

# UC Berkeley - INFO 134/234 - CRYPTO PRODUCER THEORY

Noel, Thomas & Sockalingum, Briac

April 2024

## 1 Introduction

In 2021, El Salvador announced it adopted Bitcoin as a legal tender[1]. This increased the discussion towards the nature of crypto-assets as currencies, and if they can be included in real economies instead of being first and foremost an investment asset. Because (macro)economists have soon disregarded cryptocurrencies, there is not a lot of research on the topic though it is beginning to take on. Most past discussions were on asset pricing, in the field of financial economics, and are today more focused on the adoption of cryptocurrencies as Central Bank Digital Currencies (CBDCs) in the context of international trade[4], and how to assess the conditions of cryptocurrencies' adoption by users/consumers. For instance, there are findings that adoption is fostered where banking and financial institutions are best developed, which might come as a contradiction to the original cryptocurrencies' narrative of financial order disruption and independence[6]. Moreover, the poignant interest of developing countries still highlights an interesting side of the field, notably in development economics and what could be the potential impact of the usage of cryptocurrencies in such regions[3], from which we can also gain insight into the research from the People's Bank of China[5]. It is also interesting to see the interest of International Organizations, mostly from the Bank of International Settlements (BIS), to conduct research since a long time on cryptocurrencies. Their main interest is to identify the extent to which cryptocurrencies abide by financial rules and how the international banking systems could adopt blockchain technologies to bring more efficiency to financial payment networks (like Visa or Mastercard infrastructure, as well as Central Banks payments systems)[2]. This is particularly relevant to this paper as it will strive to present a static analysis of different methods of payments for a producer, which could be a basis for a micro analysis of these macro discussions.

Last year, for an urban economics class, I wrote a paper about the usages of cryptocurrencies in economies[7], notably based on interviews with professionals of the field who have been there or advised clients in the implementation of cryptocurrencies, as well as economists. The main findings revolved around the dynamics in developing economies, as well as how incentives were used in El Salvador to foster the adoption of Bitcoin, and the role of education. We are shown the different policies that were mainly aimed at consumers on a micro level, or at international trade attractivity. However, the fact that in countries like El Salvador or Central Africa, big corporations are the first adopters of cryptocurrencies as a payment method may push us to investigate the producer dynamics. We know more and more merchants are turning to Bitcoin in these local economies, the

question is how they initiate their reflection.

Thus, reflecting on the ideas I synthesized in the text I believed that producer theory could be the most interesting problem to try solving. Indeed, it poses questions that were not necessarily addressed in my previous paper, which was more focused on consumer interest and governments' possible mechanism design, and also falls into a neoclassical understanding where the producer directly impacts the exchange economy. This paper thus presents a first try at modeling a producer problem of profit maximization with respect to different cost variables: notably the means of payment chosen as marginal cost. I will try to do a static analysis of this model.

## 2 The Model: A Producer Problem in Economies Where Crypto are Accepted as a Legal Tender

### 2.1 Conditions and assumptions

Let  $N$  be the number of consumers in the economy,  $M$  be the number of firms, and  $U_i$  the utility function associated with individual  $i$ .  $U_i$  is assumed to be an increasing function of  $N$  and  $M$ , which characterizes the existence of a network effect in the economy for the different payment methods. In other words, the higher the number of consumers using a specific method of payment or the higher the number of firms accepting this method of payment, the higher the utility of the consumer for using this payment method.

I consider three different payment methods: Bitcoin (or more generally cryptocurrencies), cash, and banking account. Nevertheless, some consumers may use different methods of payment, thus it amounts to consider seven different types of consumers: those who only use one method of payment (3 situations), those who use two methods of payment (3 situations), and those who use the three methods of payment (1 situation). Therefore, there are seven different ways accepted for purchasing goods in our economy, that will be solved in this paper as two main sets. I denote by  $A$  to  $G$  the situations considered. More precisely situations  $A$  to  $C$  refer to methods of payments that do not use Bitcoin (which correspond to the set of options  $X$ ), and situations  $D$  to  $G$  (which correspond to the set of options  $Y$ ) refer to methods of payments that use Bitcoin.

