state rights to discovered hoards no doubt discourage the reporting of the contents of these hoards in most cases. The effect of a new hoard discovery on coin prices naturally depends on the quantity and characteristics of the coins in the hoard.

Ancient coinage, unlike its modern counterpart, was struck by hand from engraved dies that produced coins in highly sculpted relief.[5] As a result, they are more akin to works of art than to commodities produced in a uniform manufacturing process. Variations in ancient coins available at auctions today occurred prior to striking (the artistry evident in the carving of dies; die defects including wear, rust, cracks, etc., that are transferred to the coins; the quality of the metal used in the coins; ancillary markings including symbols of mints, magistrates, and on rare occasions, signatures of die makers and dates reckoned to some base date; re-striking of older coins whose images affect that of the new die); at the time of striking (weakly-struck coins, shifts in the positioning of the die between strikes of the hammer, off-centered strikes); or after striking (wear of the coin through use prior to being "lost;" ancient test cuts by traders to ensure the metal content of the coin; degradation of the coin during storage, which in the present case typically would exceed two millennia; and preservation of the coin by

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[4] Personal correspondence. Rynearson is a prominent numismatist and expert on ancient coins; see www.paul-rynearson.com.

[5] Jenkins (1990) provides a brief introduction to the methods used to produce ancient coins. These methods changed little until the late 16th Century, when minting machinery was used regularly for the first time in Europe.

discoverers, collectors and dealers over a period sometimes as long as several centuries.)

Other key factors that may affect modern-day values of ancient coins include the date and place of issue. The coins of Alexander minted at Sidon and Ake in Phoenicia are marked with dates of local eras. At all other mints, coin dates must be induced indirectly. The presence of a magistrate's name or symbol provides the contemporary equivalent of a date in most cases. The criterion of style is also used. The evolution of Greek art generally provides a reliable basis, in combination with other factors, to establish a chronology of coins. In general, the reverse on posthumous issues of Alexander silver tetradrachms have the legs of the seated Zeus crossed in front of the throne, while on lifetime issues the legs are parallel. Finally, a sequencing of dies often is possible due the economic fact that dies were costly to produce and the technical fact that obverse dies, nested in the anvil, normally outlasted reverse dies, which received the full blow of the minter's hammer. Overlaps between obverse and reverse dies, together with gradual die wear, reveal the order of striking.[6] A comprehensive cataloguing of dies used to produce the lifetime coinage of Alexander appears in the authoritative works of E.T. Newell (1935) and especially Price (1991).

II

The Hedonic Price Methodology and Data

The conventional model of demand and supply in economics treats goods as homogeneous; market prices adjust to ensure that the quantities supplied and demanded of a given good are equal to each other, as in a competitive market or auction. This model is not realistic in the case of goods that are heterogeneous and whose characteristics significantly shape their prices. Ancient coins are such goods. The wide range in realized auction prices for Alexander the Great tetradrachms reflect differences in coin traits that may include conditions and artistry of dies, quality of metal, the striking process, preservation, mint, and the year in which the coin was produced, e.g., whether it was a lifetime or posthumous issue. It is the supply and demand not of the coins, themselves, but of the characteristics that imbue ancient coins with their value that determine the prices we observe at auctions. Coins also appreciate over time, and it is possible that coins with certain traits appreciate differently than others. For example, the appreciation rate may be higher for coins of superb quality than for lower-grade specimens.

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[6] Very few dies survive to modern times. Die linking is based on analysis of the coins, themselves, where (as in the case of Alexander issues), the number of surviving coins is sufficiently large.

