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Cryptocurrency and Blockchain: an Introduction to Digital Currencies

Cryptocurrency as an Asset Class

Jessica Wachter, Professor of Financial Management, Professor of Finance

Cryptocurrency as an Asset Class

- Lecture 1: Introduction
- Lecture 2: Risk and return to cryptocurrency
- Lecture 3: Background on asset allocation
- Lecture 4: Asset allocation with cryptocurrency

Cryptocurrency as an Asset Class

- Does cryptocurrency have a place in the portfolio of an investor?
- Can we use the concepts we have developed in these lectures to answer this question?

Opinions of Cryptocurrency as an Asset Class

- “A fraud, worse than tulip bulbs” — Jamie Dimon, JP Morgan CEO on September 12, 2017
- “Probably rat poison squared” — Warren Buffet, Berkshire Hathaway CEO on May 5, 2018
- “Crypto is the mother of all scams and (now busted) bubbles” — from the title of Nouriel Roubini’s congressional testimony, October 2018

Two Views of Cryptocurrency as Part of a Portfolio

- View 1: Traditional finance, from a theory perspective
- View 2: Traditional finance, from a data perspective

View 1: Traditional Finance - Theory Perspective

- The Capital Asset Pricing Model (CAPM) is one of the great achievements of finance, and still the benchmark theory for expected returns
- CAPM — investors should hold risky securities according to market-weighted values
- The CAPM does pretty well: witness the success of indexed funds!
- What does the CAPM say about crypto?
  - One should hold zero cryptocurrency
  - Cash, or currency, has transaction value, but has no underlying value (such as debt or equity in a company) - it is simply a medium of exchange
  - CAPM would say you shouldn’t really hold any currency in your portfolio (hold as little as possible for transaction needs)

View 1: Traditional Finance - Theory Perspective

- Gordon Growth Model
  - The benchmark method for valuing companies
  - Idea: perhaps if one could value cryptocurrency using the Gordon Growth Model, one could decide if crypto was under or over-valued
  - Values companies based on their dividends, and obviously currency pays no dividends

View 2: Traditional Finance - Data Perspective

- An alternate view: Construct returns on cryptocurrency
- Examine the empirical properties of these returns
- Treat these returns as if they were returns on a traditional investment and ask:
  - If we saw an investment with returns like these, would we want to hold it as part of our portfolio?

View 2: Traditional Finance - Data Perspective

- Both View 1 and View 2 are traditional finance viewpoints
- They may be at odds (we will see)
- They each have drawbacks
  - View 1 (Theoretical): What if we are missing something important in our assumptions?
  - View 2 (Empirical): There may be serious limitations to the data
- Is there a third view?

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Risk and Return to Cryptocurrency

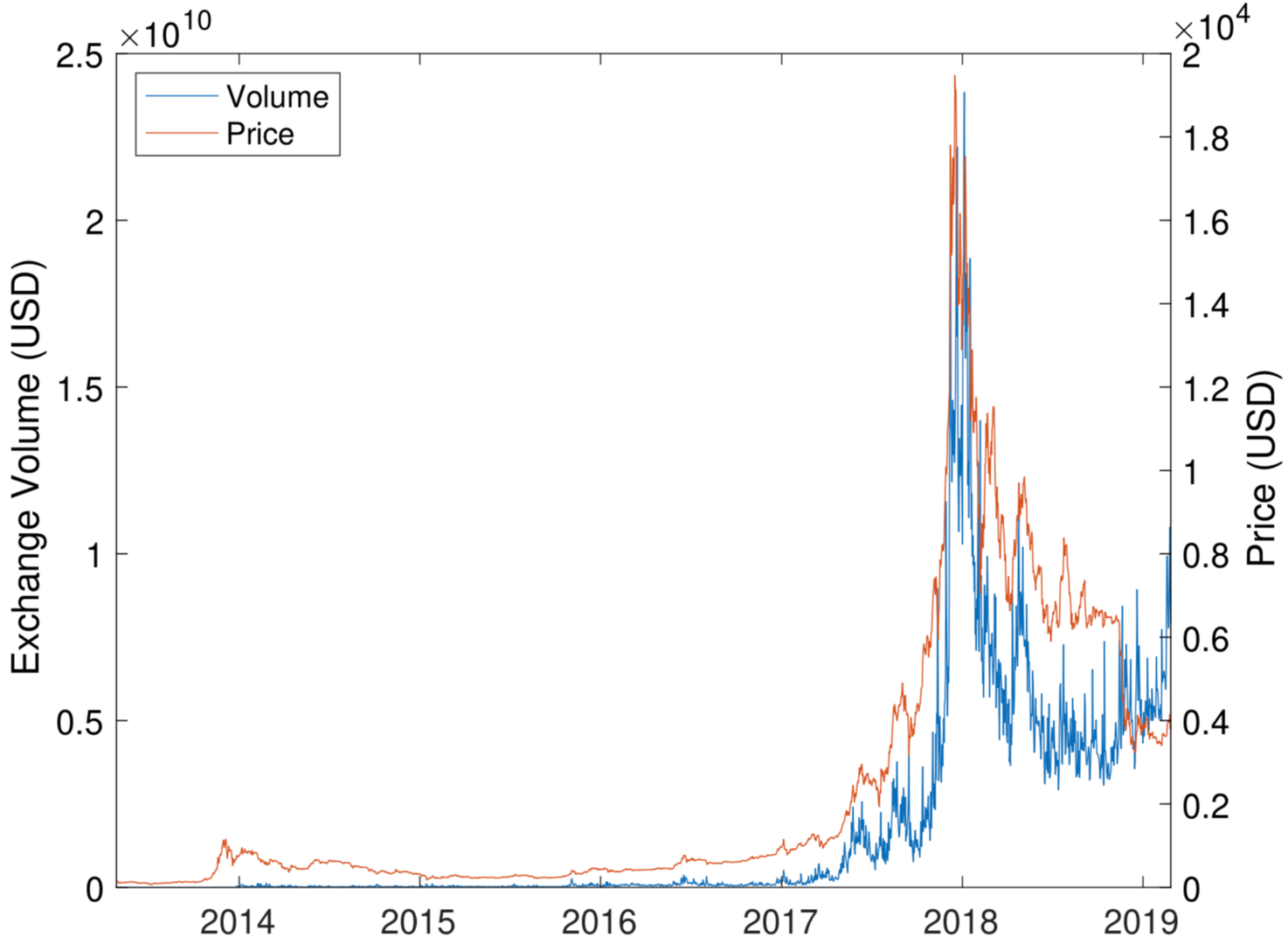
Jessica Wachter, Professor of Financial Management, Professor of Finance

Data Driven Approach

- Basic price patterns
- Defining the return to investing in crypto
- What is the average return to investing in crypto?
- What are the risks?

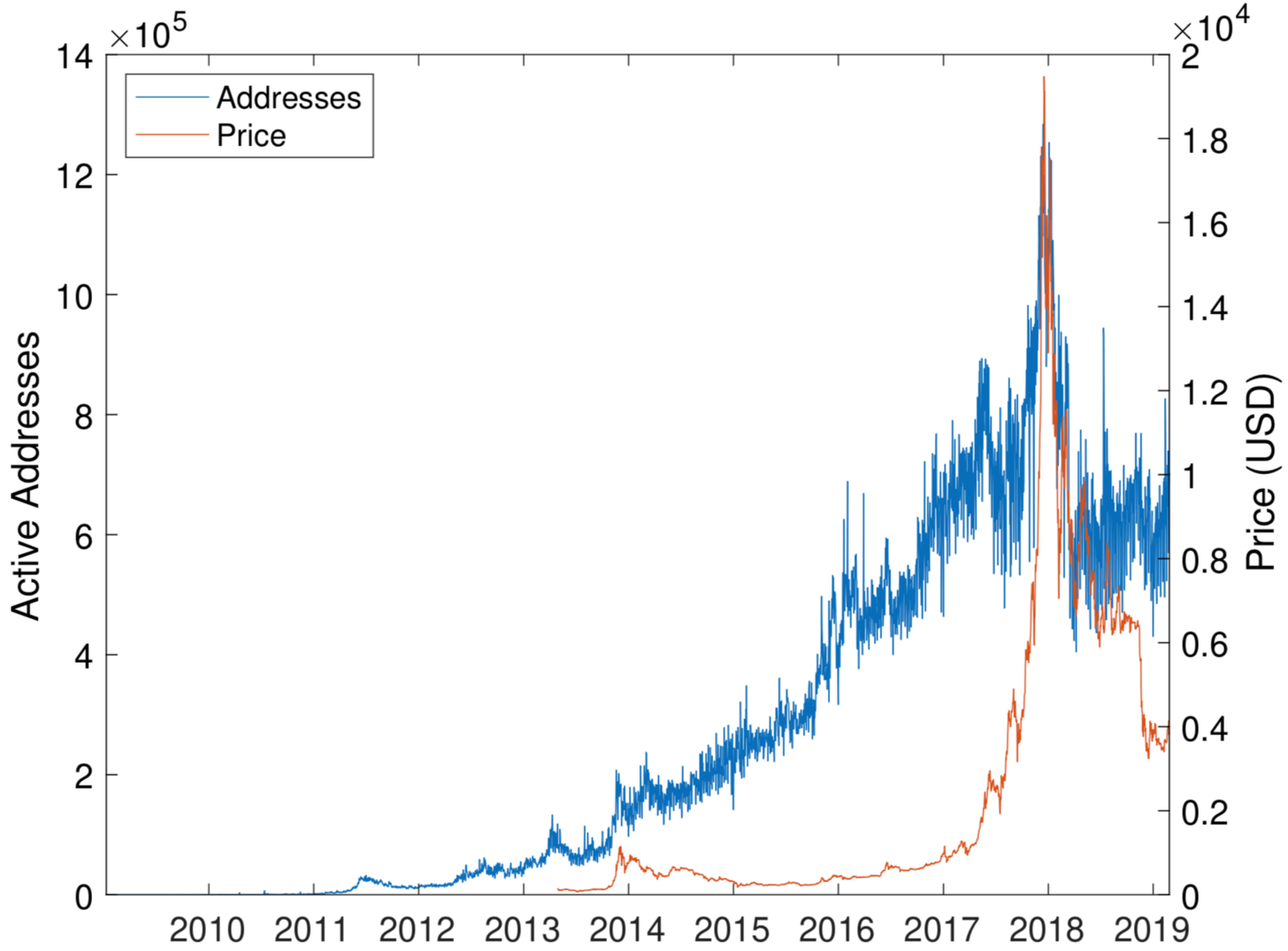
Dollar-to-BTC Exchange Rate, Along With Volume

