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區塊鏈技術如何促進國際貿易與永續發展？

How Can Blockchain Technology Facilitate International Trade and Sustainability Development?

指導教授:何靜嫺 博士

研究生:李韋良 撰

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摘要

區塊鏈技術具有成為大眾接受（不可竄改）及去中心化的特色。近年來，大部分政府與環境當局已經在催促區塊鏈應用以促進國際貿易與環境保護。我們的第一個模型分析智能合約應用於國際貿易。我們的第二個模型提出一個全球環境的架構，將區塊鏈用於記錄成員國的環境永續的程度，這些紀錄將會廣播給所有區塊鏈的成員，並用於決定出口至其他國家的程度。我們分析每一個國家在此架構加入的動機，並證明環境永續的程度在區塊鏈的架構會比有考慮社會福利對其他國家的外部性，即社會規範或外溢效果的時候高。

JEL 分類系統：L13, Q56, Q58

關鍵詞: 區塊鏈, 國際貿易, 環境永續, 政策

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Abstract

Blockchain technology has the properties of being public members (cannot be changed) and decentralized. Recently, many governments and environmental authorities have been urging the applications of blockchain to facilitate international trade and environmental protection. Our first model analyzes the application of smart contracts to international trade. Our second model proposes a global environmental scheme where blockchain technology is used to record member counties' environmental sustainability levels. These records will be broadcasted to all members of the blockchain and will be used to determine the level of exports to other countries. We analyze each country's incentive to join this scheme and show that the levels of environmental sustainability are higher than those obtained by considering welfare externalities across countries, e.g., from a spillover or social norm effects.

JEL Classification: L13, Q56, Q58

Keywords: Blockchain, International trade, Sustainable environment, Policy

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1 Introduction

A blockchain is a digital information recording method capable of recording data using a logbook approach (De Leon et al., 2017). Blockchain technology has several features that attract policy applications in various fields such as health and international trade. The important features[1] include: *distributed, immutable,* and *decentralized.*

"*Distributed*" means that all network participants have a copy of the ledger for complete transparency. A public ledger will provide complete information about all the participants on the network and transactions. "*Immutable*" means that the stored data cannot be changed later. Since every node in the network has a copy of the digital ledger. Without the approval of a majority of nodes, no one can add any transaction blocks to the ledger. This means that any user on the network won't be able to edit, change or delete it. "*Decentralized*" means that there is no central governing authority that will responsible for all the decisions. Each and every node in the blockchain network has the same copy of the ledger. As a blockchain network does not depend on human calculations it is fully organized and fault-tolerant. The decentralized nature of blockchain facilitates creating a transparent profile for every participant on the network.

Blockchain technology has been used for health and agriculture to protect biodiversity and sustainability. For cross country transactions, blockchain technology is capable to facilitate international trade and environmental protection. For example, it is believed that smart contracts on blockchains can simplify the international trade documental flows from manufacturer to customs (Melkonyan et al., 2021). Traditionally, the supplier needs to hand in certification to prove the satisfaction of standards in import countries. Some agricultural products require a source of origin to trace types of fertilizers and chemical residuals. After verified, products will transport to the customs departments to prepare the clearance procedures. It contains documents like permits, invoices, and packing lists. Later, the manufacturer gets a bill of landing

[1] https://www.geeksforgeeks.org/features-of-blockchain/

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to exchange payments from banks once buyers announce the product receiving confirmation. It's a complicated process concerning document delivery and verification. Smart contracts are a possible solution to save time and effort in this multi-party interaction of international trade.

Several preliminary policy concepts have been proposed.[2] On Feb. first, 2018, the European Commission launched the EU Blockchain Observatory and Forum. The group promoted European development in blockchain activities by triggering cooperation with experts, technologists, and stakeholders (European Commission, 2018). They wanted to build a supporting, visibility expertise about new paradigms with blockchain. Later, 21 Member States and Norway signed the European blockchain partnership and corresponding European blockchain service infrastructure. It contributed to the construction of digital services of blockchain infrastructures and further built a market consultation in the improvement of blockchain solutions (European Commission, 2019b). The EU's targeted with blockchain technology included environmental sustainability (European Commission, 2019a), data preservation, digital identity, security, and interoperability for them and the outside world. The United Nations Environment Programme (UNEP) proposed sustainability goals in clean energy and low-carbon transition with blockchain applications. A peer-to-peer decentralized infrastructure could monitor energy demand and supply with transparency. The smart contract could further automate energy transactions and simplifies many processes (UNEP and SAF, 2022).

We attempt to contribute to this line of literature by proposing a global environmental scheme that the blockchain technology can be used to record member countries' environmental sustainability levels. These records will be broadcasted to all members of the blockchain and will be used to determine the level of exports to other countries. We analyze each country's

[2] https://ec.europa.eu/commission/presscorner/detail/en/IP_18_521

https://digital-strategy.ec.europa.eu/en/policies/blockchain-strategy

https://digital-strategy.ec.europa.eu/en/news/european-countries-join-blockchain-partnership

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incentive to join this scheme and show that the levels of environmental sustainability are higher than those obtained by considering welfare externalities across countries, e.g., from a spillover or social norm effects.

Before the global environmental scheme on blockchain, we provide an economic analysis explaining how cross-chain trades work through smart contracts in blockchain. Our results show that the seller will propose a price which is positively related to the size of collateral. The probability of completing the contract (i.e., players choose to continue for all four stages) is increasing with the size of collateral.

Next, for the global environmental scheme on blockchain, (1) We first show that environmental trade regulations have no effect on optimal sustainability choices, but will increase home country's profit and welfare while decrease other country's welfare. (2) Both proportional output and profit schemes applied to blockchain derive a higher sustainability level compared to free trade and regulation trade. (3) The larger market scope of the foreign market is the sufficient condition for the sustainability level of proportional profit to be bigger than that of proportional output. (4) The centralized decision at the sustainability level will be smaller than that decentralized blockchain outcome, and the potential expression will be a social norm effect in a grand coalition.

Joining a blockchain is similar to forming a coalition. Its difference from the traditional cross-country coalitions comes from the two properties of blockchains. First, it is assumed that each country's environmental sustainability level is recorded and broadcasted to all member countries. So all members' environmental sustainability levels are publicly known and cannot easily be changed. These records will be used to form the trade policy which regulates a foreign country's import to home country. Second, a blockchain is decentralized. There is no centralized authority to determine the global optimal environmental sustainability level. Under a centralized scheme, the countries with more efficient technology are obliged to reduce more solution, and this could lower the incentives of country with a larger economic scope to join the

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centralized convention.

We attempt to make incremental contributions to the following line of literature. First, the existing environmental agreements and policies, announcements and acts are mostly centralized and determined by authorities. For example, in Na and Shin (1998)'s model structures, three countries decided between joining the coalition or being individualistic under prior or posterior uncertainty to change their payoff. In the coalition, members combined production and cost into a large entity to maximize profit jointly. The optimal value came from centralized decisions. Different from the existing literature, our global environmental scheme is decentralized. We will further compare to the solutions under centralized coalition.

Second, in blockchain with international trade and environmental protection, most articles focused on public access and real-time verification for the record on the blockchain (Jain and Sedamkar, 2020; HØjund and Nielsen, 2019; Belu, 2019). Our model uses the properties that transactions can be automatically recorded and broadcasted to every node in the network, to design a scheme that combines international trade and environmental sustainability. Reinsberg (2020) designed a token named "greencoin" to claim carbon credits and connect with the country's climate actions. Our papers uses the blockchain recording characteristic itself to combine firms' decisions with sustainability. Similar to the concept from UNECE (2020) in providing transparency and traceability application in agriculture and food, we propose public sharing data as a source about environmental abatement, standards, or sustainability checking.