In a hedonic model, the price of a good *i* (say, an Alexander III tetradrachm) at time *t*, p_{it}, is the sum of the values contributed by the good's key attributes. For example, suppose z_{it1} is the grade of coin i sold at auction at time t, and π_1 is the effect of the coin's grade on its realized price (the "hedonic price" associated with coin grade). Then the product $\pi_1 \, x \, z_{it1}$ would be the contribution of grade to the realized price. Another variable, say, z_{it2}, might measure whether the coin is a lifetime strike or not; π_2, the effect of this variable on the realized price; and $\pi_2 \, x \, z_{it2}$ the contribution of a lifetime strike to the realized price.[7] If coins have K such defining traits, then in its simplest, linear form the realized price would simply be the sum of the values contributed by all of the traits:

$$p_{it} = \pi_0 + \pi_1 z_{it1} + \pi_2 z_{it2} + ... + \pi_K z_{itK} + \delta t + e_{it}$$

The parameter δ measures the appreciation of the coins over time *t*, controlling for all coin traits for which measures are included in the model. It is the amount by which the price increases when one goes from one year (say, $t = 2005$) to the next year ($t = 2006$). It is possible that coins with certain traits appreciate differently over time. In this case, interactions between traits and the time trend should be included in the model, making it possible to test whether, for example, the appreciation rate δ is higher for coins of superb quality than for lower-grade specimens.

Data on Prices and Characteristics of Alexander Tetradrachms

Decomposing the price of a good into the effects of the good's traits requires first having information on the prices of a large number of such goods in a competitive market situation. Auctions provide an ideal setting in which to perform such an analysis, because the prices realized at auction reflect both buyers' willingness to pay and sellers' willingness to accept buyers' offers. Estimated prices set by dealers and sellers prior to the auction, like suggested retail prices, are not ideal, because strictly speaking they reflect only the sellers' valuations of goods and their traits.

When both estimated and realized coin prices are available, it is possible to test the extent to which estimated prices influence realized prices and the discrepancy between the two, which are the result of one party (the seller) valuing characteristics differently than the other party (the bidder).

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[7] In practice, these trait variables often are constructed as 0-1 "dummies." For example, z_{it1} might be an indicator variable equal to 1 if a coin is of extra fine quality and 0 otherwise, and the weight π_1 would measure the effect that being of extra fine quality has on the realized price of the coin. A coin that is not of extra fine quality would enjoy no such price gain. If z_{it2} indicates a lifetime issue, then the weight π_2 would measure the difference in coin value between lifetime and posthumous issues that are of otherwise similar quality.

Hedonic price analysis requires information on the characteristics of goods that potentially give shape to their market prices. The publications of major auction houses provide, for each coin specimen offered, the information deemed by the auction house / seller to be most pertinent to accurately represent the coin and its condition to potential buyers. A caveat is that not all buyers have access to the same information. While some are able to observe a coin first-hand, by attending auctions or visiting auction houses, high transaction costs preclude most potential bidders from doing so. In some cases, serious collectors seek to narrow their information gap by hiring trusted agents to travel to the auction site or auction house and observe coins. How these efforts to augment personal information sets may affect the realized prices of ancient coins is not known. What is known, though, is that the majority of those who bid on ancient coins in on-line auctions have access only to the information provided in the auction catalogue.

Auction catalogues also include photographs. How to translate visual data from coin photographs into variables for statistical analysis is not straightforward, and no attempt is made to do so here. There is no numismatic equivalent of a Wine Spectator Magazine taste-test score. On the other hand, to a greater extent than fine wines, coins are imbued with visible characteristics that are amenable to verbal description. Using data from a single reputable auction house provides us with several advantages in this regard. It ensures that the grading standards are uniform and the textual descriptions of coins in the auction catalogue closely match up with the objective characteristics of the coins. Hopefully, the catalogue descriptions include important information that otherwise would be evident only from an in-person inspection of coins.[8]

Examples of catalogue photographs and corresponding descriptions of two grades of Alexander the Great silver tetradrachms appear in Figures 1(a)-(b). Specimen 1(a) is described as "nicely toned, struck in high relief and of lovely style," from the mint of Miletus, the largest of the Ionian cities in present-day Turkey. Specimen 1(b) is a lower ("good very fine") grade coin struck at Tyre, in present-day Lebanon. The higher price of the first coin is likely to reflect its grade and earlier year of striking as well as other characteristics mentioned in the text (place of striking, inasmuch as output at some mints was more prolific than at others; date of auction sale; and positive descriptives), or other characteristics ascertained from the photograph or perhaps by the presence of a bidder at the auction. Most bids at CNG mail-bid sales now arrive through the CNG website, only on rare occasions benefiting from an agent or personal inspection of the coins.