- The orange line shows how the price of one bitcoin varies in terms of dollars
- The blue line shows the transaction volume



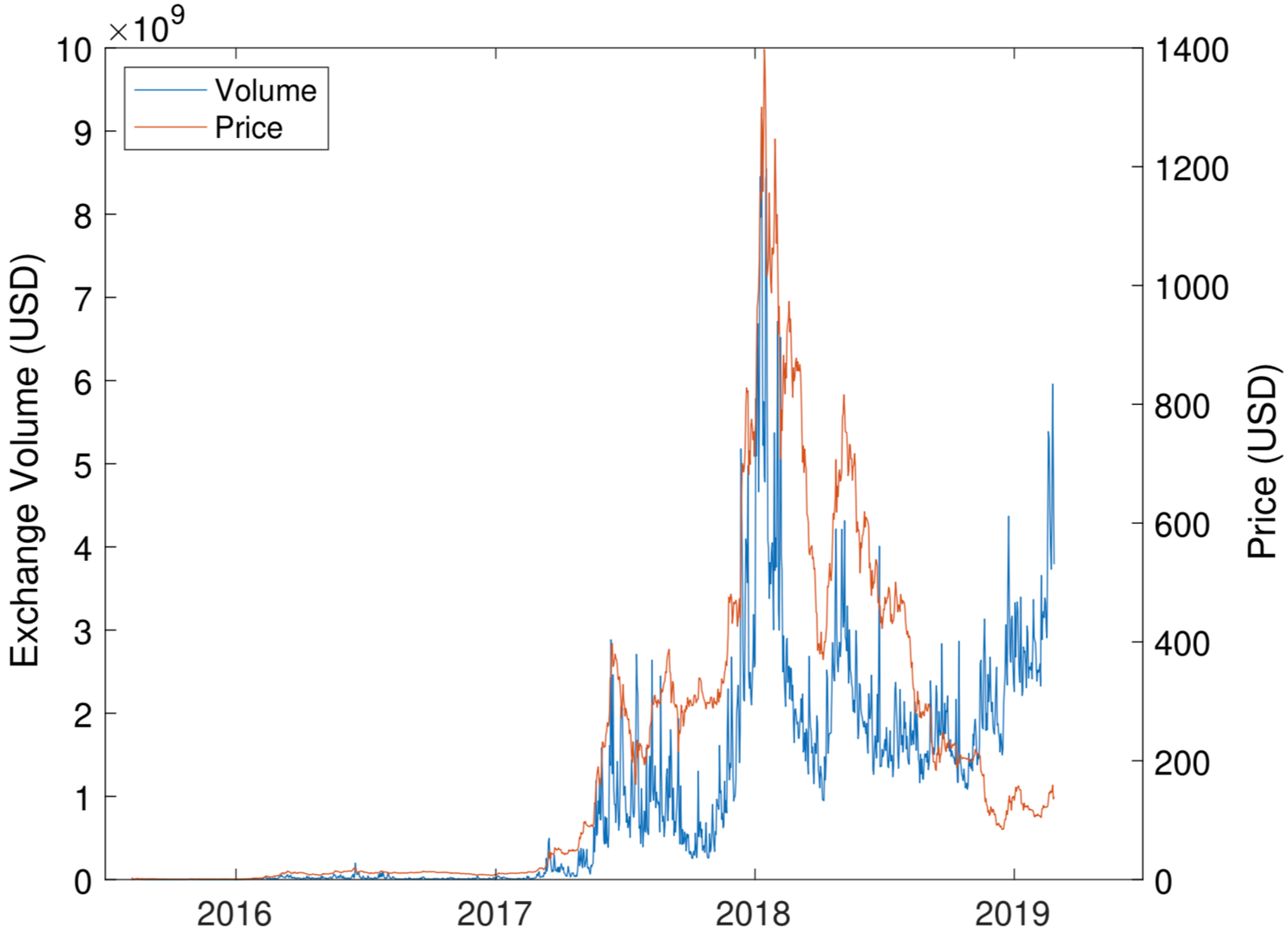
Dollar-to-BTC Exchange Rate, Along With Active Addresses

