QUANTUM SUPREMACY : in FINANCIAL MARKETS (FOREX)*

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The paper presents how to achieve market dominance, implementing the oldest plain vanilla price arbitrage strategy, using the newest quantum entanglement phenomena.

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* Applicable also to any financial market

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I. INTRODUCTION.

“It from bit” symbolizes the idea that every item of the physical world has at bottom—a very deep bottom, in most instances — an immaterial source and explanation; that which we call reality arises in the last analysis from the posing of yes-or-no questions and the registering of equipment-evoked responses; in short, that all things physical are information-theoretic in origin and that this is a participatory universe.”
– John A. Wheeler, [3]

Thirty years later from this statement it’s time to update it and propose that “It from qubit” could be the last truth.

This paper will present a novel approach to the use of quantum techniques that we nickname quantum supremacy applied to the financial markets and particularly to the FOREX market.

We’ll demonstrate that having two entangled devices, more on the definition of entanglement in Section 3 of the paper, it’s possible to achieve a full dominance in the FOREX using a very simple plain vanilla strategy, price arbitrage between two far away markets.

II. DYNAMICS OF FOREX (FX) MARKET

Each day, billions of monetary units are exchanged on the foreign exchange currency market. FX trading is used to determine currency exchange rates across the world. While people have been trading currencies for thousands of years, modern technology has changed the way that many banks and individual investors do business.

One of the key technologies in the evolution of the markets has been high frequency trading (HFT) and its impact in the FX trading has been extraordinary.

A. High Frequency Trading (HFT)

According to the dictionary of financial terms of NASDAQ [4]
High Frequency Trading (HFT)

Refers to computerized trading using proprietary algorithms. There are two types high frequency trading.

Execution trading is when an order (often a large order) is executed via a computerized algorithm. The program is designed to get the best possible price. It may split the order into smaller pieces and execute at different times.

The second type of high frequency trading is not executing a set order but looking for small trading opportunities in the market.

It is estimated that 50 percent of stock trading volume in the U.S. is currently being driven by computer-backed high frequency trading. Also known as algo or algorithmic trading.

B. Direct Market Access (DMA)

Access to the markets was historically being mediated by banks or direct brokers at the markets. From the last decennials of the past century this interrelation has given pass to the direct access to the markets named DMA (Direct Market Access).

According to David Polen [5] :
There are two distinct market segments that use DMA - the human trader and the blackbox. I like to call this "Human DMA" and "Highfrequency Trading (HFT) DMA".

With Human DMA, the extreme is a buy-side that has traders manually executing trades and looking at market data over the Internet-

With HFT DMA, the extreme is a blackbox co-located at the exchange. One market segment is sub-millisecond and the other is more than tens of milliseconds - sometimes hundreds of milliseconds.

C. Strategies

About the strategies used by the black-boxes, in 2014 the Security and Exchange Commission (SEC) appears to emphatically say that two strategies, order anticipation and momentum ignition, are manipulative and illegal. The SEC writes [6]:

"Directional strategies generally involve establishing a long or short position in anticipation of a price move up or down. The Concept Release requested comment on two types of directional strategies – order anticipation and momentum ignition – that 'may pose particular problems for long-term investors' and 'may present serious problems in today's market structure.'

An order anticipation strategy seeks to ascertain the existence of large buyers or sellers in the marketplace and then trade ahead of those buyers or sellers in anticipation that their large orders will move market prices (up for large buyers and down for large sellers).

A momentum ignition strategy involves initiating a series of orders and trades in an attempt to ignite a rapid price move up or down.

As noted in the Concept Release[7], any market participant that manipulates the market has engaged in conduct that already is illegal. The Concept Release focused on the issue of whether additional regulatory tools were needed to address illegal practices, as well as any other practices associated with momentum ignition strategies."

1. Latency-Arbitrage

Going down to the technicalities, Latency Arbitrage is an important concept when discussing High Frequency Trading, and refers to the fact that different people and firms receive market data at different times.

These time differences, known as latencies, may be as small as a billionth of second (a nanosecond), but in the world of high speed trading, such differences can be crucial. So crucial, in fact, that trading firms pay lots of money to be located closer to exchanges' servers– each foot closer saves one nanosecond.

Latency arbitrage occurs when high frequency trading algorithms make trades a split second before a competing trader, and then resell the stock seconds later for a small profit.