All of the information in the textual descriptions is easily translated into variables amenable to the statistical analysis of hedonic prices. Table 1 reports that the average realized price of Alexander the Great tetradrachms is $431, with a standard

[8] Differences in auction designs and in the practices of particular auction houses also may affect realized prices. By limiting our data to a single major auction house, we avoid such complications.

deviation of almost exactly the same magnitude ($430), indicating considerable price variation. The prices range from $95 to $5,750.[9] The average estimated price prior to auction is $386; it ranges from $150 to $3,000. The average "miss" or difference between realized and estimated price is $45, with a strikingly large standard deviation of $243 (not shown in the Table). Of all Alexander tetradrachms transacted, 48% were struck at a mint that was active during Alexander's lifetime, but only 6% were actually struck during his reign. Approximately 1 in 5 coins have a grade of "extra fine" or higher as per the descriptions. The text description of the coin contains a positive descriptive (see above) in 8.5% of the cases and a negative descriptive in 25.8% of the cases. The coin is characterized as "rare" or "scarce" in 7.7 percent of the descriptions.[10]

III

Findings: What's in the Price of an Alexander Tetradrachm?

The results of two hedonic price models are reported in Table 2.

The first model (Model 1) examines the effects of coin characteristics on the realized auction price. That is, it decomposes the realized price into the contributions of each coin characteristic. These contributions may be positive (as in the case of a high grade or positive descriptive), or negative (in the case of a low grade or flaw). The expected realized price of a coin is the sum of the values contributed by the coin characteristics plus an unexplained error.

The second model (Model 2) adds the estimated price to the hedonic price equation. The price estimate conveys information about the quality and scarcity of coins to potential buyers. It also establishes a reservation price for the auction; typically, bids are not accepted below 60-80% of the estimated price. If buyers and auction houses value all coin traits equally, the estimated price will contain all of the information needed to predict the realized price. Otherwise, coin traits that are weighed

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[9] These prices do not include the buyer's commission of 15% at this auction house. Multiplying all of the realized prices by 1.15 to reflect this commission also multiplies all of the effects of the coin traits, whether positive or negative, by 1.15. However, it does not change the percentage of the realized price that is explained by a given trait.

[10] Another key factor that can influence the auction price is a coin's provenance—whether from a well-known collection or noted as an example in an important study. In the sample we study, mentions or provenance were too rare to include as a variable in the analysis. In the future, when more auction data (particularly on coin types for which mentions of provenance are more frequent), provenance could be added to the list of coin traits.

differently by bidders will have a significant effect on realized prices even when the estimated price is included in the model.

For each model the table presents both the estimated dollar effect and the estimated percentage effect of the coin trait on the realized price, controlling for all other traits in the table. (The numbers in the second column of each panel those in the first column divided by the mean realized price of $431.) A "*" indicates that the effect of the trait on the realized price is statistically different from zero at above the 95% confidence level.[11]

Model 1: Effects of Coin Traits on Auction Prices

By far the most important factors determining the realized auction price of Alexander tetradrachms are the grade and year of striking. A condition of "extra fine" or higher adds an estimated $339, or 78.7%, to the coin price (see the panel marked "Model 1" in Table 2). If the coin is both "extra fine" and struck during Alexander's lifetime, an additional premium of $1,034 (240.4%) is added. A descriptive of "rare" or "scarce" is associated with an increase in realized price of $591 (137.4%), "toned" with an increase of $133 (31.0%), and other positive traits, with an increase of $254 (59.0%).

Mention of a negative trait decreases the realized price by $65 (15.1%). Although statistically significant, this is not very large compared with the $591 effect of positive descriptives reported above. This may have a logical explanation. Buyers look for positive attributes in ancient coins, and—especially if they cannot handle the coin prior to auction—they may assume that a coin at auction has some flaws unless convinced otherwise. This would make the negatives already factored into the coin's base price if not reflected in the published grade of the coin. If this is true, then including the negatives in the model would provide little new information to help predict the realized price.