- Recall that an address is a user of Bitcoin

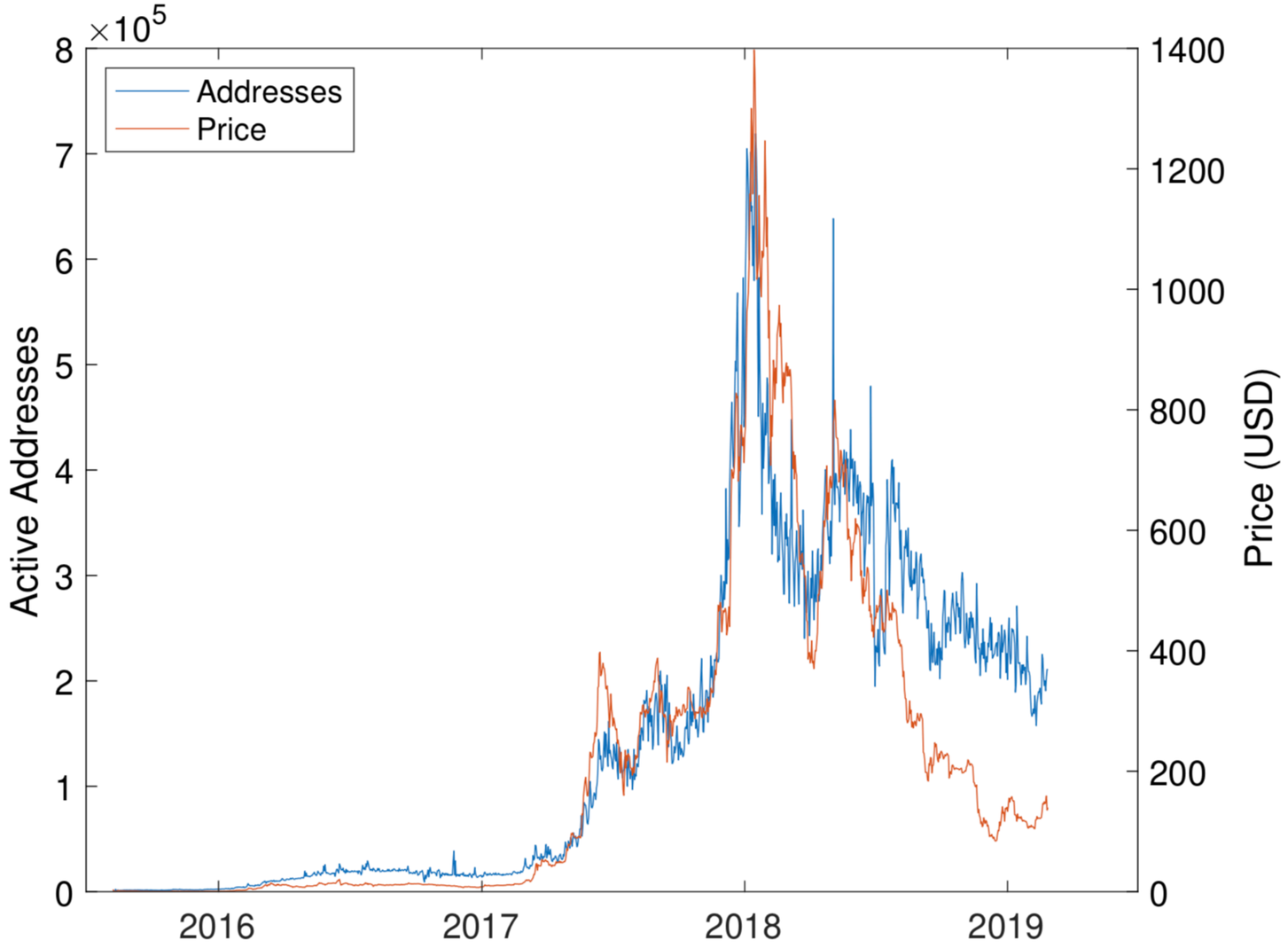


Dollar-to-ETH Exchange Rate, Along With Volume

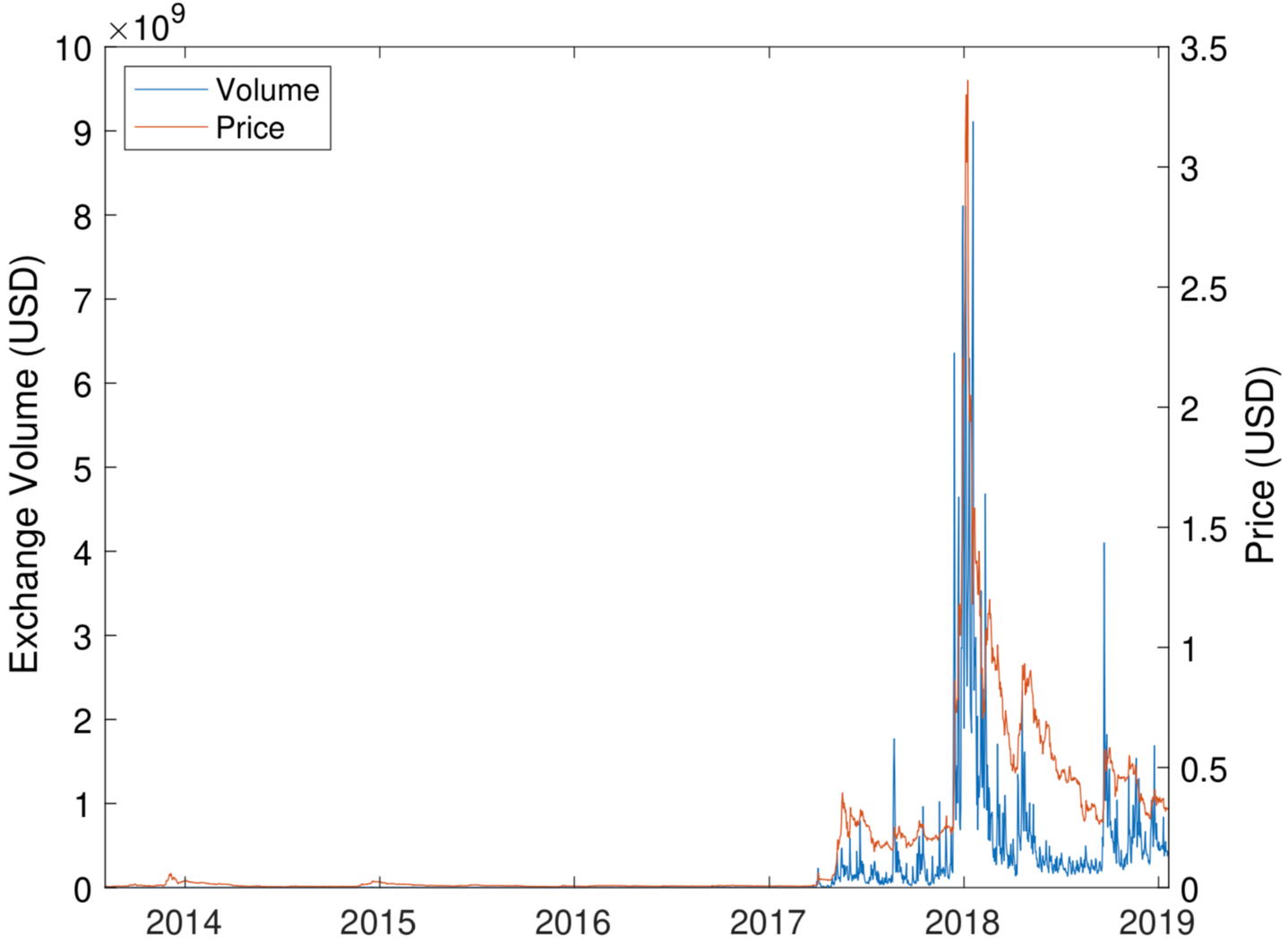
- The orange line shows the price of one ether in terms of dollars
- The blue line shows the transaction volume
- Ether is the currency whose blockchain is generated by the Ethereum platform



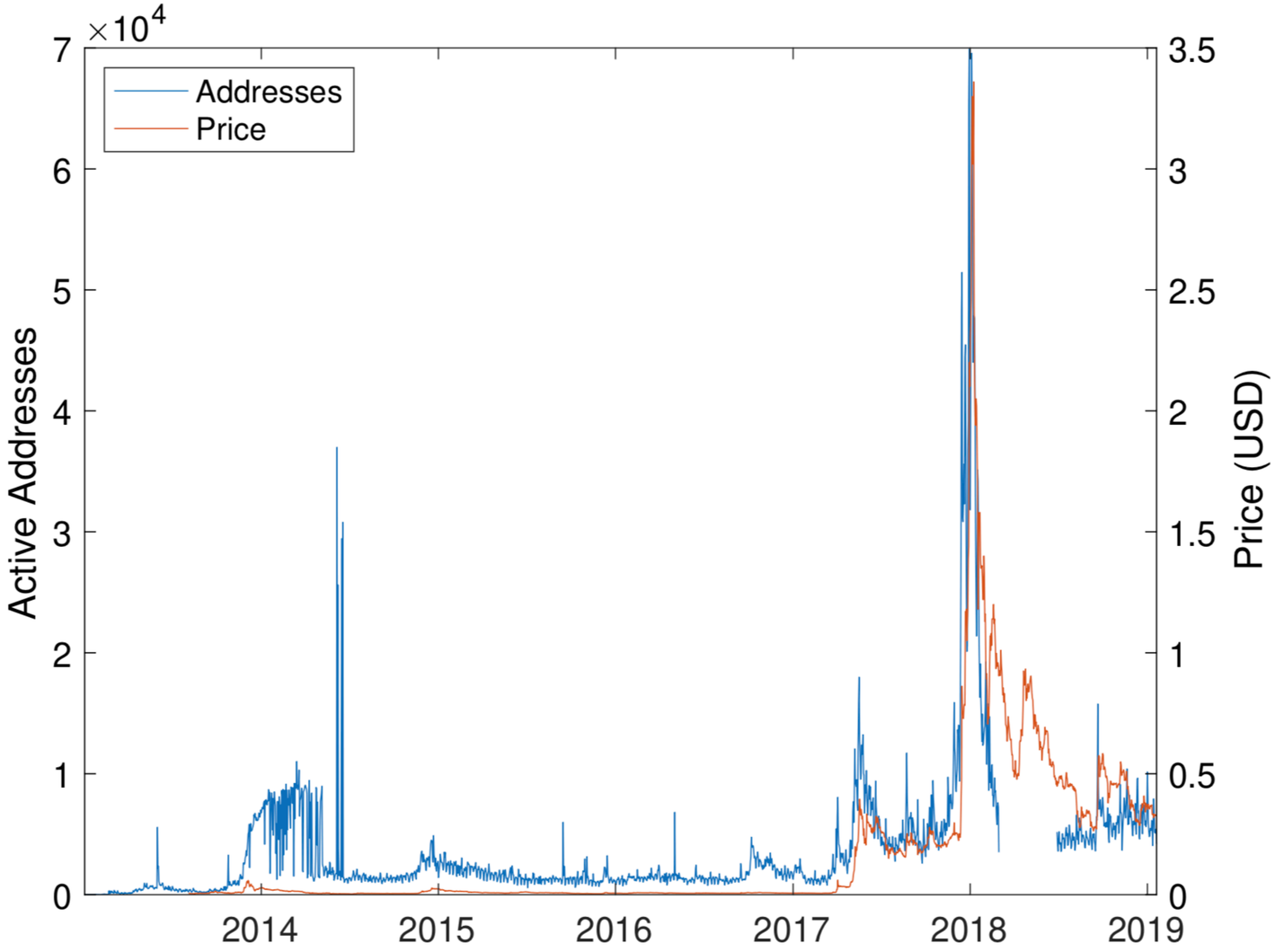
Dollar-to-ETH Exchange Rate, Along With Active Addresses



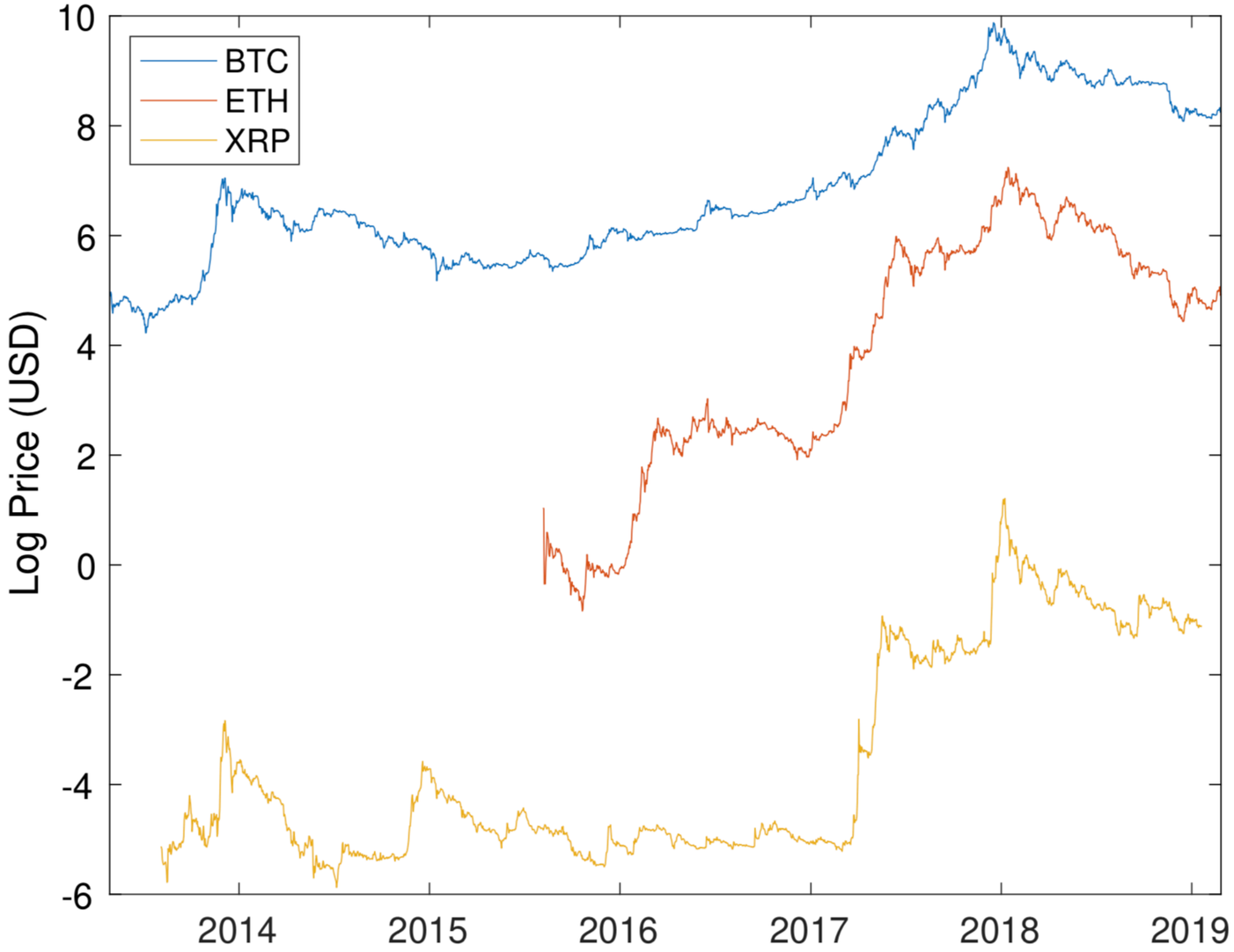
Dollar-to-ETH Exchange Rate, Along With Volume



Dollar-to-ETH Exchange Rate, Along With Active Addresses



Log Prices


BTC
ETH
XRP
Log Price (USD)
10
8
6
4
2
0
-2
-4
-6
2014
2015
2016
2017
2018
2019

Summary Thus Far

- From these simple plots, we see that currency prices have stabilized following the crash in early 2018
- Prices track volume closely
- Prices track active addresses to some extent
- Active addresses have stabilized as well
- Currency prices for these three are very high relative to where they began
  - However, many cryptocurrencies have failed

Returns

- Cryptocurrency is a store of value, and as such, it is an asset
- We will refer to the price of bitcoin as the number of dollars it takes to buy one bitcoin
- Consider the strategy:
  - Purchase one bitcoin today
  - Tomorrow, exchange that bitcoin for dollars
- What is the return on this strategy?