Third, Lai et al. (2003) showed that social norm played a crucial role in environmental actions. A high compliance rate followed with a lower penalty for minimizing social loss when considering social sanctions in the decision. We also present a centralized scheme to consider a positive externality effect similar to social norm, and compare to our decentralized environmental scheme. We can find a similar interpretation about the sustainable consensus that affects a country's welfare and further change the optimal sustainability level.

Fourth, Brander and Krugman (1983) analyzed the free trade equilibrium in imperfect com-

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peting markets. Our paper also assumes imperfect competition between home and foreign products, but focuses on heterogenous products. Hence regulations on trade will also affect consumers' surplus by reducing the product variety. Our discussion on the two environmental schemes, the trade regulating and the centralized scheme are not mentioned by them.

Fifth, Xu et al. (2021) focused on token swaps between different blockchains and the contract structures that made the recipient must accept the deal in the last decision stage. Our model instead studies trades across blockchains, with a buyer buying product with tokens and smart contracts.

The rest of the paper is organized as follows. In Section 2, we review the relevant literature performance on features of blockchain, blockchain related in cross blockchain and international trade, and government policy. In Section 3, we focus on a cross blockchain model with purchasing from another entity. In section 4, we expand our model into international trade with regulation and free trade. In Section 5, we further analysis same international trade structure with blockchain applied, and finally, we conclude by summarizing our findings in Section 6.

2 Related Literature

2.1 Features of Blockchains

Blockchain technology was a method to record time-flowed transaction data with a synchronized decentralized ledger. From the first blockchain paper in Nakamoto (2008), the smallest unit of blockchain was a block, consisting of several transactions, a hash function, nonce, and part of the previous block information. Transactions were the transformation of an asset from some people's accounts with private signatures signed on hash (Nakamoto, 2008). The hash function was an encryption result (Easley et al., 2019). From point of Yang et al. (2018), a nonce was a list of random numbers added at the ending position of the hash function. With each nonce input, people could derive different hash value feedback. The encryption could solve only when

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the overall hash value was smaller than a threshold. There were no further tips or tricks to accelerate the solving speed. Try-and-error was the only method to calculate the value (Ren et al., 2020). The nonce length would adjust the difficulty of solving the hash function (Chen et al., 2021). The shorter the nonce was, the easier the hash would be. Some previous block messages wrote into the current block, making a single block connected to a blockchain (Yang et al., 2018; Wang et al., 2019).

One classification method of blockchain depended on who became the recordkeepers, or we called them "miners" (Chen et al., 2021). First, the public one allowed anyone to construct their nodes to become miners (Chen et al., 2021). Everyone owned the right to access and read data on it without further permission (Kosba et al., 2016). Second, the private one controlled the blockchain maintenance power to secret members (Wang et al., 2019). Ordinary people could not control and read any information and data. Third, consortium blockchain restricted miners into prespecified groups (Chen et al., 2021). Merchants or business associates tended to use it to protect the data access to the pre-defined groups (Wang et al., 2019). Another classification was the miners' competition methods to get the record ownership. First, the well-known protocol was Proof-of-Work (PoW), used by the most famous blockchain, bitcoin (Nakamoto, 2008). Under PoW, miners competed with each other in solving the hash function in the previous paragraph aforementioned (Easley et al., 2019; Harwick, 2021). The first miner who solved the hash could get the right to record the transactions into one block and receive a block reward and transaction fee (Easley et al., 2019; Harwick, 2021). The reward would distribute if and only if the block he had recorded connected with the other six blocks afterward (Chen et al., 2021). In other words, others miners supervised the recordkeeper's behavior if they wanted to get rewards. The design ensured the transactions were recorded based on the truth and prevented miners wrote down fake ones (Ray et al, 2018). There would be only one and the longest blockchain accepted by most miners that existed (Chen et al., 2021; Ray et al., 2018). Some criticism about PoW would be electricity waste, environmental protection, and

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distortion of economic resource conditions (Benetton et al., 2019). It triggered another design, Proof-of-Stake (PoS). Under the PoS structure, the qualified miners or validators would choose randomly when the next block was generated (Chen et al., 2021), and the probability depended on the holding duration or amount of blockchain native token (Ray et al., 2018).

Blockchain represented tamper-proof data property, traceability, and resistance from single-point failure under a public and PoW consensus. First, the time-flowed features came from the generation of blocks (Chen et al., 2021; Ray et al., 2018). It allowed users to trace the source of origin (Li et al., 2020). Combined with publicly known data, people could read and access them from the current block to the oldest one (Chen et al., 2021). The duration of the emergence of the next block is fixed at approximately ten minutes. When numerous machines devoted themselves to solving the hash, the difficulty increased to balance the block-generating time (Ray et al., 2018). Second, the tamper-proof condition would depend on the competition status of miners. Currently, the calculation power of a mining pool might be over half to increase the probability of calculating (Chen et al., 2021). However, one computer's power was not over 51% among all others' nodes. None of a single entity controlled the recording right (Ray et al., 2018). In other words, it's decentralized that no centralized entity could affect the validation and record process (Easley et al., 2019). It ensured the longest chain consensus that larger than half of the miners accepted records from the historical block to the current generated (Chen et al., 2021; Ray et al., 2018). People who wanted to fork blockchain required validation power with money and time devoted to constructing a supercomputer (Chen et al., 2021). Third, this synchronization property made blockchain prevent a single point failure, which didn't need to worry about the balance sheet disappearing (Chen et al., 2021; Wang et al., 2019). Once a new block generating, it broadcasted to all the miners' computers worldwide (Harwick, 2021). They received the latest block information and synchronized to identical forms simultaneously. All of them preserved the same blockchain data. From the holistic view, several copies are distributed on different computers, preventing a single point of failure (Chen et al., 2021).

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However, the decentralized peer-to-peer system made the transaction less efficient (Qu, 2021). Took the bitcoin blockchain, for instance, the acceptance of deals would be sure after six blocks that the miner got the bitcoin reward. Instead, in a centralized transaction institution, the character of an intermediary brought efficiency and facilitated trade without any waste period (Ahn et al., 2011). Moreover, blockchain was not equal to an accurate information record (Qu, 2021). In permission and private blockchain, miners were controlled by a specific entity with some qualification. The recording power existed in a small or preserved party. The data showed there were not trustworthy compared to the permissionless blockchain mechanism. An inevitable feature of blockchain was the supervision of data input (Maulana and Juliarto, 2021). Miners could ensure the accuracy of this transaction without any ability to control what would be the input. If the data recorded was wrong from the source of origin, the validation mechanism could not control the behavior.