Realized prices of Alexander tetradrachms are increasing significantly over time. They rose at an average annual rate of $38 (8.9%) between 2001 and 2006.[12]

Taken together, all of these variables "explain" 41% of the variation in realized prices observed at auction. This is not a bad performance for a statistical model of this kind: we do much better at predicting the realized auction price with this model in hand than without it. (In the latter case, our best estimate for any given coin would simply be the average auction price.) Nevertheless, we can do better by bringing the auction's estimated price into the model.

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[11] The variance of realized prices is significantly related to coin characteristics (see Model 3, below). To correct for heteroskedastic errors, the Huber/white/sandwich variance estimator was used for both Models 1 and 2.

[12] The appreciation rates reported here easily exceeds the rate of inflation as measured by the Consumer Price Index (CPI), which rose an average of 2 percentage points per year between 2001 and 2006.

Model 2: Effects of Coin Traits with Auction Estimated Prices

How do auction-house price estimates affect the realized prices of Alexander tetradrachms? We examine this question by adding the estimated price as an explanatory variable in Model 1. If bidders value coin traits in the same way that the auction house does, there will be a one-to-one correspondence between the estimated and realized price, and the effect of all coin characteristics, controlling for this estimated price, will be nil. A positive effect of a given trait would imply that bidders place a higher value on the trait than the auction house, and the trait has an effect on the realized price that is not reflected in the dealer's price estimate. Conversely for a negative trait effect.

Not surprisingly, the price estimate has a significant effect on the realized price (see "Model 2" in Table 2). Other things being equal, a $1 increase in the price estimate is associated with a $1.04 increase in the realized auction price. Adding the price estimate increases the explanatory power of the model considerably; we are now able to explain 74% of the variation in realized prices. Clearly, the estimated price contains a significant amount of information that influences what bidders are willing to pay for a coin at auction. In most cases, the effects of the individual coin traits are smaller now, because they are already reflected in the estimated price (compare the columns for Models 1 and 2 in the Table).

Nevertheless, several coin traits continue to have a significant effect on the realized price even when the ex-ante estimate is included. A grade of "extra fine" or better on a lifetime issue still adds $551 (127.2%) to the coin's realized price. This premium represents the bidders' valuation of a high-quality lifetime issue above and beyond what is already reflected in the auction price estimate. Other traits for which there is a bidders' premium over the estimated price include a coin's description as "rare" or "scarce" ($208) or "toned" ($53; other positive traits do not have a significant effect once the estimated price is included in the model).

Interestingly, appreciation over time continues to be significant and positive even when one controls for the estimated price. In other words, the gap between realized and estimated prices is increasing at a rate of $22.73 per year. This finding is consistent with a dynamic market in which prices are appreciating at a rate that outstrips seller's ability to estimate. It is also consistent with an estimation strategy aimed at encouraging multiple bids at auction, by setting the estimate below what the market will bear.

Model 3: Auction-price Volatility

Different coin characteristics influence not only the expected realized price but also the volatility of prices at auctions. For example, a "good" or "fine" grade coin might invite a small number of bids while a "superb" grade attracts many bids that can produce wide swings in the realized price in light of well-known auction dynamics.

Model 3 employs a procedure similar to the one proposed by Just and Pope (1978) to analyze output variability in crop production. We use this procedure to model the variability of auction-price outcomes in a hedonic framework. To do this, the estimated hedonic prices from Model 2 are used to predict the realized price of each coin, based on the coin's own traits and the auction-house price estimate. This predicted price is then subtracted from the actual realized price at auction. The absolute value or square of this difference represents an estimate of auction price surprise. We will consider the absolute value of the differences, because they are easier to interpret than the squared differences.[13] We then ask which coin traits incite the greatest volatility in auction prices, as well as whether auction prices are becoming more or less volatile over time.