Returns

- With \$1, you can purchase $1/P_t$ units of bitcoin, where P_t is the price of bitcoin today (at time t)
  - Why? With P_t, you can purchase P_t $(1/P_t) = 1$ unit of bitcoin.
- You wake up tomorrow:
  - In your account are $1/P_t$ units of bitcoin
  - Each are worth P_{t+1}, that is the price one day after you purchased them.
- Daily return:

$$R_{t+1}^{\not{B}} = \frac{P_{t+1}}{P_t} - 1 = \frac{P_{t+1} - P_t}{P_t}$$

Returns

- Your return is the rate of growth of your investment
- For example, if the price of Bitcoin went up by 3% of its value:

$$R_{t+1}^{\not B} = \frac{P_{t+1}}{P_t} - 1 = \frac{1.03 \times P_t}{P_t} - 1 = 0.03$$

- We could repeat this exercise with any one of the cryptocurrencies
- We could then ask, what is the average daily return over the sample for each cryptocurrency?

Returns

- Answer for Bitcoin: $E[R_{t+1}^{\text{Ƀ}}] = 0.254\%$
- This means, on average, $1 invested in Bitcoin became $1.00254

- For Ether: $E[R_{t+1}^{\Xi}] = 0.584\%$

- For Ripple: $E[R_{t+1}] = 0.514\%$
- (At the time of this writing, Ripple has no symbol)

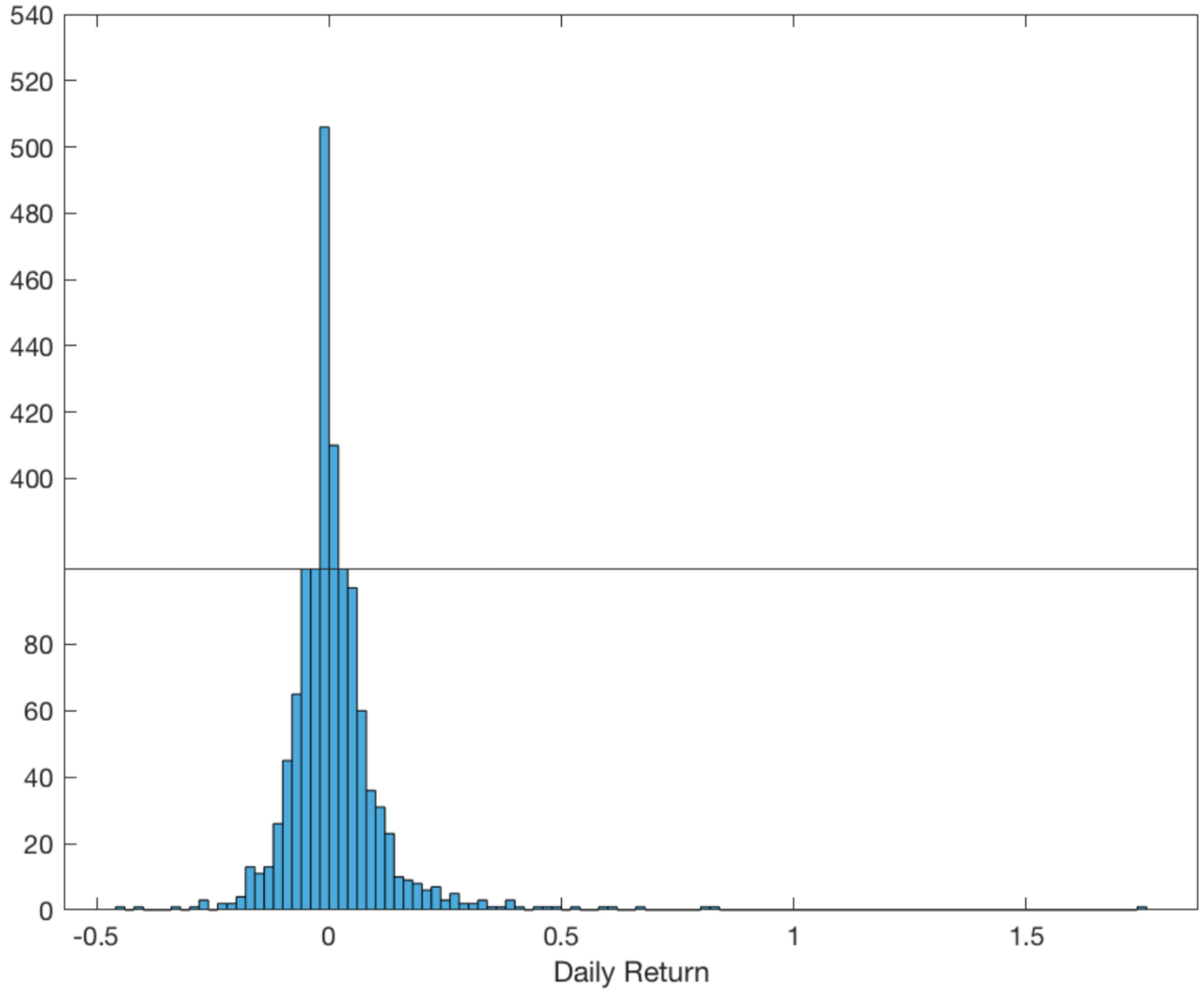
Means Versus Medians

- Reported were statistical averages (means)
- Technically: you sum up the daily returns and divide by the length of the sample period
- This is (usually) the best estimator of what you are truly expected to earn
- However, your returns on a day-to-day basis could look very different

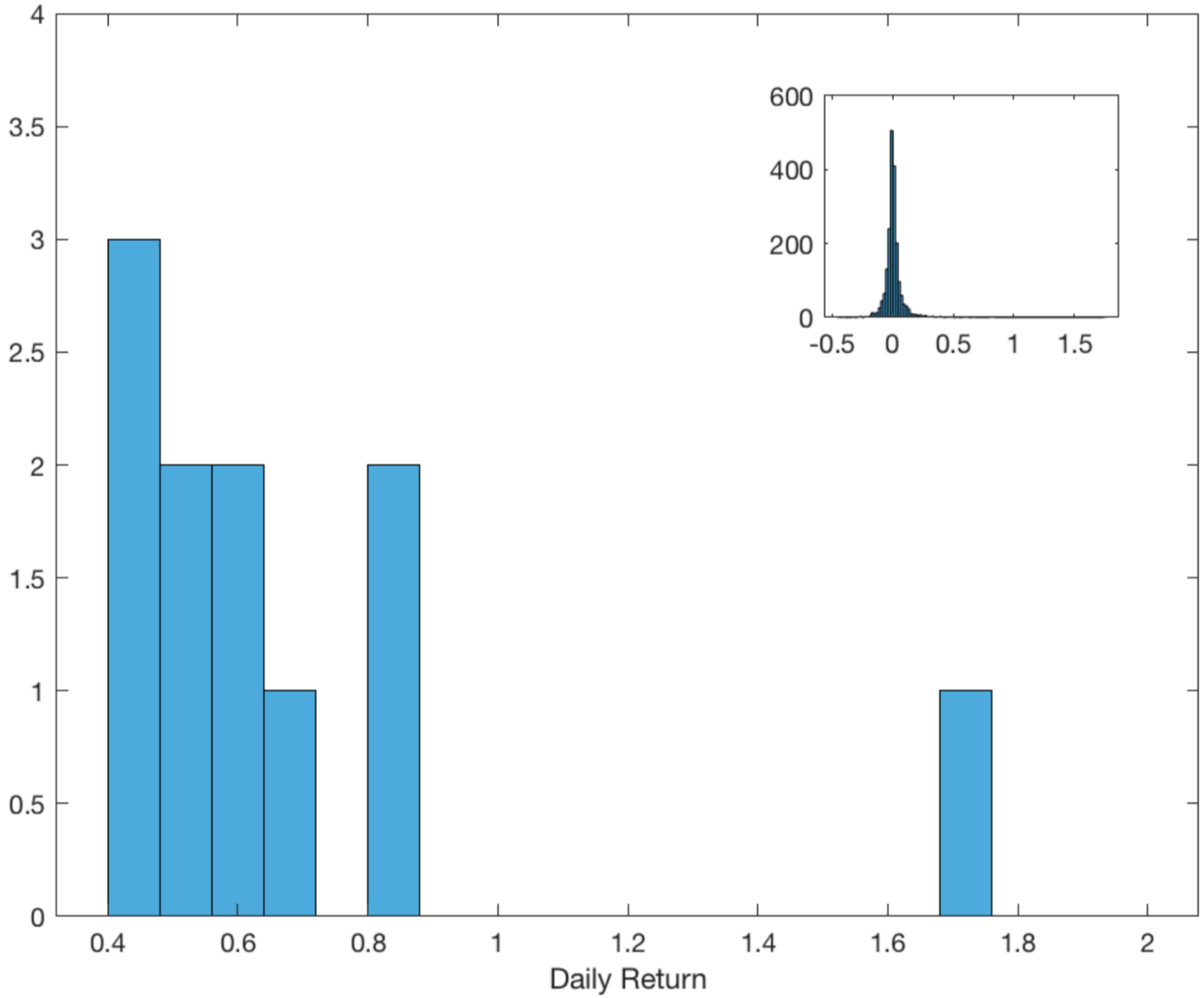
Daily Median Returns (in %)

- Median return on Bitcoin: 0.183 < 0.254
  - Namely, well below its mean
- Median return on Ether: −0.092 << 0.584
  - On most days, you lost money on Ether
- Median return on Ripple: −0.278 << 0.514
  - On most days you really lost money on Ripple
- This implies that cryptocurrency returns are positively skewed