From Nakamoto (2008)'s expression on how to deal in blockchain, when users announced transactions, either for payment or receipt, they used a private key to sign the transaction and miners verified the trading amount and own public key. Afterward, the miners' competition process would happen as aforementioned. One of the fastest miners owned a period to write down what happened inside the transaction into a block (Chen et al., 2021) after solving the puzzle of the hash function. The emergence of a programming language applied to Blockchain called smart contract on the surface of Ethereum virtual machine opened another door toward blockchain transactions (Wood, 2014). The smart contract executed scripts on the computers with conditions and parameters, making users follow instructions and restrictions (Wang et al., 2019). In the field of the traditional peer-to-peer exchange system, consumers bought products from a retailer or intermediary. They needed a fair and convinced third party to protect the money flow. Banks and credit card issuers tended to act the characters. It required an additional handling charge to ensure the safety and maintenance costs (Tapscott and Tapscott, 2017). Through blockchain technology, transaction counterparties could interact directly (Jain and

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Sedamkar, 2020). Via a public and permissionless blockchain, there was no requirement for a reliable third party bridging both sides. They could trust each other based on an adequate mechanism for miners to record correct transaction data.

Qu (2021) and Maulana and Juliarto (2021) mentioned the potential problem of accurate data input through blockchain. Matsushima & Noda (2020) found a unique equilibrium to reach the correct result that no other party would report a wrong message. A digital court based on a smart contract structure punished reneged agents. If there were a positive fraction of honest behavioral agents purely motivated by material payoff, psychological incentives influenced both types of agents. A repeated report with a randomized selection for a period to solve the punishment of truthful information. However, a preliminary assumption of agents' behavior proportion is required and applied through a smart contract.

Blackburn et al. (2022) researched the centralized concept at the emergence of the mining bitcoin period. More than six blocks came from the same miners, controlling computation power over a half. It's a dilemma for miners to write fake transactions and benefit themselves during the stream or cooperate to maintain the whole blockchain. Strikingly, none of the evidence indicated any deviation action for those miners. The earlier consensus maintenance required a centralized behavior though the original intention was decentralized. The research scope is a little different from our analysis in that participant joining blockchain and making the report didn't rely on a centralized decision.

2.2 Related Literature on Blockchains

In the literature review topic of cross-blockchain, Schulte et al. (2019) summarized the concept and current obstacles to solving cross-blockchain token transferring and smart contract interaction. Qasse et al. (2019) discussed how different interoperability methods worked and achieved communication inclusive of sidechains, blockchain routers, subchains in a smart contract, and industrial projects. Borkowski et al.(2019) and Johnson et al. (2019) focused more on the fu-

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ture extensions of cross-blockchain technology protocols. Robinson (2020) classified them into value swapping, cross-chain messaging, and blockchain pinning, then drew the advantages, disadvantages, or improvements. To achieve data recording and storage ability in the cross-chain transactions, Wanchain was a mathematical protocol of the information changing process to fulfill the medical data exchange and connection between different hospitals (Wang and He, 2021). Chain relay XCLAIM framework satisfied audit ability, consistency, atomic swap, scale-out, and compatibility properties (Zamyatin et al., 2019). A cross-blockchain information synchronization and verification mode solved the interoperability of data recording, storage, and expression (Gu et al., 2020).

To analyze atomic swap, Herlihy (2018) constructed a directed graph framework with vertexes in transaction parties and arcs in asset transfer. Bennink et al. (2018) and Robinson and Ramesh (2020) analyzed the simplest case of single-chain to cross-chain coin-token swap in smart contract structures. States verification in smart contracts ensured decentralized and atomic transferring in a permissionless witness network (Zakhary et al., 2019). On the topic of the data synchronization process, it's important to reduce the transactions storage and cost for the relayer (Frauenthaler et al., 2020). A virtual chain, a data storage model supporting the cross-blockchain transaction, released the pressure of storage blocks and achieved a high throughput in processing transactions in heterogeneous protocols (Wang et al., 2020).

In incentive analysis, Sigwart et al. (2019) built a cost and benefit analysis with enough incentive for clients to continuously submit and dispute new block headers from source chain to destination chain. Borkowski et al. (2018) proposed that source blockchain validity verification must verify the counterparty (target) blockchain with an appropriate mechanism to ensure motivation. Dubovitskaya et al. (2021) used a finite extensive-form game and imperfect information design framework to model agents' behavior of stopping or continuing in cross-ledger transactions. The asset price fluctuation and success rate would dominate behaviors. In the smart contract operation, Nissl et al. (2020) and Goyal et al. (2021) drew steps from announcement

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to validation for interaction by description and transaction cost analyses. Pillai et al. (2020) investigated the transaction process based on the logical judgment of specific statuses like exit and entry transactions under strong assumptions of users' behaviors and minimum level of trust. The hash time lock contract(HTLC) analyzed two different token transactions with a private key, hash function, and related maturity (Xu et al., 2021).

Belu (2019) illustrated blockchain-applied technology related to international trade. Business to business foreign trade transactions involved multiple sectors from manufacturers to service providers. Contracts, payments, and insurance of products could benefit from the blockchain with instantaneous verification and reduce cost by a smart contract. Logistic operations included goods departure, container, and packing. Transparency and digitalization decreased supply chain tracing costs. Payments without the third authority in finance lowered transaction waiting periods. Jain and Sedamkar (2020) proposed that multiple entities from buyers, sellers, and regulators in international trade interacted together. Blockchain could provide a secure and decentralized environment without a third party, and a chance for small and medium-sized enterprises involved in the trade finance system. Schwab and Ohnesorge (2019) analyzed blockchain trade integration in developing countries. Financial system improvement for the intermediary removal reduced costs for both counterparties. A tamper-proof supply chain storage enhanced verification of sustainability. Customs and products taxation benefited from information disclosure and prevented fraud and corruption. Digitalization and traceability characters improved intellectual property protection. Li et al. (2020) focused on the maritime supply chain application. For benefits, digital documents in blockchain could reduce associated costs in different stamps and approvals for a single product. Workflow automation based on smart contracts executed data instantly and lowered transaction time and delays. The encrypted technology and immutability features of blockchain preserved data to the original one enhancing security. Information sharing and transparency among stakeholders optimized limited port space problems. Emissions in the maritime industry decreased by minimizing transaction costs and monitoring

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the discharge of waste data.

Chen et al. (2019) focused on document transformation cross-border from both businesses and government authorities securely. The author proposed an attribute-based encryption method under blockchain to access data and share safety. Data usage ensured tampered-resistant and verification ability when adding a hash to the InterPlanetary File System. HØjlund and Nielsen (2019) found the relationship with smart contracts. Based on the tamper-proof properties of blockchain, the smart contract could reach better performance and cost reduction compared to traditional transactions. From the data of thirty-six interviews with industry stakeholders, transaction costs comparison with three international trade scenarios showed smart contracts could govern international trade by a trusted environment, collateral locked and released, and penalty design.

Siddik et al. (2021) discussed the influence magnitude of blockchain with a time series of whole world data from 2009 to 2018 under a generalized linear model. Controlling GDP per capita, inflation rate, foreign direct investment, taxation rate, and business freedom ranged between 0 to 100, with a long-term same direction movement among all variables. Further, the VAR Granger causality test found blockchain will influence international trade unidirectional. In the literature review topic, Derindag et al. (2020) analyzed blockchain usage in cross-border business. The potential problems would be inadequate legal environment about cryptocurrency and interoperability issues from generating of numbers blockchain protocols. Ambrozie and Sorcaru (2021) classified the published in Springer within the keyword "blockchain" and find the famous research fields in cryptocurrencies and supply chains. The author restricted literature in economics, business, and management areas with language in English.