2. Regulation (USA)

The previous Congress dealt with potential regulation of HFT (US Congress HFT Overview of Recent Developments 2016)[8]. We very briefly refer here to the Testimony on Regulatory Reforms to Improve Equity Market Structure by Stephen Luparello, director, Division of Trading and Markets, U.S. Securities and Exchange Commission, Before the Senate Committee on Banking, Housing and Urban Affairs Subcommittee on Securities, Insurance and Investment. This declaration was made March 3, 2016.

Luparello said SEC staff was developing a recommendation for the SEC to consider addressing the use of aggressive, destabilizing trading strategies that could exacerbate price volatility.

Until today regulation is still a working process.

D. Summary

It can be extremely challenging to earn a profit when trading currency. In many cases, investors can lose significant sums of money. Exchange rates can be impacted by a variety of factors. This can include economic conditions, politics, weather, shipping conditions, piracy, technology advances and more.

Many HFT programs are installed in specialized data centres located near an exchange (Co-location). Since the speed of execution is limited by the speed of light, many programmers and investors try to minimize the amount of time it takes for an order to be executed. This is possible by minimizing the amount of time it takes data to travel between the operator premises and an exchange.

Most HFT programs are designed to profit from very small price differences in a currency. In many cases, a program will make a profit of only a few cents per trade. However, millions of these types of trades every day can yield a significant profit.

Our approach in this paper we'll be to use the oldest strategy, price arbitrage between two locations, profiting the quantum supremacy. (The spooky action at a distance; in Einstein words).

III. QUANTUM INFORMATION AND QUANTUM COMPUTATION

A. Introduction (Ref:[1])

a. Quantum computing fundamentals. All computing systems rely on a fundamental ability to store and manipulate information. Current computers manipulate individual **bits**, which store information as binary 0 and 1 states. Quantum computers leverage quantum mechanical phenomena to manipulate information. To do this, they rely on quantum bits, or **qubits**.

b. Quantum Properties. Three quantum mechanical properties — superposition, entanglement, and interference — are used in quantum computing to manipulate the state of a qubit.

1. Superposition
   Superposition refers to a combination of states we would ordinarily describe independently. To make a classical analogy, if you play two musical notes at once, what you will hear is a superposition of the two notes.
2. Entanglement
   Entanglement is a famously counter-intuitive quantum phenomenon describing behavior we never see in the classical world. Entangled particles behave together as a system in ways that cannot be explained using classical logic.
3. Interference
   Finally, quantum states can undergo interference due to a phenomenon known as phase. Quantum interference can be understood similarly to wave interference; when two waves are in phase, their amplitudes add, and when they are out of phase, their amplitudes cancel.

B. Quantum State – Vector representation (Ref:[2])

What then is a qubit?
Just as a classical bit has a state – either 0 or 1 – a qubit also has a state. Two possible states for a qubit are the states $|0\rangle$ and $\langle 1|$, which as you might guess correspond to the states 0 and 1 for a classical bit.

Notation like $|\_\rangle$ and $\langle\_|$ is called the Dirac notation, and we'll be seeing it often, as it's the standard notation for states in quantum mechanics. The difference between bits and qubits is that a qubit can be in a state other than $|0\rangle$ or $\langle 1|$. It is also possible to form linear combinations of states, often called superpositions:

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle \tag{1}$$

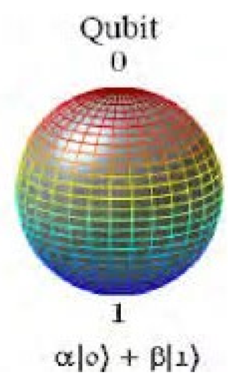

FIG. 1. Qubit Bloch Sphere representation

The numbers α and β are complex numbers, although for many purposes not much is lost by thinking of them as real numbers. Put another way, the state of a qubit is a vector in a two-dimensional complex vector space. The special states $|0\rangle$ and $\langle 1|$ are known as computational basis states and form an orthonormal basis for this vector space.

We can examine a bit to determine whether it is in the state 0 or 1. For example, computers do this all the time when they retrieve the contents of their memory. Rather remarkably, we cannot examine a qubit to determine its quantum state, that is, the values of α and β. Instead, quantum mechanics tells us that we can only acquire much more restricted information about the quantum state. When we measure a qubit we get either the result 0, with probability $|\alpha|^2$, or the result 1, with probability $|\beta|^2$.Naturally, $|\alpha|^2 + |\beta|^2 = 1$, since the probabilities must sum to one. Geometrically, we can interpret this as the condition that the qubit's state be normalized to length 1. Thus, in general a qubit's state is a unit vector in a two-dimensional complex vector space.