Return Distribution for Ripple



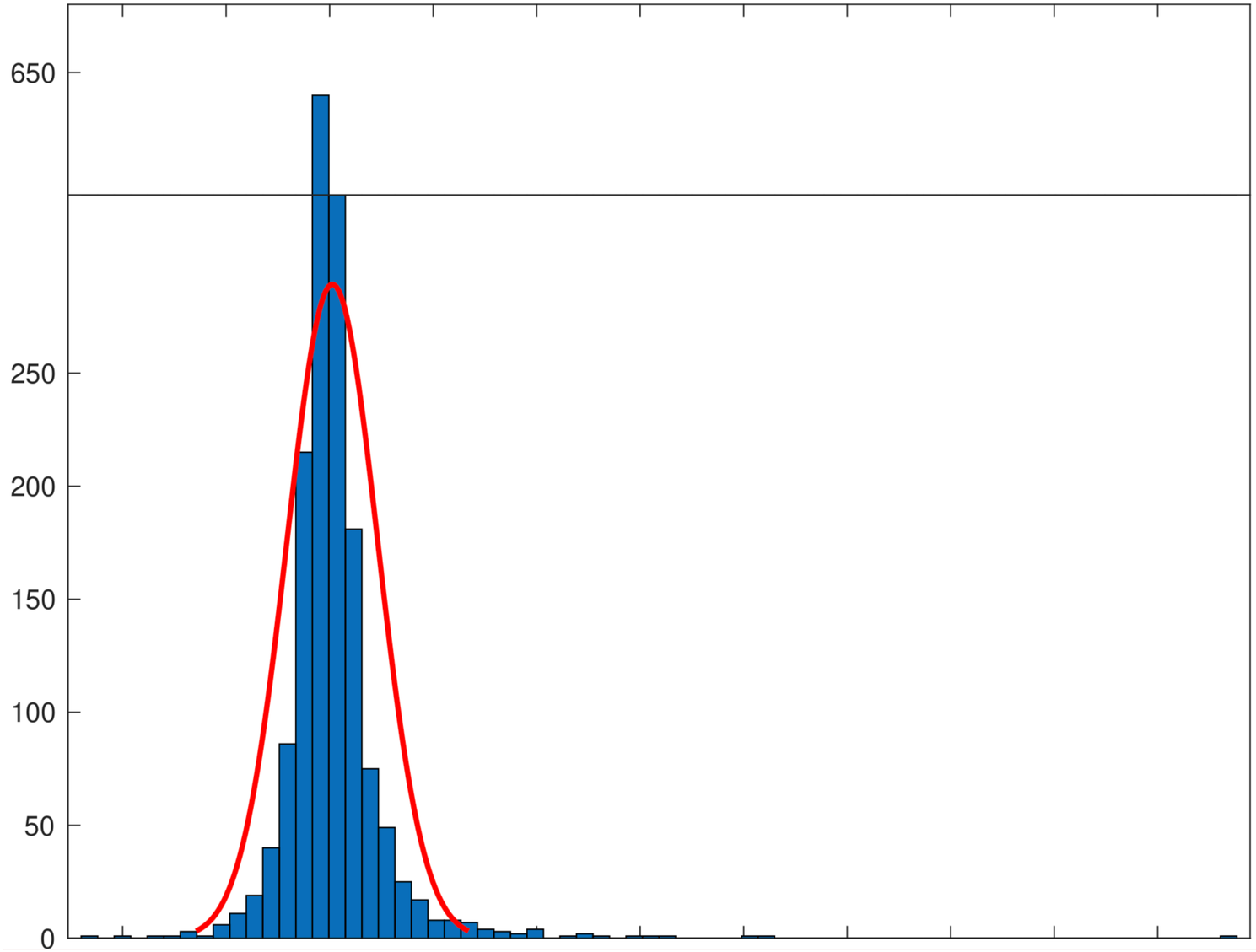
Return Distribution for Ripple (cont.)



Volatility

- If a return is normally distributed, volatility measures risk
- For example: returns on Ripple have a standard deviation of 8.78% per day, and a mean of 0.52% per day
- If Ripple returns were normally distributed, 95% of returns would fall between 2 standard deviations above and below the mean
  - Namely, 18% and -17%
  - That's a huge amount of daily volatility
- However, the normal distribution does not describe Ripple very well

Return Distribution for Ripple



- Most returns are more concentrated than our volatility discussion suggests
- However, there are outliers
- A normal distribution would imply a return of > 160% as statistically impossible
- But that did happen

Return Distribution for Ripple

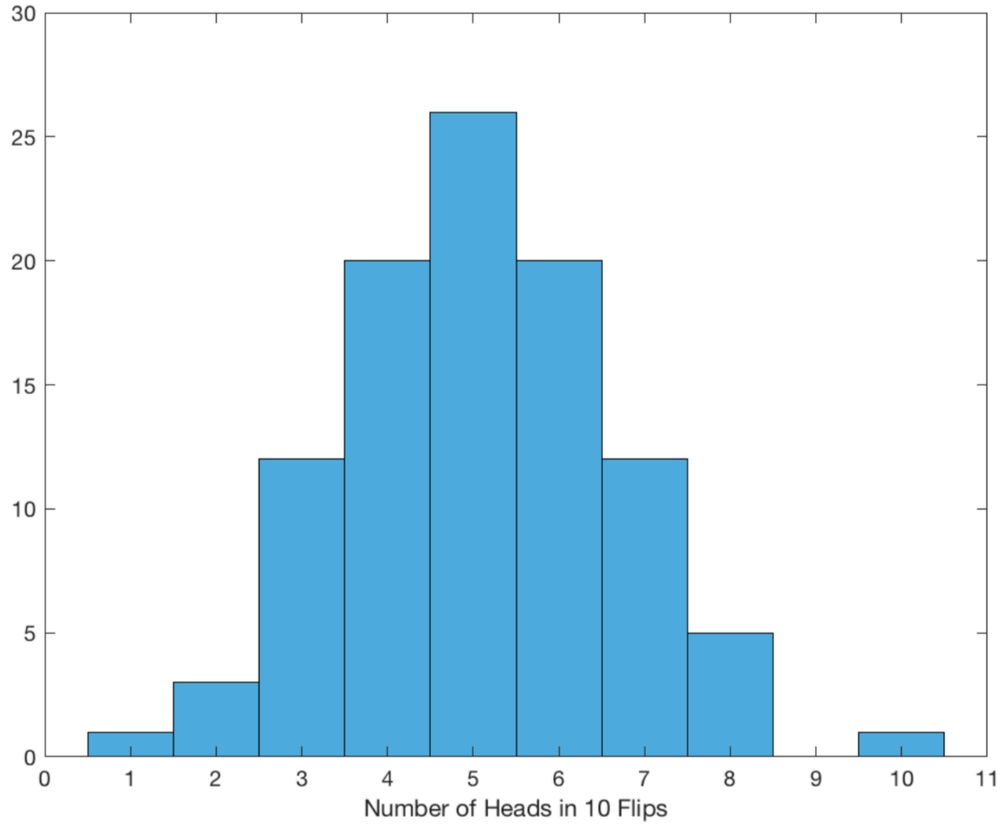
- Most returns are more concentrated than our volatility discussion suggests
- However, there are positive outliers
  - A normal distribution would imply a return of > 160% as statistically impossible
  - But that did happen

Caveats

- This discussion does not assume transaction costs, which can be substantial
- Example: a $10 purchase of bitcoin on Coinbase yields only $8.50 worth of the coin
- Survivor bias

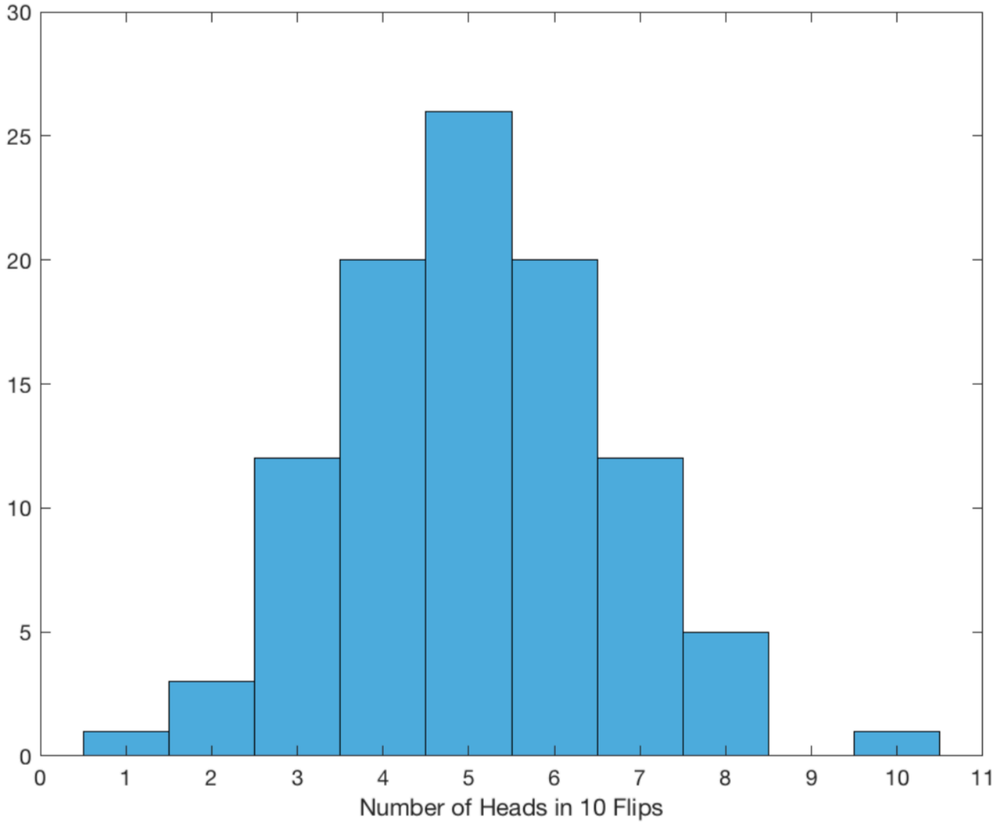
Survivor Bias

- I flipped 100 coins ten times
- Here is a histogram describing the number of heads:



Survivor Bias

- Now suppose I look only at the number of heads for the top 3
- These are 8, 8, and 10
- Should I conclude that flipping a coin almost always yields heads?
- Of course not!
  - It is an artifact - I decided to pick the top 3
- The focus on three cryptocurrencies has the same concern