Melkonyan et al. (2021) analyzed current issues in the Eurasian Economic Union and potential solutions in the blockchain. The trade platform gap between members, corruption in transactions from lack of transparency brought economic benefit inequality. Document flow complexity lowered good-delivering periods. Digitalization of transactions, security information

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storage with hash, and tamper-proof data were the benefits for blockchain applications. Maulana and Juliarto (2021) analyzed blockchain possibility and challenges of implementation in international trade. The complex and growing sectors generated communication problems among different stakeholders to acquire accurate information. The possible obstacles were blockchain knowledge among most people, the data quality protection that blockchain could not influence what to input, and integration with traditional systems like ERP and tracking systems.

2.3 Government Policies and Environmental Regulations

Governments' policies focused on health, agriculture, and environmental areas to protect biodiversity and sustainability. Take the EU for example (Chen, 2009), EU had already focused on a balance between economic development and environmental protection acts. EU announced the waste and litter regulations following three principles. Reducing packages, raising recycling proportion, and landfill emissions were the standards. EU focused on animal and humanity product safety with chemical concentration and carcinogen-possibility ingredients usage classified by production magnitude. The regulation drafted lists toys, cosmetics, and measurement instruments with mercury.

Several preliminary policy concepts have been proposed. For example, the United Nations declared Montreal Protocol in 1985 on limited usage of chlorofluorocarbons to protect against further damage to the ozone layer. The EU counsel revised corresponding regulations on sales, usage, and production according to ozone deleting substances defined by the Protocol. The executive committee operated imported quota certification and license verification (Chen, 2009). The emergence of the United Nations Framework Convention on Climate Change (UNFCCC) from New York in 1992 promotes other climate protection conventions. The first convention was the Kyoto Protocols signed in 2005. It controlled carbon dioxide emissions. With more than 55 members accepting the deal, it came into force. Parties had the right to withdraw from the Protocol three years after ratification (Protocol, 1997). The second one was the Paris Agreement

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declared in 2015. It focused on greenhouse gas emissions to prevent the temperature from rising over 1.5 Celsius (Agreement, 2015). The enhanced transparency framework planned to start before 2024 encouraged associated parties to report their contributions to climate change. Transparent information allowed the expert to access and review those data (UNFCCC, 2022). Lack of economic analysis on each member's incentive to join and effects on market and member countries' welfare.

3 Cross-Blockchain Trade

The existing cross-blockchain trade research focused on token swaps (Xu et al., 2021; Herlihy, 2018). Take Xu et al. (2021)'s paper as an example, the transaction initiator designed the key used to unlock the locked token. The recipient had to lock its token with the same key. Later, the initiator decided whether to unlock tokens by inserting the key. After unlocking, the key would transfer to the recipient's side. Hence, the recipient would accept the deal in the last decision stage because the initiator had taken out the locked token in the previous period, without any chance of rejection. There would be a probability of unilateral deviation of taking away all tokens and no transformation of keys for the initiator.

Hence, our model considers a token-and-product cross-blockchain exchange. We adjust the HTLC structure to let both counterparties own the key. The unlocking determination requires both parties to insert their key, so the recipient has the right to reject the transaction if the price is out of expectation. There is no requirement to transfer the key and riskless of stealing the locked token in the previous study.

This section studies a smart contract between a buyer and a seller. Buyer A is from chain A and will use token$_a$ issued by chain A to pay for the product. Seller B is from chain B and will receive the token$_a$ and deliver the product through a smart contract.

To simplify the analysis, assume that at period t, the buyer proposes to pay p units of token$_a$

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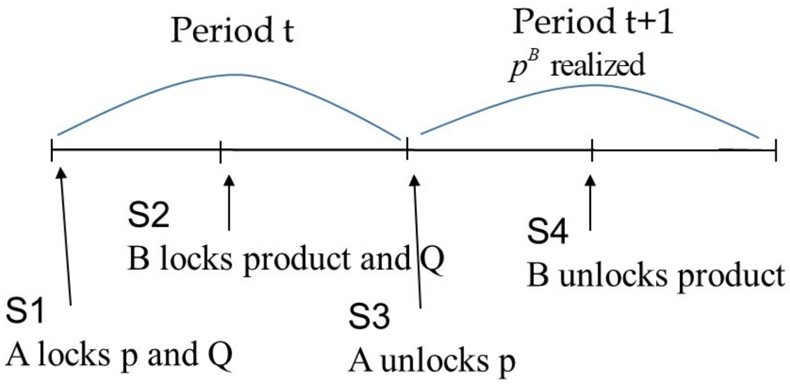

Figure 1. Sequence of actions for trade in blockchain

for one unit of product to be delivered at period $t+1$. The price of token$_a$ is numeraire and assumed to be 1. However, the value or future price of this product is uncertain at $t+1$, and we assume that the value of this product is denominated by token$_a$ and is uniformly distributed over $[a, b]$. The expected future value of product is hence: $\frac{1}{2}(b-a)$. The product value will be realized at the beginnings of $t+1$, and let p^B denote the realized product value. This implies that if the expected future product value is sufficiently higher than the agreed deal, it is still possible that the contract is terminated in the middle and the seller retains the product.

Once both parties agree on these terms of trade, the buyer will generate a key K and hash H, which is stored in an oracle. Blockchain oracles are entities that connect blockchains to external systems, thereby enabling smart contracts to execute based upon inputs and outputs from the real world. The oracle represents the smart contract which acts according to a sequence of if-else conditions. The key K is divided into two parts, K_A and K_B for buyer A and seller B, respectively. The generated keys are the only solution to unlock the hash H and to further unlock the locked p token$_a$ and to initiate delivering the locked product from chain B. The maturity of oracle represents a limited duration for the whole trade process. When it expires, it will return the locked token and product to their original owners. The trade proceeds in a four stage game within two periods as follows (see Figure 1).

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Sequence of Actions At *stage 1*, the buyer decides whether to input the key K_A to lock the p unit of token_a and a collateral Q on the oracle. The locked p units of token_a and the collateral Q are observable by the seller (through publicly shared transaction records). Upon seeing the locked token_a and the collateral, the seller takes his action at stage 2.

At *stage 2*, the buyer decides whether to input the key K_B, and lock one unit of product and the collateral Q to the oracle. The locking of the product and the collateral are observable by the buyer.

At *stage 3*, upon observing the locking of the product and the collateral by the seller, the buyer now decides whether to proceed the deal by inputting the private key K_A, or to terminate the deal by not inputting the key.

Then the oracle will automatically check whether the field of key K_A is empty or not. If it is empty, then the orcale will not continue to the next stage. If the field of key K_A is filled and correct, then the oracle will continue to the next stage.

At *stage 4*, upon observing whether the key K_A has been filled by A, the seller now decides whether to proceed the deal by inputting the private key K_B, or to terminate the deal by not inputting the key.

Then the oracle will automatically check whether the field of key K_B is empty or not. If it is empty, then the deal will be cancelled. If the field of key K_B is filled and correct, then the oracle will will transfer the unlocked p token_a to the seller and initiate the shipping of the product to the buyer.

Notice that players' decisions in the two periods are different in three aspects. (i) The expected product value is discounted at t. (ii) At $t+1$, the provision of collateral at period t can improve players' expectation for a successful deal. (iii) The product value is uncertain at period t and is realized at the beginning of $t+1$.

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3.1 Characterization of equilibrium

In what follows, let $V_{t+1}^{i}(c)$ and $V_{t+1}^{i}(s)$ denote player i's payoff at period $t+1$, if the seller's decision is to continue (c) or to stop (s) at period $t+1$. The uncertainty about the product value will be released and we denote the realized value as: p^B. Moreover, let δ be the common discount factor.