The findings appear in Table 3. They reveal significant effects of both the estimated price and coin traits on the variability of auction outcomes. Higher estimated prices are associated with somewhat wider price swings at auction: a $10 increase in the estimated price is associated with a $1.96 increase in the average difference between the realized and predicted price. Coins characterized as "rare" or "scarce" show significant price variations—an average $206 difference between realized and predicted prices. Auction price surprise is also greater for specimens that are toned ($34) or have other positive descriptives ($50).

Controlling for all of the coin traits, it is evident that the price variability at auctions is increasing over time. The absolute difference between realized and predicted prices is increasing by $14.52 per year, meaning that it was $72.60 larger in 2006 than it was five years earlier. High-grade coins do not necessarily have greater price variability than lower-grade coins: The effect of an extra-fine or higher grade on the price deviation is small ($12) and not statistically significant. However, the auction-price surprise is increasing much more rapidly (by an additional $29 per year) for coins in "superb" condition.[14] Those who have experienced the bidding frenzy for top-quality ancient coins in recent years will not find this surprising.

IV

Conclusions

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[13] The analysis was repeated using the squared difference between realized and predicted prices, which gives a consistent estimate of auction price variance. Using the square instead of the absolute value of the difference between realized and predicted prices did not qualitatively change the results presented here. When the squared difference is used, the error term in the second-stage estimation violates the zero-mean assumption, but the estimate can be corrected using the method proposed by Harvey (1976).

[14] This finding comes from including an interaction between the year and coin grade in the regression equation. Such interactions were found to be insignificant in Models 1 and 2, and they are significant only for the superb grade in Model 3.

Hedonic analysis of coin prices at auction requires information both on characteristics of coins and on a sufficiently large number of coin transactions to value coin traits with a reasonable degree of precision. The Alexander the Great tetradrachm naturally lends itself to this type of analysis, because of its abundance and the uniformity of its type relative to other ancient coins. Many other types of tetradrachms from the ancient Greek world, from Sicily to Syria, survive to be traded in coin auctions. Few, however, are traded frequently enough to support an analysis like the one presented here at the present time. One could combine various coin types and even denominations in the same hedonic analysis by adding controls for coin type (in statistical parlance, "dummies") as explanatory variables in the model. However, this would be like mixing apples and oranges (or, more aptly, turtles and owls).[15] Even with Alexander tetradrachms, there is not a sufficient number of transactions to identify some price effects that may be of interest, for example, the value of being struck at a particular mint and point in time, or of bearing the marks of specific magistrates. The prices of particularly rare coins, by definition, do not lend themselves to statistical analysis. The availability of data on an increasing number of coin transactions from multiple auction houses will alleviate these problems and make increasing numbers of coin types amenable to price analysis in the future. Data from a diversity of auction houses might also facilitate an analysis of how auction designs affect price outcomes.

To a seasoned numismatist there is no substitute for holding a coin in one's own hand to assess its qualities. The appreciation of fine ancient coins, like fine wines, is an art, and the formal analysis of auction prices is not intended to replace personal inspection by numismatic experts in determining a coin's value. Unfortunately, most buyers are not able to hold their coins until after the auctioneer's gavel falls, and an important part of the valuation of ancient coins, like other items, involves the search for prices of other specimens having similar known features. An on-line data base with information on past sales of ancient coins greatly facilitates the search for comparable specimens. Nevertheless, synthesizing information from multiple sales of coins with heterogeneous traits can be a challenge for even a seasoned numismatist.

Hedonic price analysis can be a useful tool for processing and synthesizing information about past sales. It can also offer insights into ways in which price estimates, together with coin traits, shape auction prices and price volatility over time. The findings presented here suggest that buyers value certain characteristics of ancient coins differently than the auction house when it sets the estimated price. They also reveal that both the level and the volatility of prices of high-quality ancient coins are increasing, as on-line auctions make a limited supply of ancient numismatic treasures accessible to an ever-greater number of people via the click of a mouse.

[15] The turtle was the type on the coins of ancient Aegina, the owl, of ancient Athens.