Summary and Conclusions

- Prices of cryptocurrency appear to have stabilized
- Active addresses have grown, and prices seem to rise with them
- The top three cryptocurrencies have positive mean returns, but Ripple and Ether have negative medians
  - Most days you would lose money
  - But, there are positive outliers
- Returns subject to survivor bias

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Review of Portfolio Theory

Jessica Wachter, Professor of Financial Management, Professor of Finance

Introduction

- Portfolio theory developed by Markowitz (1952)
- This is still benchmark portfolio theory
- It does require an approximation — that returns are normally distributed
- However, the most important insight from this theory, that there are gains from diversification, transcends the assumption of normally distributed returns
- I will then review the Capital Asset Pricing Model of Sharpe (1962)

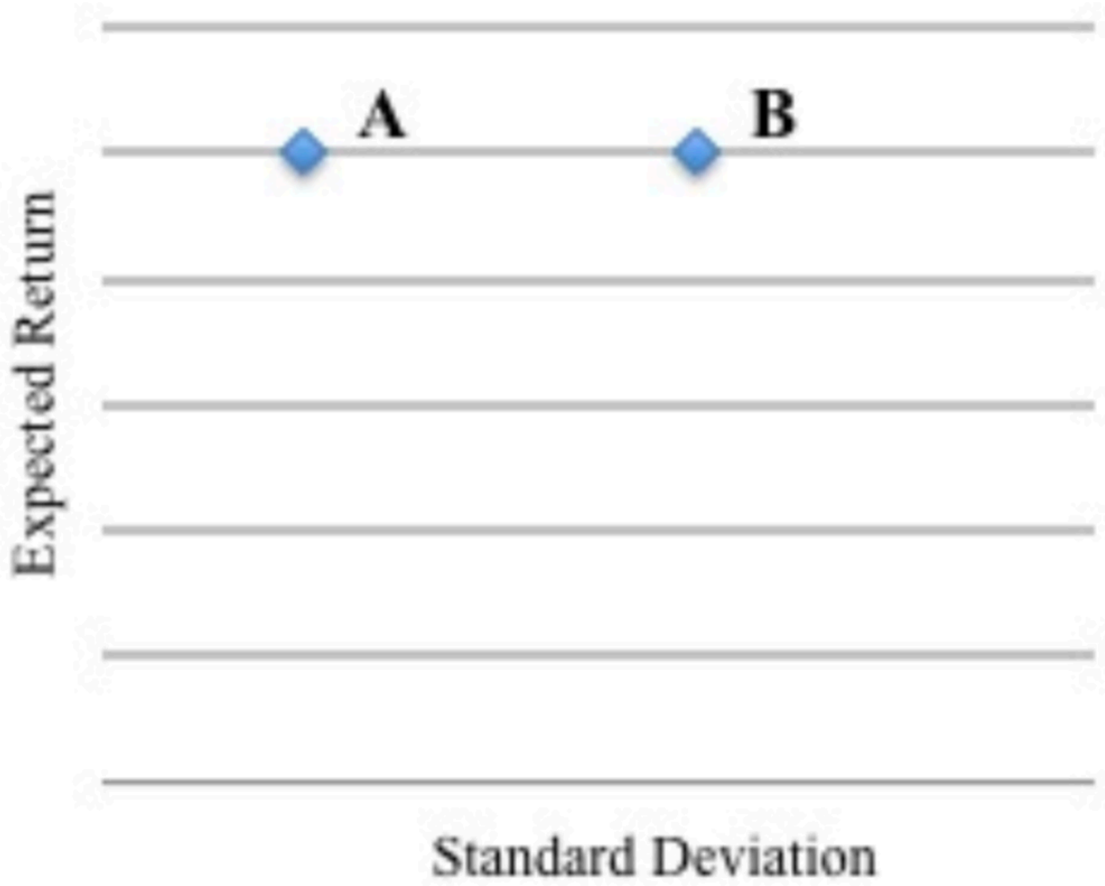
Assumptions of Portfolio Theory

- Investors prefer more to less
- Investors are risk averse
- Returns are normally distributed

Mean-Standard Deviation Diagram

- Between points *A* and *B*, which is preferred?

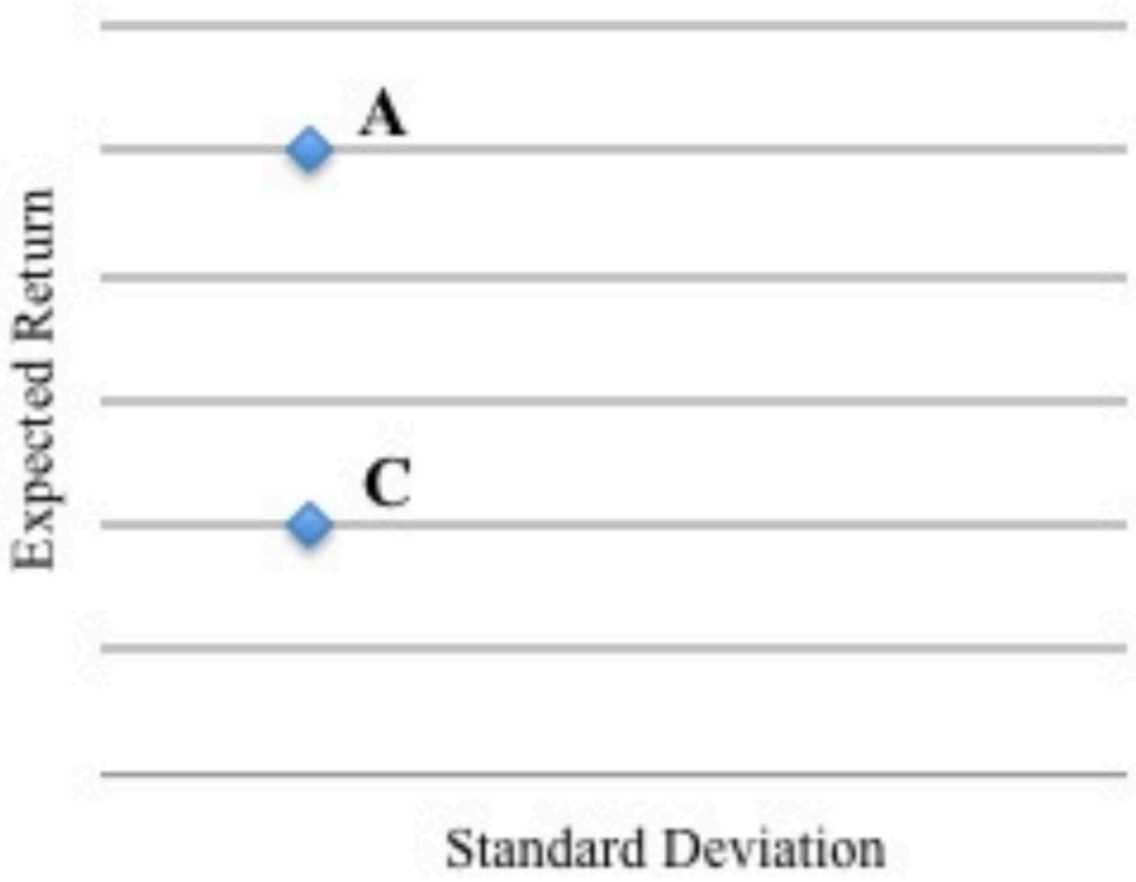
- *A* and *B* have the same mean
- *A* has a lower standard deviation than *B*
- *A* dominates *B*



Mean-Standard Deviation Diagram

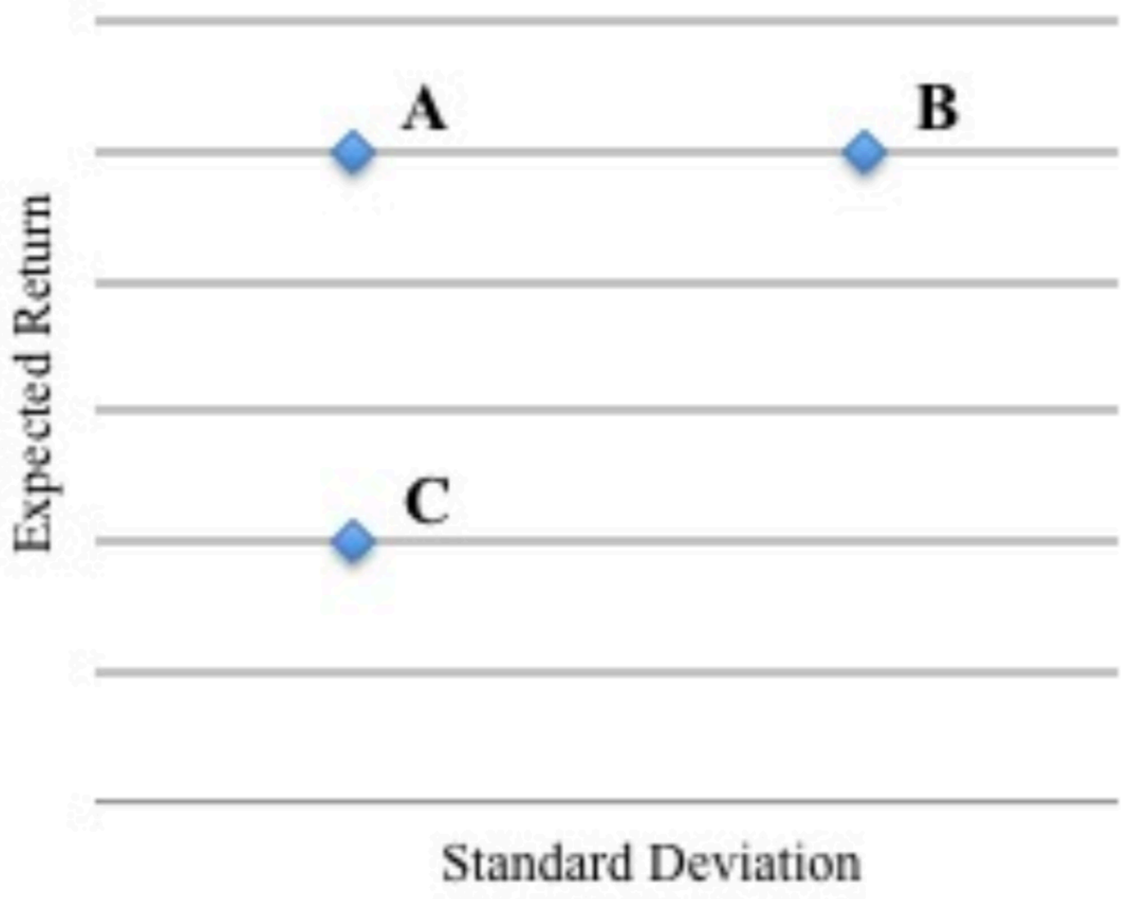
- Between points *A* and *C*, which is preferred?