C. Measurements (Ref:[2])

Suppose we have two qubits. If these were two classical bits, then there would be four possible states, 00, 01, 10, and 11. Correspondingly, a two qubit system has four computational basis states denoted $|00\rangle$, $|01\rangle$, $|10\rangle$, $|11\rangle$.

A pair of qubits can also exist in superpositions of these four states, so the quantum state of two qubits involves associating a complex coefficient − sometimes called an amplitude − with each computational basis state, such that the state vector describing the two qubits is

$$|\psi\rangle = \alpha_{00}|00\rangle + \alpha_{01}|01\rangle + \alpha_{10}|10\rangle + \alpha_{11}|11\rangle \quad (2)$$

Similar to the case for a single qubit, the measurement result x (= 00, 01, 10 or 11) occurs with probability $|\alpha_x|^2$, with the state of the qubits after the measurement being $|x\rangle$. The condition that probabilities sum to one is therefore expressed by the normalization condition that $\sum_{x\in\{0,1\}^2} |\alpha_x|^2 = 1$,where the notation $x \in \{0, 1\}^2$ means 'the set of strings of length two with each letter being either zero or one'. For a two-qubit system, we could measure just a subset of the qubits, say the first qubit, and you can probably guess how this works: measuring the first qubit alone gives 0 with probability $|\alpha_{00}|^2 + |\alpha_{01}|^2$, leaving the post-measurement state

$$|\psi\rangle = \frac{\alpha_{00}|00\rangle + \alpha_{01}|01\rangle}{\sqrt{|\alpha_{00}|^2 + |\alpha_{01}|^2}} \quad (3)$$

Note how the post-measurement state is re-normalized by the factor $\sqrt{|\alpha_{00}|^2 + |\alpha_{01}|^2}$ so that it still satisfies the normalization condition, just as we expect for a legitimate quantum state.

D. Entanglement (Ref:[2])

An important two qubit state is the Bell state or EPR pair, β_{00}, that we'll make use in our methodology section.

$$\beta_{00} = \frac{|00\rangle + |11\rangle}{\sqrt{2}} \quad (4)$$

This innocuous-looking state is responsible for many surprises in quantum computation and quantum information. The Bell state has the property that upon measuring the first qubit, one obtains two possible results: 0 with probability 1/2, leaving the post-measurement state $|\phi\rangle = |00\rangle$, and 1 with probability 1/2, leaving $|\acute{\phi}\rangle = |11\rangle$.

As a result, a measurement of the second qubit always gives the same result as the measurement of the first qubit. That is, the measurement outcomes are correlated.

These correlations have been the subject of intense interest ever since a famous paper by Einstein, Podolsky and Rosen, in which they first pointed out the strange properties of states like the Bell state. EPR's insights were taken up and greatly improved by John Bell, who proved an amazing result: the measurement correlations in the Bell state are stronger than could ever exist between classical systems. These results were the first intimation that quantum mechanics allows information processing beyond what is possible in the classical world.

This "amazing" correlation will be at the base of our Quantum Supremacy over the FOREX market.

IV. METHODOLOGY

A. Set-up

Market strategy will be made in the FOREX market over London and New York markets based on the pair EUR/USD. Let's name the price of this pair **P**.

For the implementation of our strategy we'll use the Alice and Bob characters invented by Ron Rivest, Adi Shamir, and Leonard Adleman in their 1978 paper "A method for obtaining digital signatures and public-key cryptosystems. In our scenario we suppose that A and B (also known as Alice and Bob) are two market machines located (collocated) in London (Alice) and New York (Bob).

Initially, at the start of the market session, both machines shared several entangled pair of qubits (2N). Let's name for the first interchange the qubits **Aq1**, **Aq2** for Alice and **Bq1**, **Bq2** for Bob.

Aq1,**Bq1** are a pair of Bell's qubits β_{00} and the same for the other pair **Aq2**, **Bq2**.

Let's establish a reference via the GPS clock shared by both parties, using 20 Hz cycle, so each 50 milliseconds, and name this time reference T_0.

B. Price Communication

At this time A and B sends the current price **P** of its market to the other. Taking in account the 7,000 Kilometres distance the time taken to the signal to arrive to the other end is approx. (fibre-optics or radio transmission could made differences in the final time), 43 milliseconds. Let's name these prices Pl_0 (London Price) and Pn_0 (New York price) at T_0.