Table 1
Descriptive Statistics for Variables in Hedonic Price Analysis

Variable	Mean	Standard Deviation	Minimum	Maximum
Realized Price	430.94	430.17	95	5,750
Estimated Price	385.96	313.6	150	3,000
Lifetime Mint	0.48	0.5	0	1
EFPlus	0.21	0.4	0	1
Lifetime Strike	0.06	0.24	0	1
Positive Descriptives	0.08	0.28	0	1
Toned	0.38	0.49	0	1
Rare or Scarce	0.08	0.27	0	1
Noted Flaws	0.26	0.46	0	2
Year Number (1=2001)	3.73	1.99	1	6
Number of Observations	586			

Table 2
Estimated Effect of Coin Characteristics on Realized Auction Prices

	Model 1		Model 2	
	Estimated Effect on Coin Price			
Coin Trait	**$**	**%**	**$**	**%**
Estimated Price ($10 increase)			1.04*	2.40
Lifetime Mint	30.90	7.18	-9.20	-2.12
EFPlus	338.59*	78.71	31.67*	7.31
Lifetime Strike	17.15	3.99	58.81	13.58
EFPlus and Lifetime Strike	1,034.37*	240.44	550.79*	127.16
Positive Descriptives	253.73*	58.98	63.41	14.64
Toned	133.48*	31.03	53.17*	12.28
Rare or Scarce	591.24*	137.43	208.01*	48.02
Noted Flaw	-64.84*	-15.07	-12.07	-2.79
Year Number (1=2001, 2=2002, etc.)	38.24*	8.89	22.73*	5.25
Constant	94.23*	21.90	-101.09*	-23.34
Share of Variation in Realized Prices Explained by Model (R-square)		.41		.74
Sample Size		586		

* Denotes that the effect is significantly different from zero at more than the 95% significance level.

Table 3
Estimated Effect of Coin Characteristics and Auction Price Estimates on Auction Price Surprise[α]

Coin Trait	Model 3	
	Estimated Effect on Coin Price Variability	
	$	% of Mean Realized Price
Estimated Price ($10 increase)	1.96**	0.45
Lifetime Mint	-11.66	-2.71
EFPlus	12.38	2.87
Lifetime Strike	25.50	5.92
EFPlus and Lifetime Strike	-28.77	-6.68
Positive Descriptives	50.08**	11.62
Toned	33.67**	7.81
Rare or Scarce	206.35**	47.88
Noted Flaw	0.91	0.21
Year Number (1=2001, 2=2002, etc.)	14.52**	3.37
Superb * Year	29.44**	6.83
Constant	-37.77**	
R-squared		.37
Sample Size		586

[α] The absolute value of the difference between the realized price and the price that would be predicted by Model 2, given each coin's characteristics and estimated price.

* Denotes that the effect is significantly different from zero at or above the 95% significance level.

Figure 1a
Extremely Fine Issue from the Miletus Mint

Tetradrachm (Silver, 17.08 g 1), Miletus, 323-319. Head of Herakles in lion-skin headdress to right. Rev. Zeus, wearing himation, seated to left on backless throne, holding eagle in his right hand and scepter with his left; below throne, monogram. Price 2105. Thompson 159 a (this coin). Nicely toned, struck in high relief and of lovely style. Extremely fine. Estimate: CHF 1'000.00. Price realized: 2,700 CHF (approx. 2,230 U.S. Dollars as of the auction date). Auction date: April 23rd, 2007

Figure 1b
Good Very-Fine Issue from the Tyre Mint

KINGS of MACEDON. Alexander III 'the Great'. AR Tetradrachm (17.19 g, 6h). Tyre mint. Struck under Demetrios Poliorketes, circa 301-286 BC. Head of Herakles right, wearing lion skin / Zeus Aëtophoros seated left; monogram in left field, monogram below throne. Price 3540; Hersh, Tyrus 30 (obv. die X). Good VF. Estimate: 300 USD. Price realized: 310 USD. Auction date: June 14th, 2006

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