- *A* and *C* have equal standard deviations
- *A* has a higher mean
- *A* dominates *C*



Mean-Standard Deviation Diagram

- What about *B* and *C*?
- *Neither dominates the other*



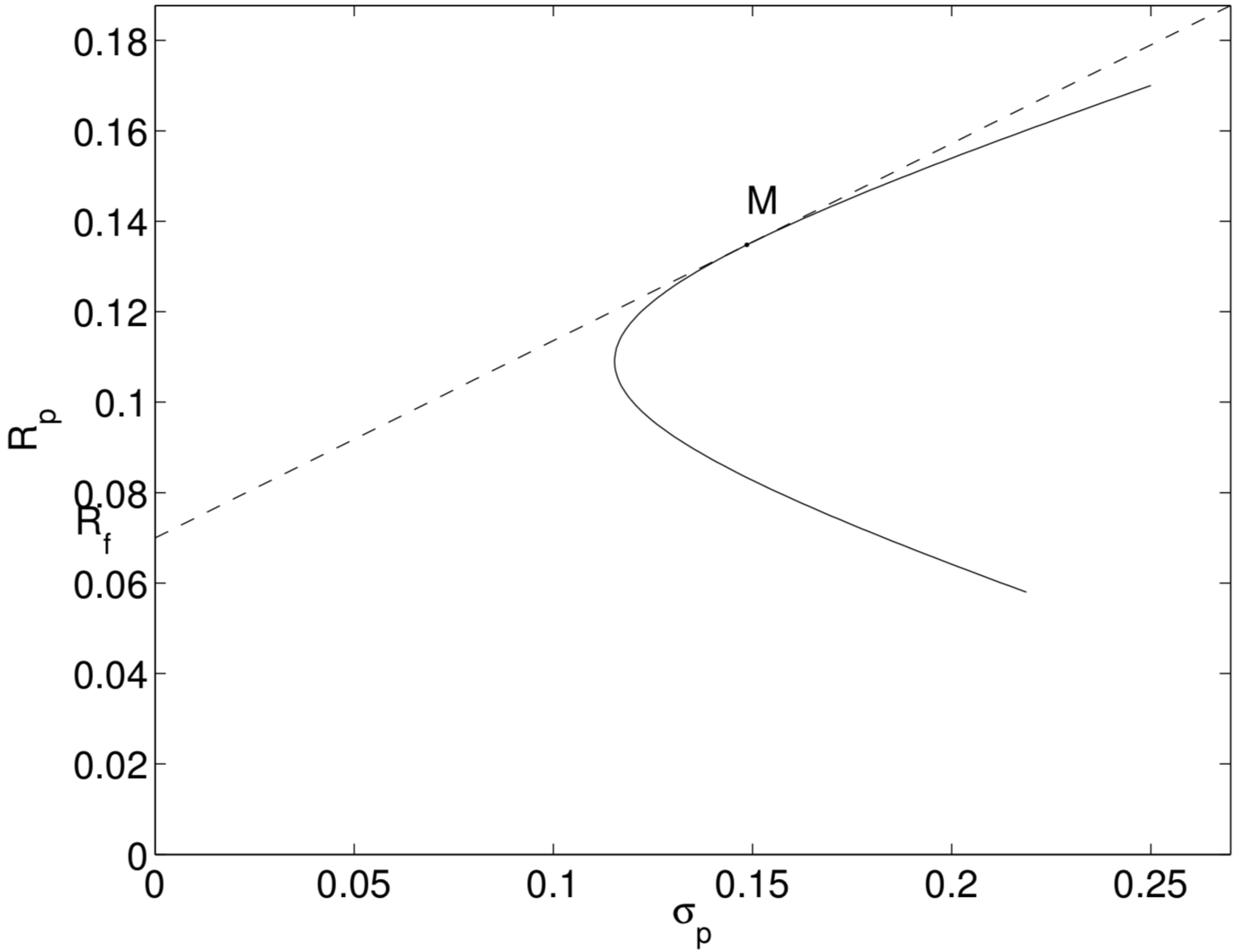
Mean-Standard Deviation Diagram

- Markowitz showed that the set of all risky assets lie inside of a sideways “U”
- This sideways “U” is called the risky asset frontier
- By combining risky assets cleverly, you can get to the top part of the frontier (called the efficient frontier)

The tangency portfolio

- Now introduce a riskless asset (like a Treasury bill)
- The tangency line from the riskless asset to the frontier tells you the best possible risky asset portfolio

The Tangency Portfolio



The Tangency Portfolio

- The tangency portfolio has the highest slope possible
- Any portfolio with a lower slope will be sub-optimal and inefficient
- Any portfolios with higher slope cannot be attainable
- This slope: $(E[R] - RFR)/\sigma$ is called the Sharpe ratio
- The line from the risk-free rate to the tangency portfolio is called the *capital allocation line*

The Mutual Fund Theorem

- The portfolio allocation problem can be divided into two steps
  1. Determine the tangency portfolio ⇒ this is the optimal combination of the risky assets, or the Mutual Fund.
  2. Determine where you want to be on the capital allocation line

Consequences of the Mutual Fund Theorem

- Bill Sharpe realized an amazing consequence of the Mutual Fund Theorem
- If everyone holds the same portfolio, then the market portfolio (which is the weighted average of everyone's portfolio) is the best possible portfolio
- Namely, the market portfolio is efficient

Consequences of the Mutual Fund Theorem

- Due to Sharpe (1964)
- Called the Capital Asset Pricing Model (CAPM)
- The market portfolio – the portfolio that holds assets according to their market weights – is efficient
- The market portfolio has the highest Sharpe ratio possible
- Expected returns on assets are determined by their βs with respect to the market portfolio:

$$E[R_i] = RFR + \beta(E[R_M] - RFR)$$

where

$$\beta = Cov(R_i, R_M)/Var(R_M)$$

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Asset Allocation with Cryptocurrency

Jessica Wachter, Professor of Financial Management, Professor of Finance

Introduction

- The theoretical view is simple
  - Because cryptocurrency has no intrinsic value and pays no dividends, it should not be part of the optimal portfolio
- Here I develop the empirical view

Introduction

- Previously: Cryptocurrency has high average returns
- The standard deviation (risk) is also very high
- Returns are positively skewed
- Betas with the S&P 500 are less than one

Sharpe Ratio

- The Sharpe ratio is one way to adjust for the risk of an asset
- It is named for Bill Sharpe, the Nobel Prize winning economist and investor of the CAPM
- The Sharpe ratio is the slope of the capital allocation line

$$Sharpe\ ratio = \frac{Expected\ return - Riskfree\ rate}{Standard\ deviation\ of\ return}$$

- It tells you the extra return you receive per unit of standard deviation.

Sharpe Ratio

- Let's use the statistics I showed you last time to compute the Sharpe ratio on the three major cryptocurrencies
- Because these are daily returns, and the interest rate is so low, we will use a risk-free rate of zero
- Thus we compute:

$$Sharpe\ ratio = \frac{Expected\ return}{Standard\ deviation\ of\ return}$$

Sharpe Ratio (cont.)

- Some caveats:
  - Recall: the return tells you your percent gain on a strategy that exchanges dollars for cryptocurrency, and then converts the cryptocurrency back to dollars
  - It assumes no trading costs
  - It uses average returns - the Sharpe ratio on a portfolio could be high, even if you lose money on most days
  - Recall survivor bias

Sharpe Ratio (cont.)

- Bitcoin
  - Average daily return = 0.253%, Standard deviation = 4.37% ⇒
  - Daily Sharpe ratio on Bitcoin = 0.253/4.37 = 0.058
- Ether
  - Average daily return = 0.579%, Standard deviation = 7.22% ⇒
  - Sharpe ratio on Ether = 0.579/7.22 = 0.080
- Ripple
  - Average daily return = 0.520%, Standard deviation = 8.78% ⇒
  - Sharpe ratio on Ripple = 0.520/8.78 = 0.059

- As a comparison, Sharpe ratio on the S&P 500 = 0.056

Sharpe Ratio - Conclusion

- The conclusion based on the Sharpe ratio comparison:
  - The Sharpe ratios for Bitcoin and Ripple are about the same as on the S&P 500
  - Ether is higher, but not overwhelmingly so
  - Due to issues of survivor bias and trading costs, this would most likely argue against investing in cryptocurrency as an asset class