The potential outcomes that A and B will have regarding the prices at T_0 are:

1. $Pl_0 = Pn_0$ State ϕ_0 (London equal price than New York)
2. $Pl_0 > Pn_0$ State χ_0 (London greater price than New York)
3. $Pl_0 < Pn_0$ State ψ_0 (London lesser price than New York)

An arbitrage strategy could be established in the states χ and ψ but not in ϕ.

We'll introduce a 5 milliseconds guard time to cover potential delays of the signal due to any circumstances.

C. Price Reception and Comparison with current prices

At T_0+48 msec. that we'll consider as T_1, A and B had new prices of **P** at their respective markets. Let's name these new prices Pl_1 (London) and Pn_1(New York).

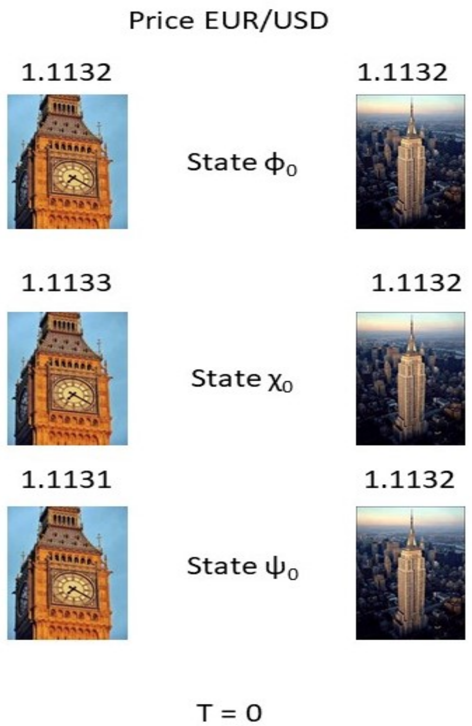

FIG. 2. Initial Price States

It's obvious that if the price in London is greater than in NY (state χ_0) a very simple strategy consists to buy the pair in NY and to sell it in London that will carry on a profit in the transaction. The same occurs if London is lesser than in NY (state ψ_0). In his case the strategy consists to sell the pair in NY and to buy it in London and the strategy will carry also on a profit.

To be successful in this strategy we need:

1. The prices when both parties received the information regarding the other partner side have not changed to the opposite condition. So for example, at time T_1, $Pl_1 > Pn_1$

2. Both parties can communicate the other side the condition 1 satisfied in its leg of the market.

The second condition allows that both parties go forward in the buy/sell process doing the transactions concurrently.

Logically a further "classical" communication regarding condition 2 will introduce a new delay of 43 milliseconds allowing the markets to change its positions during the delay and removing any potential benefit.

At this point we'll introduce the Quantum Supremacy mechanism based on the qubits shared previously between A and B.

D. Quantum Processes

At the moment T_1 we'll have, related to the potential movements of the market, the next conditions:

Alice side:

If State χ_0

1. Condition **GO**: $Pl_1 \geq Pl_0$. The market is in the same or more favourable conditions that in T_0

2. Condition **NO-GO**: $Pl_1 < Pl_0$. The market is in less favourable conditions that in T_0

If State ψ_0

1. Condition **GO**: $Pl_1 \leq Pl_0$. The market is in the same or more favourable conditions that in T_0

2. Condition **NO-GO**: $Pl_1 > Pl_0$. The market is in less favourable conditions that in T_0

FIG. 3. Alice at T_1

Bob side:

If State χ_0

1. Condition **GO**: $Pn_1 \leq Pn_0$. The market is in the same or more favourable conditions that in T_0

2. Condition **NO-GO**: $Pn_1 > Pn_0$. The market is in less favourable conditions that in T_0

If State ψ_0

1. Condition **GO**: $Pn_1 \geq Pn_0$. The market is in the same or more favourable conditions that in T_0

2. Condition **NO-GO**: $Pn_1 < Pn_0$. The market is in less favourable conditions that in T_0

FIG. 4. Bob at T_1

The manipulations of the qubits that Alice and Bob will make with their qubits depending of the previous conditions are:

Alice makes a measure in Aq_1 that is:

1. State ϕ_0 – Do nothing

2. States χ_0 and ψ_0 – and Condition **GO** $\Rrightarrow$ makes a measure using $M = |1\rangle\langle 1|$

3. States χ_0 and ψ_0 – and Condition **NO-GO** $\Rrightarrow$ makes a measure using $M = |0\rangle\langle 0|$

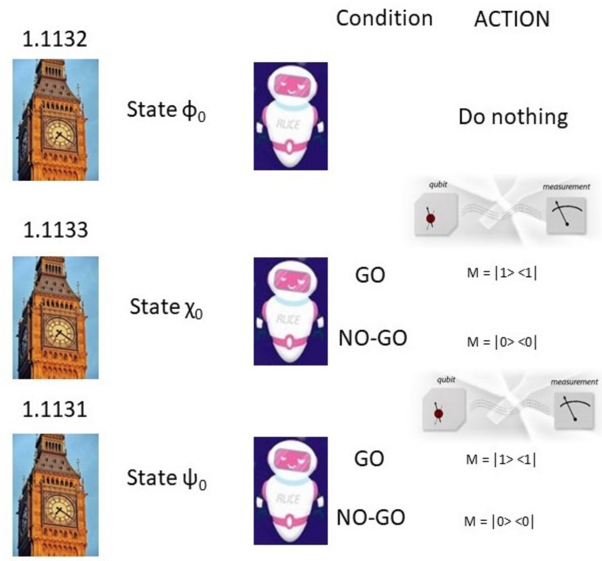

FIG. 5. Alice Measurement

Bob makes a measure in Bq_2 that is:

1. State ϕ_0 – Do nothing

2. States χ_0 and ψ_0 – and Condition **GO** $\Rrightarrow$ makes a measure using $M = |1\rangle\langle 1|$

3. States χ_0 and ψ_0 – and Condition **NO-GO** $\Rrightarrow$ makes a measure using $M = |0\rangle\langle 0|$

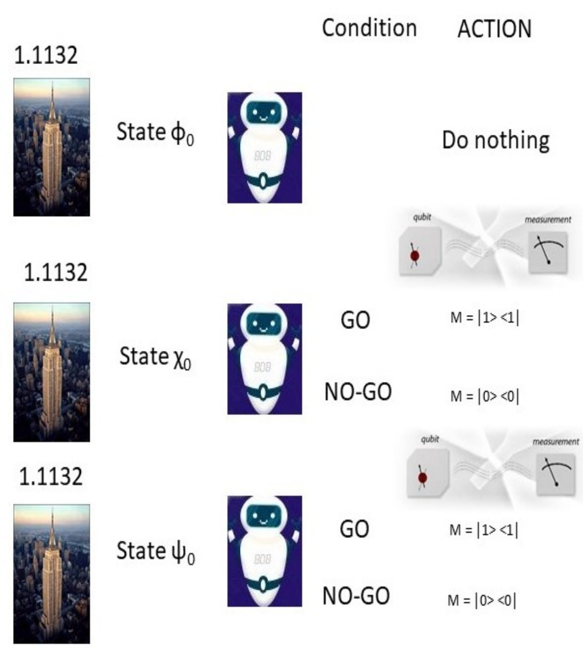

FIG. 6. Bob Measurement

Taking in consideration the characteristics of the measure processes described in the Section (3), after the measure of Alice and Bob of their qubits Aq_1 and Bq_2 with the Matrix $|1\rangle\langle 1|$ the qubits will finish in the state $|1\rangle$ and after the measure of Alice and Bob of their qubits with the Matrix $|0\rangle\langle 0|$ the qubit will finish in the state $|0\rangle$.

Going now to the entanglement properties presented also in Section III.D, instantaneously to the abovementioned measures, the entangled qubits of Alice and Bob, Aq_2 and Bq_1 will pass to the states $|1\rangle$ and $|0\rangle$ if their pairs had finished in these states. (Remember the properties of the Bell state β_{00}).

A measure by Alice or Bob to these qubits will allow to determine the GO or NO-GO condition of his partner with probability 1, without the need of any classic information exchange between them.

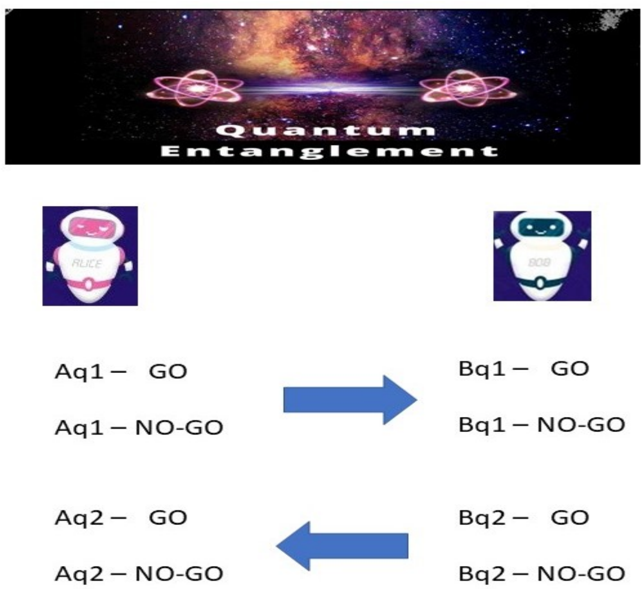

FIG. 7. Quantum Entanglement

E. Summary

Summarizing at the end of the process Alice and Bob will have each of them the conditions **GO** or **NO-GO**corresponding to both partner positions.