SITUATIONS		
Letters	Situations	Set
A	Cash Only	X
B	Open Card Payment Network Only	
C	Both Cash & Card Network	
D	Bitcoin Only	Y
E	Bitcoin & Cash	
F	Bitcoin & Card Network	
G	All 3 methods	

The utility of a consumer using method  $k$  is defined by  $U_i^k$  and there are  $N^k$  consumers using this payment method.

One should nonetheless bear in mind that the goal of this paper is to focus on firms' decisions, not on consumers' decisions. Yet it is useful to provide theoretical conditions on the decision of consumers to understand where the  $N^b$  comes from (for the sake of time, I won't resolve it in this paper, but it would also be a necessary addition to an extended version of the paper). A consumer will decide to choose the combination of payment methods that provide her the highest utility, so, the equilibrium condition is simply given by

$$U_i^A = U_i^B = \dots = U_i^G$$

where the letters correspond to the different situations/combinations of payment methods.

The next step is to define the profit function. I denote by  $\pi_j^b$  the profit function of firm  $j$  accepting Bitcoin only, and it is an increasing function of  $N^b$  and  $M^b$  the number of agents (consumers + firms) using Bitcoin as a payment method. In other words, one has  $\pi_j^b = (\underbrace{N^b}_{+}, \underbrace{M^b}_{+})$ . It is assumed that the price charged to consumers depends on the method of payment accepted by the firm, and the cost structure is also specific to each situation (payment methods accepted). It is assumed that there is no fixed cost (this is a strong assumption that could be changed in later work, but it shouldn't change the results for this paper in the short run, only the equilibrium profit) and denoted by  $c^k$  the marginal cost of situation  $k$ . Using traditional notations for price,  $p^k$ , and quantity  $q^k$ , one can express the profit function of a firm-accepted payment method situation  $k$  as follows:

$$\pi_j^k = P^k(q^k)q^k - c^k q^k$$

Next, since all the payment methods present different degrees of volatility, cash and bank accounts being low-volatility payment methods compared to cryptocurrencies, one needs to discuss the implications of this variable in the model, in order to be truthful to the usage of this method of payment. Indeed, a positive volatility that would negatively affect the price of Bitcoin would be incurred as a cost for the producer. In this model it is captured by the fact that firms that accept Bitcoin may face a negative profit if the volatility is negatively oriented, therefore for the situation that includes cryptocurrencies one needs to reason in terms of expected profit. This is also motivated by the willingness to keep the model simple and tractable, but I recognize that there might exist different ways of capturing the volatility in the profit function of the firm. By denoting  $\gamma$  the probability that the volatility of the bitcoin is positive (and so there is no crash or strong increase of Bitcoin during this period) and assuming that when there is a crash the profit of firm  $j$  is simply equal to its costs, the profit of a firm using only bitcoin can be written as follows:

$$\mathbf{E}(\pi_j^k) = \gamma[P^k(q^k)q^k - c^k q^k] - (1 - \gamma)c^k q^k$$

The next step is to express the relation between price and quantities exchanged in each situation. An important remark is that I will assume that the different types of consumers (different in their methods of payment) have different willingness to pay, thus the demand equation is situation-specific. Denoting by  $a^k$  the willingness to pay of consumers using a method of payment  $k$ , I assume the following demand function:

$$p^k = a^k - q^k$$

We now have all the elements to write the firm's profit function in all cases and solve the model. There are two types of situations: the one which do not include Bitcoin and therefore one needs to consider the profit function, and the one that includes Bitcoin and should be derived through the expected profits function. Within each case, the methodology is similar, therefore I will consider only the general situation (denoted by  $k$ ) for both situations. The following paragraphs present the main steps to solve the model.

## 2.2 Solving the Model

### 2.2.1 Situations without volatility

I first derive the equilibrium solutions for the situations that do not include Bitcoin as a payment method (i.e., situations A to C). Denoting by  $X$  the set of options of these situations, one can rewrite the profit function firm of firm  $j$  choosing option  $k \in X$  as follows:

$$\pi_j^k = (a^k - q^k)q^k - c^k q^k \quad (1)$$

The first-order condition of the maximization program is given by:

$$\frac{\partial \pi_j^k}{\partial q^k} = 0 \Leftrightarrow a^k - 2q^k - c^k = 0$$

Finally, the equilibrium conditions are given by:

$$\begin{cases} (q^k)^* = \frac{a^k - c^k}{2} \\ (p^k)^* = \frac{a^k + c^k}{2} \\ (\pi^k)^* = \left(\frac{a^k - c^k}{2}\right)^2 \end{cases}$$

As we can see from these results for the market equilibrium under certainty, the insight is very traditional with the profit depending on the costs at play in the price and quantity functions. The consumers' willingness to pay is also a variable of interest and can be tested in numerical applications.