We will solve this four-stage game by backward induction. Recall that at period $t+1$, the product value is realized and we denote it as p^B. First, at *stage 4*, given that buyer A has input the key K_A, then if seller B inputs the key K_B (to continue), the payoffs are

$$V_{t+1}^{B}(c) = p + Q \quad \text{and} \quad V_{t+1}^{A}(c) = p^B + Q.$$

That is, if the seller also chooses to continue and complete the contract, then the product (valued p^B) will be delivered automatically by the oracle. The seller will receive p as scheduled. Both players will have their collateral Q back.

On the other hand, if B decides not to input the key and terminate the contract, then their payoffs are:

$$V_{t+1}^{B}(s) = p^B \quad \text{and} \quad V_{t+1}^{A}(s) = p + Q.$$

That is, since B terminates the contract unilaterally, Q will be taken by the oracle. The seller keeps the product whose value is p^B. The buyer retains his locked token p and the collateral Q. Hence, the seller's decision is to input the key at stage 4 iff

$$p^B \leq p + Q. \tag{1}$$

For further usage, define $\overline{p_c} \equiv p + Q$.

Next, at *stage 3*, given that the buyer's decision at stage 4, if A inputs the key K_A, then his payoff is $V_{t+1}^{A}(c)$.

However, if A terminates, then A and B will respectively receive:

$$p \quad \text{and} \quad p^B + Q.$$

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That is, since A terminates the contract unilaterally, Q will be taken by the oracle. The seller keeps the product whose value is p^B and the collateral Q back. Hence, the buyer's decision is to input the key at stage 3 iff

$$p \leq p^B + Q.$$

For further usage, define $\underline{p_c} \equiv p - Q$.

At *stage 2*, given that the decisions at stages 3 and 4, if B decides not to lock the product, then he retains the product whose expected value is $\frac{1}{2}(b-a)$. There is no need for the collateral.

However, if B decides to lock the product and pay the collateral, then the expected payoff is

$$\delta[(\frac{\underline{p_c} - a}{b-a})E(p^B + Q) + (\frac{b - \underline{p_c}}{b-a})(\frac{b - \overline{p_c}}{b-a}E(V^B_{t+1}(s)) + \frac{\overline{p_c} - a}{b-a}E(V^B_{t+1}(c)))] - Q.$$

That is, given A's decision at S3, if $\underline{p_c} \leq p^B$, then A will input the key to continue. Hence the probability of continuing is $\frac{b-\underline{p_c}}{b-a}$, and the probability of terminating is: $\frac{\underline{p_c}-a}{b-a}$. If the procedure stops, then B will receive $p^B + Q$. If the contract continues, then given B's decision at S4, if $p^B \leq \overline{p_c}$, then B will input the key to continue. Hence the probability of continuing is $\frac{\overline{p_c}-a}{b-a}$, and the probability of terminating is: $\frac{b-\overline{p_c}}{b-a}$. If the procedure stops, then B will receive $E(V^B_{t+1}(s))$; if the contract continues, then B receives $E(V^B_{t+1}(c))$. Recall that

$$V^B_{t+1}(s) = p^B \text{ and } V^B_{t+1}(c) = p + Q.$$

Hence, $E(V^B_{t+1}(s))$ and $E(V^B_{t+1}(c))$ are $\frac{1}{2}(b-a)$ and $p+Q$, respectively.

Hence, B will lock the product and collateral if

$$\delta[(\frac{\underline{p_c}\text{-}a}{b\text{-}a})E(p^B{+}Q){+}(\frac{b\text{-}\underline{p_c}}{b\text{-}a})(\frac{b\text{-}\overline{p_c}}{b\text{-}a}E(V^B_{t+1}(s)){+}\frac{\overline{p_c}\text{-}a}{b\text{-}a}E(V^B_{t+1}(c)))]\text{-}Q \geq \frac{1}{2}(b\text{-}a).$$

Substitute the definitions of $\underline{p_c}$ and $\overline{p_c}$ and $E(p^B + Q) = \frac{1}{2}(b-a) + Q$ to the above inequality, so we have:

$$(p\text{-}Q\text{-}a)(\frac{1}{2}(b\text{-}a) + Q) + (b{+}Q\text{-}p)(\frac{b\text{-}p\text{-}Q}{2} + \frac{p{+}Q\text{-}a}{b-a}(p{+}Q)) \geq \frac{(b\text{-}a)}{\delta}(\frac{1}{2}(b\text{-}a)Q). \tag{2}$$

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Lemma 1 *When a=0 and b=1, there exists a threshold* $p^*=\left(Q+\frac{1}{2}\right)$ *such that for all* $p \leq p^*$, *equation (2) holds.*

Proof. See the Appendix. ■

Intuitively, when p is sufficiently small, B will continue to lock the product.

Finally, at *stage 1*, given that the decisions at stages 2. 3 and 4, if A decides to lock p token$_a$ and pay the collateral, then the expected payoff is

$$\delta[(\frac{\underline{p_c}\text{-}a}{b\text{-}a})E(p)+(\frac{b\text{-}\underline{p_c}}{b\text{-}a})(\frac{b\text{-}\overline{p_c}}{b\text{-}a}E(V_{t+1}^A(s))+\frac{\overline{p_c}\text{-}a}{b\text{-}a}E(V_{t+1}^A(c)))]-Q. \tag{3}$$

That is, given A's decision at S3, if $\underline{p_c} \leq p^B$, then A will input the key to continue. Hence the probability of continuing is $\frac{b-\underline{p_c}}{b-a}$, and the probability of terminating is: $\frac{\underline{p_c}-a}{b-a}$. If the procedure stops, then A will retain p. If the contract continues, then given B's decision at S4, if $p^B \leq \overline{p_c}$, then B will input the key to continue. Hence the probability of continuing is $\frac{\overline{p_c}-a}{b-a}$, and the probability of terminating is:$\frac{b-\overline{p_c}}{b-a}$. If the procedure stops, then A will receive $E(V_{t+1}^A(s))$; if the contract continues, then A receives $E(V_{t+1}^A(c))$. Recall that

$$V_{t+1}^A(s)=p+Q \quad \text{and } V_{t+1}^A(c)=p^B+Q.$$

Hence, $E(V_{t+1}^A(s))$ and $E(V_{t+1}^A(s))$ are $p+Q$ and $\frac{1}{2}(b-a)+Q$, respectively.