So, two GO conditions will allow to settle from both parties the Buy/Sell transaction making the corresponding profit.

FIG. 8. Trade Summary

Taking in account that first measurement with the chosen matrix is made at T_1 exact ($\Delta T < 100$ nanoseconds), the second measurement would be made at $T_1 + 1$ microsecond to have the assurance that the first measurement has already taken place by the other party.

In this condition the trade is settle by both parties at $T_1 + 2$ microseconds using machines that perform Tick to Trade in this 1 microsecond delay.

Trade is close and next cycle will start at $T_0 + 50$ milliseconds as the new T_0.

To close this section let us, using the dynamics of the market as presented in Section II, to make a quick and of course not very serious calculation of the potential that the above strategy could bring over this pair.

Considering that the **GO** conditions are established by a minimum 1 pip (0.01%), price difference between the positions, and these **GO** conditions have a probability of 10% (minimum), the 20 Hz cycle gives us 2 trades successful each second. Having 10 hours market trading, he total number of successful trades are 72,000. With the previous 1 pip profit per trade we obtain 7.2% profit per day over the nominal amount of the transactions.

V. IMPLEMENTATION

A. Structure and Technologies

The previous devised strategy could be implemented under the structure of a Hedge Fund (HF) under the category of extremely technological High Frequency Trading.

The base as presented is the arbitration of one pair (EUR / USD) at FOREX markets between New York and London.

Technologies for the implementation will be forefront in these three domains:

1. Tick-to-Trade

Tick-to-Trade in the order of 1 microsecond (1 μ sec). The current (posted) fastest time is 98 nanoseconds. So, we can be 10 times slower to the top performers of the table regarding this technology.

2. Communications

Communications between London and New York using existing Fibre-optics links or in a further step radio waves over the Atlantic. Satellite connectivity with Low Orbit Satellites could also be considered. In any case our 43-msec. mark is easily achievable from any of these technologies.

3. Quantum supremacy

Quantum supremacy in execution, through the entanglement mechanisms between the devices co-located with the execution computers at the premises of the FOREX markets in London and New York.

B. State of the Art

The markets of London and New York will be the launching ones due to its maximum volume and reliability. Also initially as described in the paper we can operate over one pair. There's no reason to think in further expansions of the operations to other places and other pairs, in which the HF can operate.

It's clear that the hurdle for the expansion, and for the launch of course, will be the availability of the devices that will support the quantum supremacy.

As today, November 2019, the availability of qubits entangled in different locations to perform quantum communication is one of the hottest applications. The main benefit for Quantum Communication is in the Quantum Key Distribution (QKD) processes and currently is a matter of normal business. In July last year, Alberto Boaron of the University of Geneva, Switzerland, and colleagues reported distributing secret keys using QKD over a record distance of more than 400 kilometres of optical fiber, at 6.5 kilobits per second. In contrast, commercially available systems, such as the one sold by the Geneva-based company ID Quantique, provide QKD over 50 kilometres of fibre.

The critical issue for all the current developments is the distance that the photons as carriers of the quantum information could achieve.

C. Disclaimer

The companies of the Author, RQuanTech (Geneva) and Criptosasun (Madrid), are working in a device that would implement the entanglement of qubits at the distances required by the setup of the methodology discussed in Section IV and the implementation presented in Section V

Taking in account that this development is a work in progress we can not now assure that the milestones proposed will be achieved.

VI. CONCLUSIONS

It's clear that Quantum Supremacy will not only disrupts financial markets nor all the other markets in the world.

Regarding the current quarrel between IBM and Google over the claim of the later, Ethan Siegel has written in Forbes magazine[9], "Progress in the world of quantum computing is astounding, and despite the claims of its detractors, systems with greater numbers of qubits are undoubtedly on the horizon. When successful quantum error-correction arrives (which will certainly require many more qubits and the necessity of addressing and solving a number of other issues), we'll be able to extend the coherence timescale and perform even more in-depth calculations"

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