### 2.2.2 Situations with volatility

Then one needs to derive the equilibrium conditions for the situations that include Bitcoin as a payment method (i.e., situations D to G). Denoting by  $Y$  the set of options of these situations, one

can rewrite the profit function firm of firm  $j$  choosing option  $k \in Y$  as follows:

$$\mathbf{E}(\pi_j^k) = \gamma[(a^k - q^k)q^k - c^k q^k] - (1 - \gamma)c^k q^k \quad (2)$$

The first-order condition is:

$$\frac{\partial \mathbf{E}(\pi_j^k)}{\partial q^k} = 0 \Leftrightarrow \gamma[a^k - 2q^k - c^k] - (1 - \gamma)c^k = 0$$

Finally, the equilibrium conditions are given by:

$$\begin{cases} (q^k)^* = \frac{\gamma a^k - c^k}{2\gamma} \\ (p^k)^* = \frac{\gamma a^k + c^k}{2\gamma} \\ \mathbf{E}(\pi_j^k)^* = \left(\frac{\gamma a^k - c^k}{2}\right)^2 - (1 - \gamma)c^k \left[\frac{\gamma a^k - c^k}{2\gamma}\right] \end{cases}$$

Here, the market equilibrium is sensibly the same as under certainty, apart from the probability  $\gamma$ . The results for the market equilibrium under uncertainty depend on the costs at play in the price and quantity functions, as well as probability  $\gamma$ . The volatility of Bitcoin is key to the profit here, which is what one would have expected.

### 2.3 Comparison between all situations

Here, we compare the two general situations and try to find conditions under which using Bitcoin-friendly methods is more profitable for a firm. Technically we can solve this:

$$(\pi^k)^* \leq \mathbf{E}(\pi_j^k)^* \quad (3)$$

We can solve for extreme values like 0 and 1 as follows.

For  $\gamma = 0$ , I tried isolated  $(1 - \gamma)c^k \left[\frac{\gamma a^k - c^k}{2\gamma}\right]$  to solve the inequality:

$$(1 - \gamma)c^k \left[\frac{\gamma a^k - c^k}{2\gamma}\right] = (1 - \gamma)c^k \left[\frac{a^k}{2} - \frac{c^k}{2\gamma}\right] = (\gamma - 1) \frac{(c^k)^2}{2\gamma} = -\frac{(c^k)^2}{2\gamma} \Rightarrow -\infty$$

We can plug back this term in the inequality for  $\gamma = 0$ :

$$\left(\frac{a^k - c^k}{2}\right)^2 \leq \left(\frac{\gamma a^k - c^k}{2}\right)^2 + \infty$$

What we can see in cases of extreme values is that for  $\gamma$  tending to 1, the two profits (under certainty and uncertainty) are equal. Meaning there is no difference in accepting methods of payments using Bitcoin or not. However, for cases when  $\gamma$  tends to 0, then the expected profits for situations where producers accept Bitcoin are strictly higher than the profit of situations when they are not accepting cryptocurrencies, as the expression tends to  $+\infty$ .

We see that the expected profit is infinitely higher than the profits under certainty (without volatility).

Now we can solve the inequality for  $\gamma = 1$ :

$$(\pi^k)^* = \mathbf{E}(\pi_j^k)^* \Leftrightarrow \left( \frac{a^k - c^k}{2} \right)^2 = \left( \frac{\gamma a^k - c^k}{2} \right)^2 - (1-\gamma)c^k \left[ \frac{\gamma a^k - c^k}{2\gamma} \right] = \left( \frac{a^k - c^k}{2} \right)^2 - (1-1)c^k \left[ \frac{a^k - c^k}{2} \right]$$

We understand here that for  $\gamma = 1$ , the profits under certainty, and with volatility (under uncertainty) are the same.

## 2.4 Discussion: Results and Parallel to the Class

Based on this model, we can understand the implications that shifting to payment methods accepting cryptocurrencies can be profitable to producers. As a matter of fact, producers should be shifting to these kinds of digital payments as they do increase their profits, or do not affect them: it is thus on the education and more qualitative costs that real-life considerations should be focused on.