Substitute the definitions of $\underline{p_c}$ and $\overline{p_c}$ and $E(p)=\frac{1}{2}(b-a)$ to equation (3), so player A's expected payoff at stage 1 becomes:

$$\delta[(\frac{p\text{-}Q\text{-}a}{b\text{-}a})p+(\frac{b\text{-}p\text{+}Q}{b-a})(\frac{b\text{-}p\text{-}Q}{b-a}(p\text{+}Q)+\frac{p\text{+}Q\text{-}a}{b-a}(\frac{1}{2}(b\text{-}a)+Q))]-Q.$$

Maximizing this expected payoff with respect to p gives the following FOC:

$$\begin{gathered}\frac{p\text{-}Q\text{-}a\text{+}p}{b-a}+(\frac{-1}{b\text{-}a})(\frac{1}{2}(b\text{-}a)+Q)\\+(\frac{b\text{-}p\text{+}Q}{b-a})(\frac{-(p\text{+}Q)+b\text{-}p\text{-}Q}{b-a}+\frac{1}{b\text{-}a}(\frac{1}{2}(b\text{-}a)+Q))=0.\end{gathered}$$

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Alternatively,

$$3p^2 - 2\,(a+Q)\,p - [2Q - \frac{1}{2}\,(b\text{-}a)]\,(b-a) + b^2 - Q^2 = 0.$$

We can solve this equation, so

$$p^A = \frac{2\,(a{+}Q)\,{+}(4\,(a{+}Q)^2\,{+}12\,\left[2Q\text{-}\frac{1}{2}\,(b\text{-}a)\right]\,(b\text{-}a)\,{+}12\,(b^2\text{-}Q^2)\,)^{1/2}}{6}.$$

For the special case $a = 0,\ b = 1$,

$$p^A = \frac{2Q + \sqrt{-8Q^2 + 24Q + 6}}{6}.$$

Proposition 2 *Buyer A's optimal price is to bid*

$$p = p^A, \quad if \;\; p^A \le p^*,$$
$$= p^*, \quad if \;\; p^A > p^*.$$

It is interesting to see how the difference $(p^* - p^A)$ will change with Q. Recall that for the special case $a = 0$, $b = 1$, $p^*{=}\left(Q + \frac{1}{2}\right)$ from Lemma 1. Hence

$$p^* - p^A = (Q + \frac{1}{2}) - \frac{2Q + \sqrt{-8Q^2 + 24Q + 6}}{6}.$$

If $Q = 0$, then $p^* > p^A$, and if $Q = 1$, then $p^* - p^A = \frac{3}{2} - \frac{2+\sqrt{22}}{6} > 0$.

Proposition 3 *For $0 \le Q \le 1$, buyer A will propose p^A and seller B will lock the product.*

Finally, the probability of completing the contract (i.e., players choose to continue for all four stages) is:

$$(\frac{b - \underline{p_c}}{b-a})(\frac{\overline{p_c} - a}{b-a}).$$

Substituting $\underline{p_c} \equiv (p - Q)$ and $\overline{p_c} \equiv (p + Q)$, we have

$$(\frac{b - (p - Q)}{b-a})(\frac{(p + Q) - a}{b-a}).$$

Taking the partial differentiation wrt Q gives: $\frac{2Q}{(b-a)^2} > 0$.

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Proposition 4 *The probability of completing the contract (i.e., players choose to continue for all four stages) is increasing with Q.*

The partial differentiation to collateral is bigger than zero, which represents that the larger collateral deposit, the more probability of accomplishing the contract. The minimum acceptable price for buyers becomes lower, and the maximum continuing price for sellers turns higher. The intuition is the expected loss of collateral when unilateral termination in any decision-making stage. It raises willingness to trade for both of the transaction counterparties.

4 International Trade and Sustainable Environment in Blockchain

We study a cross country blockchain for international trade and sustainable environment. In modelling, a blockchain is similar to a coalition,[3] while its difference from the traditional cross-country coalitions comes from the two properties of blockchains. First, it is assumed that each country's environmental sustainability level is recorded and broadcasted to all member countries. So all members' environmental sustainability levels are publicly known and cannot easily be changed. These records will be used to form the trade policy which regulates a foreign country's import to home country. Second, a blockchain is decentralized. There is no centralized authority to determine the global optimal environmental sustainability level. Under a centralized scheme, the countries with more efficient technology are obliged to reduce more solution, and this could lower the incentives of country with a larger economic scope to join the centralized convention.

To simplify the analysis, we consider a two-country (1 and 2) international trade model

[3] Na and Shin (1998) study an environmental coalition with three countries, which decide whether to join in the coalition before and after the uncertainty about their payoffs are released.

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similar to Brander and Krugman (1983), while the difference is that here domestic and foreign products are assumed differentiated rather than homogenous.

Specifically, there are a domestic firm and a representative consumer in each country. The consumer receives utility from both domestic and foreign products. Following Chonē and Linnemer (2020), we assume the following quadratic net utility function, where q_{ji} indicates the output level that firm j's product is sold in country i. So, q_{ii} and q_{ji} indicate country i's outputs for domestic and foreign products, respectively. q_{0i} is the environmental sustainability level in country i. p_{ii}, p_{ji}, and p_{0i} are the prices for country i's domestic, foreign and environmental sustainability,[4] respectively.

$$U_i = a_i \left(q_{0i}+q_{ii}+q_{ji}\right) \text{-} \sigma q_{ii}q_{ji} \text{-} \frac{b}{2}\left(q_{0i}^2+q_{ii}^2+q_{ji}^2\right) \text{-} p_{0i}q_{0i} \text{-} p_{ii}q_{ii} \text{-} p_{ji}q_{ji}. \tag{4}$$

There are four parts in this function. The first part describes the positive utility gains from consuming the environmental sustainability, domestic and foreign products. The second part (i.e., $\sigma q_{ii}q_{ji}$) indicates whether the domestic and foreign products are substitutive or complementary to consumers, with $\sigma > 0$ (< 0) indicates that they are substitutes (complements). The third part describes that the marginal utility of a product is decreasing, and this makes sure that the utility function is concave. Finally, the final part contains all the expenditures.

By maximizing this representative consumer's utility, we can derive the inverse demand function in country i. That is, from the first order condition $\frac{\partial U_i}{\partial q_{ii}} = 0$, market i's demand is given by:

$$p_i = a_i - \sigma q_{ji} - b q_{ii}.$$

For simplification, we assume a linear production cost function and the marginal cost of firm i is c_i. Moreover, we assume that the international transportation cost is assumed to be zero.

[4] Environmental prices are indices expressing the social cost of environmental emissions and other interventions. They indicate the willingness-to-pay for preventing pollution and other unwanted impacts. For example, the environmental prices in 2018 is EU28.

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Let π_{ii} and π_{ij} indicate firm i's profit at market i and j, respectively.

$$\pi_{ii} = (a_i - c_i - \sigma q_{ji} - b q_{ii}) q_{ii}, \tag{5}$$

$$\pi_{ij} = (a_j - c_i - \sigma q_{ij} - b q_{jj}) q_{ij}.$$

4.1 Before Joining Blockchain

In what follows, we will consider two scenarios before joining the blockchain: free trade and trade under environmental regulations. We will characterize the market equilibrium and the decisions of environmental sustainability level for each scenario.

The empirical analysis in De Santis (2012) showed the environmental regulation regression result from the 2SLS random effect model. The author assumed countries would choose looser environmental standards to keep competitiveness as a hypothesis. The Porter hypothesis in Ambec and Barla (2006) promoted environmental regulation could raise regulated firms in private benefits with adequate rule design. Regression results indicated a positive and significant influence on GDP when joining multilateral environmental agreements. The EU members acted positively and significantly only with those in the Kyoto agreement. However, the WTO members were influenced positively by those in UNFCCC and Kyoto agreements. That outcome favored Porter's hypothesis that regulation enhanced both countries' conditions.

4.1.1 Free Trade

Without any regulation on trade, the domestic and foreign output levels are determined in the market equilibrium. The environmental sustainability level is determined by maximizing each country's social welfare.