Another Measure: Alpha

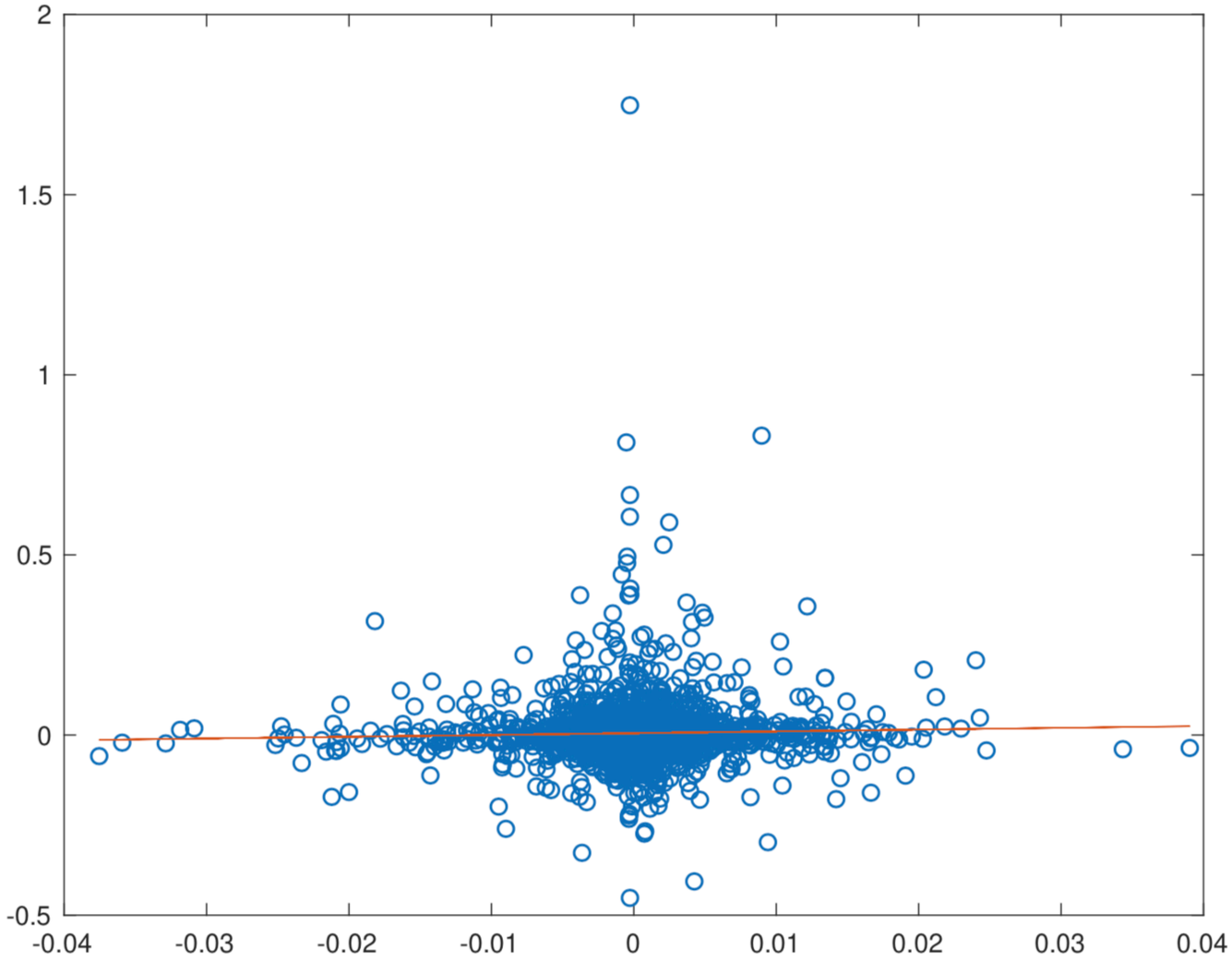
- What is the alpha on an asset?
- Alpha measures *abnormal return*
- According to the Capital Asset Pricing Model (CAPM) – the most popular theory in financial markets – for any asset with return *R*:

$$E[R] = RFR + \beta(E[R_M] - RFR)$$

for *RFR* = the risk-free rate (Tbill return)

- R_M is the return on the aggregate stock market (the S&P 500 comes close)
- $\beta = Cov(R_i, R_M)/Var(R_M)$ This measures how much an asset moves when the market moves

Security Characteristic Line - Ripple



Alpha (cont.)

- What is the alpha (α) on a security return?
- It is the part of the return that the CAPM does not explain:

$$\alpha = E[R] - (RFR + \beta(E[R_M] - RFR))$$

$$\text{normal return}$$

- According to the CAPM, α should be zero
- We might *measure* a positive α, but this — according to the CAPM — should be simply statistical noise (or survivor bias)

Daily Alphas on Cryptocurrency

- Bitcoin: 0.24%
- Ether: 0.57%
- Ripple: 0.50%

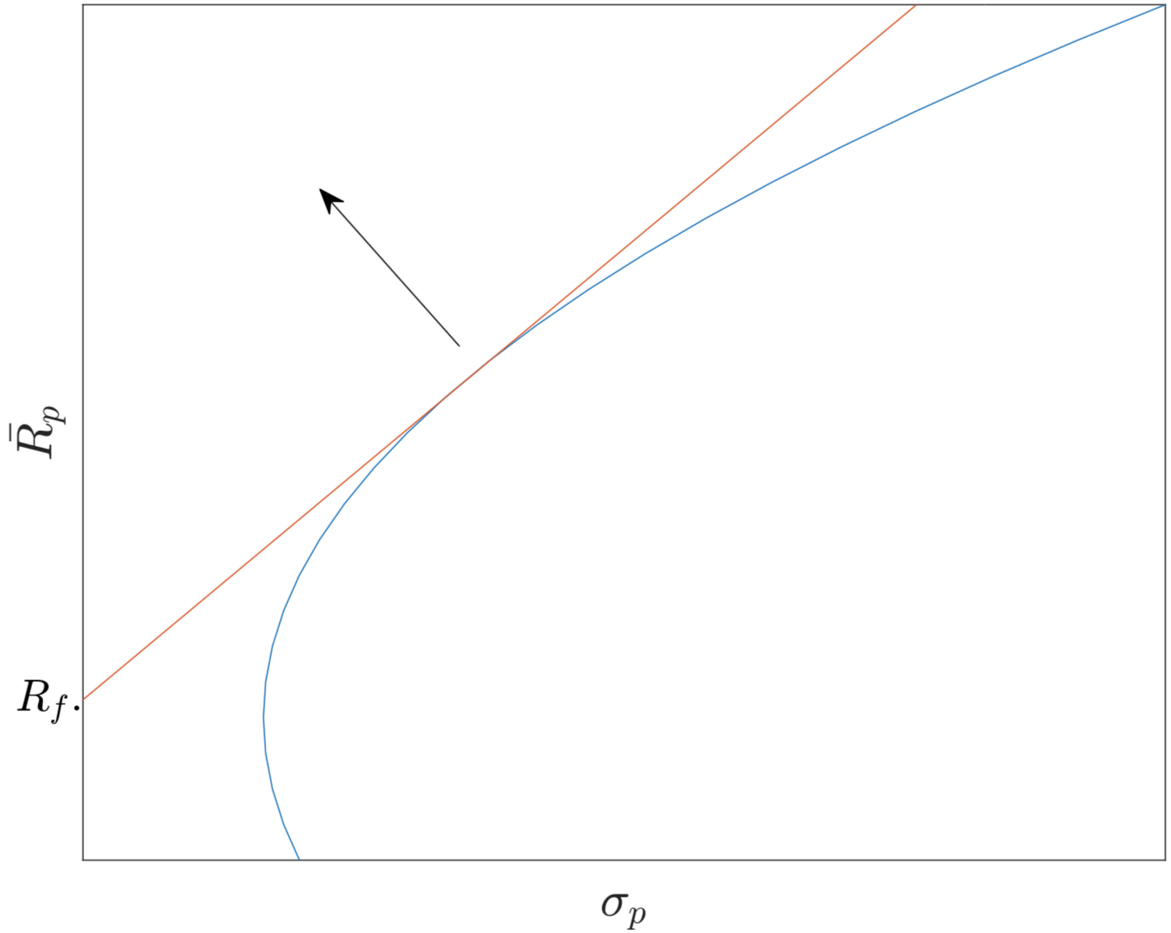
Which Measure: α or Sharpe Ratio?

- It makes a difference!
- Crypto looks better in terms of α
- I would argue: α
- Why?

Recall Portfolio Theory (last module)

- Investors should seek out the highest Sharpe ratio *portfolio*
- The Sharpe ratio is an intuitive measure of risk and return on an asset
- But it is not the most useful measure, because it does not take into account *covariance*
- Crypto has a low covariance with the market
- This makes its returns more impressive

The Investment Opportunity Set With a Positive α Investment



- Note: a positive α *investment* shifts the opportunity set outward, creating a higher Sharpe ratio on the *portfolio*

Caveats

- Note: it is not the purpose of this lecture to advocate for investing in cryptocurrency
- These are just principles of how to think about the problem
- Survivor bias, transaction costs, and mismeasurement due to the short sample all might argue against investing

The Importance of Covariance

- The return on the top three cryptocurrencies has been high
- This may in part reflect a resolution of the risk of these currencies, and so might be unlikely to be repeated
- It’s hard to measure expected returns in a small sample
- However, the covariance with the market and the associated beta is less likely to be mismeasured
- The beta on cryptocurrencies is about 0.5
- This beta is important: if it is low, then cryptocurrency has value as a hedge
- How to think about this beta?

A Simple Model of the Price of Bitcoin

- Another benchmark theory: the Gordon Growth Model
- If an asset pays dividends that grow every year at a rate *g*, and the expected return on the asset is *r*, then

$$P = \frac{D}{r - g}$$

where *D* is next year's dividends

- Strictly speaking, according to this formula, crypto's price should be exactly zero all the time, because it pays no dividends (recall the first module)
- This is the theoretical view

A Simple Model of the Price of Bitcoin

- However, if Bitcoin should be useful someday as medium of exchange, then the “dividend” reflects the convenience of exchange
- For example, many people have bank accounts, even though the rate paid by bank accounts is often below the Treasury Bill rate, which is in turn below the rate on AAA Corporate Bonds

Pricing and Covariance

- What does the pricing formula tell us about the covariance?
- The greater the economic activity, the greater the demand for currency
- Also, both cryptocurrency and the aggregate market depend positively on technological innovation
- Both of these would argue for positive covariance and high betas – the better the economy does, the more demand there is likely to be for cryptocurrency, the more likely crypto will be used as a medium of exchange, the greater the price

Pricing and Covariance (cont.)

- However, when is it likely that cryptocurrency will become a medium of exchange?
- Related: when might cryptocurrency be appealing as a store of value?
- During very bad economic times
- This will push the covariance and the beta lower
- It is likely that the beta of ≈ 0.5 reflects these two forces
- Crypto possibly has a role in a portfolio as a hedging security

Conclusions

- Cryptocurrency returns imply Sharpe ratios close to those of the market
- They have positive αs (abnormal returns) $\Rightarrow$ suggests they are a good investment
- But this does not take into account survivor bias and transaction costs
- Traditional theory says: do not hold cryptocurrency
- But traditional theory says: do not hold money of any kind
- Crypto's role as a hedge against bad economic times makes it intriguing as an investment
- Needed: a quantitative theory of cryptocurrency to take this into account

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