Considering these results, we can retrospect on how this investigation of the dynamics of different payment methods in economies for producers notably when it comes to the emerging role of cryptocurrencies as a legal and legitimate medium of exchange. The discussions above point at different economic features in cryptocurrencies that we find in information technologies. For instance, we identify network effects for payment methods, including cryptocurrencies: the more users and firms use one cryptocurrency network (i.e. blockchain), the more utility each gets from using a particular network (like Bitcoin for instance). Moreover, Bitcoin has some low marginal cost in terms of payment fees contrary to open card payment networks. This has helped us gain some insights for this model, but more broadly is interesting empirically in terms of social welfare: executing an international wire transfer will require the payment of much more fees than using most cryptocurrencies. Moreover, it seems that fixed costs are low for adopting cryptocurrencies, apart from the education and knowledge part which is nontrivial for emerging and developing economies and has implicated the need for NGOs and education programs in the cryptocurrency-as-a-payment-method's value network. These low fixed costs and marginal costs imply low switching costs for cryptocurrencies, this is especially true for two similar blockchains/cryptocurrency networks. Finally, some privacy questions might be asked as well as it seems that people have an interest in using cryptocurrencies even though it might entail some privacy issues depending on the cryptocurrency used, the consensus method, etc, some people might do transactions scrapping and discriminate on prices using this information. As a matter of fact, there might be, in some very particular cases, a privacy paradox.

## 2.5 Discussion: Limitations and Future Extensions

There are some limitations to this paper that would need to be solved before working on other situations. First of all, I did not have time to solve the inequality in part 2.3 for every value of  $\gamma$  but only for the extreme values 0 and & 1. Then, a lot of assumptions and conditions have not been demonstrated here for the sake of time: all the consumer and producer theory foundations would need to be demonstrated. Moreover, the volatility estimation should be reflected more in-depth to get more rigorous modeling. Finally, the cost estimations should be more detailed, as everything

here was simplified to varying costs.

Interesting future extensions could revolve around welfare analysis of the situations described above. Furthermore, one could also investigate cases of price discrimination through the payment method even more than in the paper. Vis-à-vis the solving of the market equilibrium under uncertainty, financial economics' methodology could help us get a view into how best to evaluate Bitcoin's volatility, for better precision of the results; this might also push us to adapt the methodology on this side to solve for the equilibrium. Finally, bringing some econometrical work to this paper might strengthen the findings, or contrast them with different conclusions.

### 3 Conclusion

In conclusion, we have seen that research on cryptocurrencies has focused on the macro and financial economics fields so far, with interesting advances and promises in terms of international trade, financial efficiency, and possibly developmental questions. However, few microeconomic analysis of cryptocurrencies have been done: hence this try to propose a first dive into producer theory and see under what conditions it might be useful for merchants to accept cryptocurrencies like Bitcoin in their set of accepted methods of payments. Here we understand that it is in the interest of the producers to include these mediums of exchange. The following works should further the efforts to get a more rigorous producer theory analysis and extend the findings to consumer theory models, notably under more advanced methodologies for situations under uncertainty.

## References

- [1] Bitcoin: El Salvador makes cryptocurrency legal tender. June 2021.
- [2] Raphael Auer, Jon Frost, Leonardo Gambacorta, Cyril Monnet, Tara Rice, and Hyun Song Shin. Central bank digital currencies: motives, economic implications and the research frontier. *SSRN Electronic Journal*, 2021.
- [3] Mu Changchun. Theories and Practice of exploring China's e-CNY. In *Data, Digitalization, Decentralized Finance and Central Bank Digital Currencies*, pages 179–190. De Gruyter, February 2023.
- [4] Johann M Cherian. Currency Dominance and National Power in the Era of Distributed Ledger Technology and Cryptocurrency. *Chinese Journal of International Review*, 4(1), 2022.
- [5] Yifei Fan. Analysis of the Policy Implications of the Positioning of e-CNY as M0. *People's Bank of China*, 2022.
- [6] Ed Saiedi, Anders Broström, and Felipe Ruiz. Global drivers of cryptocurrency infrastructure adoption. *Small Business Economics*, 57(1):353–406, June 2021.
- [7] Briac Sockalingum. Economic analysis of the implementation of cryptocurrencies in economies. 2023.