Market equilibrium First, each firm maximizes the total profits from two markets, where

$$\max_{q_{ii}, q_{ij}} \pi_i = \pi_{ii} + \pi_{ij}.$$

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From the FOCs $\frac{\partial \pi_i}{\partial q_{ii}} = \frac{\partial \pi_i}{\partial q_{ij}} = 0$, we have for $i \neq j = 1, 2$

$$a_i - c - \sigma q_{ji} - 2bq_{ii} = 0,$$

$$a_j - c - 2\sigma q_{ij} - bq_{jj} = 0.$$

The best replies functions are not symmetric in each market. First notice that from the two firm's best replies for market i, we have

$$\sigma q_{ji} = bq_{ii}.$$

By inserting this relation into the two FOCs for market i, we have the equilibrium output:

$$q_{ii}^* = \frac{a_i - c}{3b},$$
$$q_{ji}^* = \frac{a_i - c}{3\sigma}.$$

Hence market i's equilibrium price-cost margin is

$$\begin{aligned} p_i^* - c_i &= (a_i - c_i - \sigma q_{ji}^* - 2bq_{ii}^*) + bq_{ii}^* \\ &= bq_{ii}^*. \end{aligned}$$

where we use the FOC earlier. Similarly,

$$p_j^* - c_j = bq_{jj}^*.$$

Moreover, the equilibrium profits are

$$\pi_{ii}^* = b(q_{ii}^*)^2 = \frac{1}{9b}\left(a_i - c\right)^2,$$

and

$$\pi_{ij}^* = bq_{jj}^*(q_{ij}^*) = \frac{1}{9\sigma}\left(a_j - c\right)^2.$$

It is easy to see that the equilibrium outputs decrease with σ. As the degree of substitution increases, there is less differentiation between products and hence firm i has less monopoly power. The equilibrium profits are smaller.

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Environmental sustainability level First, given the market equilibrium above, we can rewritten the representative consumer's utility as:

$$
\begin{aligned}
V_i^*(q_{0i}) &= a_i q_{0i} - \frac{b}{2}q_{0i}^2 - p_{0i}q_{0i} + \frac{b}{2}\left(q_{ii}^2 + q_{ji}^2\right) + \sigma q_{ii}q_{ji} \\
&= a_i q_{0i} - \frac{b}{2}q_{0i}^2 - p_{0i}q_{0i} + \left(\frac{3}{18b} + \frac{b}{18\sigma^2}\right)(a_i - c)^2 .
\end{aligned}
$$

To abuse the notation, we assume that country i's cost for environmental sustainability is also linear: $k_i q_{0i}$ and $k_i > c_i$. This cost can be interpreted as the cost to conduct additional certification about product quality. Hence, country i's social welfare is given by

$$V_i^*(q_{0i}) + \pi_{ii}^* + \pi_{ij}^* - k_i q_{0i}.$$

The FOC of maximizing social welfare (SW) is:

$$a_i - bq_{0i} - p_{0i} - k_i = 0.$$

Thus, country i's environmental sustainability level is:

$$q_{0i}^* = \frac{1}{b}(a_i - k_i - p_{0i}).$$

Since a_i also represents market i's scale, this equation describes that the environmental sustainability level will increase with market scale and increase with the efficiency of enhancing environmental sustainability (less k_i)

Country i's optimal SW is hence

$$
\begin{aligned}
&\frac{b}{2}(q_{0i}^*)^2 + \frac{b}{2}\left(q_{ii}^2 + q_{ji}^2\right) + \sigma q_{ii}q_{ji} + \left(\pi_{ii}^* + \pi_{ij}^*\right) \\
&= \frac{b}{2}(q_{0i}^*)^2 + \left(\frac{5}{18b} + \frac{b}{18\sigma^2}\right)(a_i - c)^2 + \frac{1}{9\sigma^2}(a_j - c)^2 .
\end{aligned}
$$

4.1.2 Unilateral Firmamental Trade Regulations

Without knowing the other countries' choices for environmental sustainability level, most nations adopted customs examination on imported products. For instance, the EU reached an agreement

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for the European Green Deal in 2020 (Faichuk et al., 2022), which promoted regulations of the criteria of agricultural foods regarding chemical pesticides, fertilizer usage, organic farming... and so on. Moreover, the EU posed restrictions on the used battery, waste disposals, scrap cars, and the concentration of potentially harmful ingredients in cosmetics and toys (Chen, 2009).

The largest developed countries like the EU, Japan, the US, and Canada, employed an eco-certification for tropical timber import from central Africa. It required a specific source of origin and authorization to be available to import (Cole et al., 2021). In the United States, seafood import and aquaculture export products required certification in 2017 for complying with the U.S. Marine Mammal Protection Act. That illegal or unreported non-compliant would have no right to import and reexport to the territory of the US (Williams et al., 2016).

Market equilibrium To simplify, we consider that country j sets a predetermined environment standard, and adopt a random border inspection. Let r be the probability that product i fails to satisfy the standard set by country j and hence cannot export to country j (i.e., $q_{ij} = 0$). There is a chance $1 - r$ that product i can satisfy this requirement, and in this case, the level of export is determined in the market. Notice that, since q_{0i} is not observable by the other country, the probability of failure will not depend on the choice of q_{0i}.

Let the superscript R indicate the restricted trade, where firm i's profit becomes π_i^R, where

$$\pi_i^R = \pi_{ii} + (1 - r)\pi_{ij}.$$

Here with a chance r, product i cannot be exported to country j and thus the profit is zero.

On the other hand, for country j, there is a chance r that market j is a monopolist and $(1 - r)$ that market j is a duopolist. Therefore,

$$\pi_j^R = r(a_j - c_j - bq_{jj})q_{jj} + (1 - r)\pi_{jj} + \pi_{ji},$$

where π_{jj} and π_{ji} are firm j's duopoly profits.

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Given π_i^R and π_j^R defined as above, the equilibrium outputs are determined by

$$\max_{q_{ii},q_{ij}} \pi_i^R \quad \text{and} \quad \max_{q_{jj},q_{ji}} \pi_j^R.$$

Notice that since π_i^R and π_j^R are not symmetric, the equilibrium outputs will not be symmetric.

For firm i, the FOCs are $\frac{\partial \pi_i^R}{\partial q_{ii}} = \frac{\partial \pi_i^R}{\partial q_{ij}} = 0$, which imply

$$a_i - c - \sigma q_{ji} - 2bq_{ii} = 0, \tag{1}$$

$$a_j - c - 2\sigma q_{ij} - bq_{jj} = 0, \tag{2}$$

where we assume the two firms have identical technology: $c_i = c_j = c$. Notice that for firm i, these FOCs are the same as the free trade case.

For firm j, notice first that

$$r(a_j - c_j - bq_{jj})q_{jj} + (1-r)\pi_{jj}$$
$$= \pi_{jj} + r\sigma q_{ij}q_{jj}.$$

So

$$\pi_j^R = \pi_{jj} + r\sigma q_{ij}q_{jj} + \pi_{ji}.$$

The FOCs are $\frac{\partial \pi_j^R}{\partial q_{jj}} = \frac{\partial \pi_j^R}{\partial q_{ji}} = 0$, which imply

$$a_j - c - \sigma(1-r)q_{ij} - 2bq_{jj} = 0, \tag{3}$$

$$a_i - c - 2\sigma q_{ji} - bq_{ii} = 0. \tag{4}$$

The equilibrium in market i is determined by equations (1) and (4). We have the same output as the free trade case.

$$q_{ii}^R = q_{ii}^* = \frac{a_i - c}{3b},$$
$$q_{ji}^R = q_{ji}^* = \frac{a_i - c}{3\sigma}.$$

However, the equilibrium in market j is determined by equations (2) and (3):

$$a_j - c - \sigma(1-r)q_{ij} - 2bq_{jj} = a_j - c - 2\sigma q_{ij} - bq_{jj},$$

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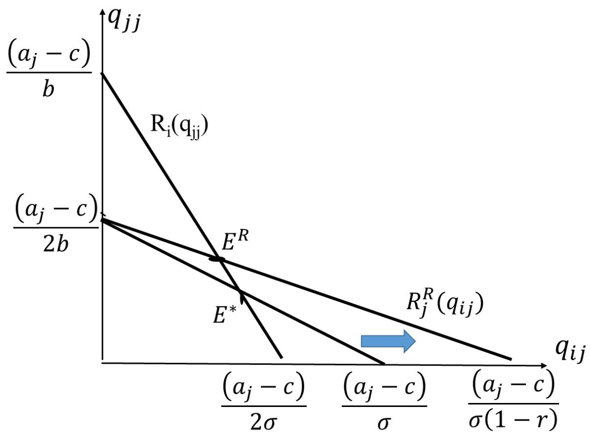

Figure 2. The best replies for regulated trade.

which gives

$$2\sigma q_{ij} + bq_{jj} = \sigma(1 - r)q_{ij} + 2bq_{jj},$$

or alternatively

$$q_{jj} = \frac{\sigma\,(1 + r)}{b} q_{ij}.$$

Replace q_{jj} by this definition into equation (2), then we have q_{ij}^R and q_{jj}^R:

$$q_{ij}^R = \frac{a_j - c}{\sigma\,(3 + r)},$$

$$q_{jj}^R = \frac{(1 + r)\,(a_j - c)}{b\,(3 + r)}.$$

Figure 1 shows how the environmental regulation changes the equilibrium in market j. Firm j's best reply function has shifted out to $R_j^R(q_{ij})$, and changes the equilibrium from E^* to E^R. Firm j's domestic output q_{jj}^R is higher than that in free trade, while q_{ij}^R is smaller than q_{ij}^*. In particular, the difference $q_{jj}^R - q_{jj}^*$ is $\frac{2r(a_j - c)}{3b(3+r)}$. This difference is increasing in r as the first order differentiation is $\frac{2(a_j - c)}{b(3+r)^2} > 0$.

Next, the equilibrium price-cost margin for market i is:

$$\begin{aligned} p_i^R - c &= (a_i - c - \sigma q_{ji}^R - 2bq_{ii}^R) + bq_{ii}^R \\ &= bq_{ii}^R. \end{aligned}$$

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and price-cost margin for market j:

$$
\begin{aligned}
p_j^R - c &= (a_j - c - \sigma q_{ij}^R - b q_{jj}^R) \\
&= \{a_j - c - \sigma(1-r) q_{ij}^R - 2b q_{jj}^R\} + b q_{jj}^R - \sigma r q_{ij}^R \\
&= b q_{jj}^R - \sigma r q_{ij}^R,
\end{aligned}
$$

where $a_j - c - \sigma(1-r)q_{ij}^R - 2bq_{jj}^R = 0$ from the FOC of firm j.

Moreover, the equilibrium profits are

$$
\begin{aligned}
\pi_i^R &= \pi_{ii}^R + (1-r)\pi_{ij}^R \\
&= \frac{(a_i - c)^2}{9b} + \frac{(1-r)(a_j - c)^2}{\sigma (3+r)^2},
\end{aligned}
$$

and

$$
\begin{aligned}
\pi_j^R &= \pi_{jj}^R + r\sigma q_{ij}^R q_{jj}^R + \pi_{ji}^R \\
&= \frac{(a_i - c)^2}{9\sigma} + \frac{(1+r)^2}{b(3+r)^2}(a_j - c)^2 .
\end{aligned}
$$

Environmental sustainability level The equilibrium sustainability level is determined by maximizing SW: for $i = 1, 2$

$$
V_i^R(q_{0i}) + \pi_i^R - k_i q_{0i}.
$$

First, for market i, since the equilibrium outputs are the same as free trade, $V_i^R(q_{0i})$ is the same as free trade.

$$
\begin{aligned}
V_i^R(q_{0i}) = V_i^*(q_{0i}) &= a_i q_{0i} - \frac{b}{2} q_{0i}^2 - p_{0i} q_{0i} + \frac{b}{2}\left(q_{ii}^2 + q_{ji}^2\right) + \sigma q_{ii} q_{ji} \\
&= a_i q_{0i} - \frac{b}{2} q_{0i}^2 - p_{0i} q_{0i} + \left(\frac{3}{18b} + \frac{b}{18\sigma^2}\right)(a_i - c)^2 .
\end{aligned}
$$

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However, for market j, there is a chance r that product i will not be imported and hence consumer surplus is lower due to lacking product variety. Hence

$$V_j^R(q_{0j}) = \left(a_j q_{0j} - \frac{b}{2}q_{0j}^2 - p_{0j}q_{0j}\right) + \frac{b}{2}q_{jj}^2 + \sigma q_{jj}q_{ij} + \frac{b}{2}q_{ij}^2$$
$$= \left(a_j q_{0j} - \frac{b}{2}q_{0j}^2 - p_{0j}q_{0j}\right) + \frac{(a_j - c)^2}{(3+r)^2}\left[\frac{(1+r)(3+r)}{2b} + \frac{b}{2\sigma^2}\right].$$

Despite the difference between $V_i^R(q_{0i})$ and $V_j^R(q_{0j})$, the terms related to q_0 are the same for both markets. Hence, the FOCs are the same: for $i = 1, 2$,

$$a_i - bq_{0i} - p_{0i} - k_i = 0,$$

which is the same as free trade.

Thus, the equilibrium sustainability levels are the same as free trade. That is, for $i = 1, 2$,

$$q_{0i}^R = q_{0i}^* = \frac{1}{b}(a_i - p_{0i} - k_i).$$

Finally, the optimal SW for country i is

$$\frac{b}{2}(q_{0i}^R)^2 + \left(\frac{5}{18b} + \frac{b}{18\sigma^2}\right)(a_i - c)^2 + \frac{(1-r)}{\sigma(3+r)^2}(a_j - c)^2,$$

and for country j:

$$\frac{b}{2}(q_{0j}^R)^2 + \frac{(a_j\text{-}c)^2}{(3+r)^2}\left[\frac{(1+r)(5+3r)}{2b} + \frac{b}{2\sigma^2}\right] + \frac{b(a_i\text{-}c)^2}{9\sigma^2}.$$

It can be easily checked that country i's SW is decreasing in r, while country j's SW is increasing in r.

Proposition 5 *Higher environmental trade regulations (i) can increase a country's social welfare and profit, while decreasing the other country's welfare and profit, (ii) have no effect on the equilibrium sustainability levels.*

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Since a country's environmental sustainability level is not observable by other countries, the environmental trade regulation cannot depend on q_{0i}. Although the exporting firm's profit is affected by this regulation, this change does not vary with q_{0i} and hence has no effect on exporting country's environmental sustainability level.

On the other hand, higher environmental trade regulations will increase the imported country's social welfare and profit. This suggests that without forming the blockchain, the importing country has a positive incentive to impose environmental trade regulations, despite that these regulations do not change the exporting country's choices of environmental sustainability level.

4.1.3 Bilateral Firmamental Trade Regulations

We now consider bilateral trade regulations, where both countries adopt a random border inspection. Let r be the probability that product i fails to satisfy the standard set by country j and hence cannot export to country j (i.e., $q_{ij} = 0$) for $i \neq j$. Again, since q_{0i} is not observable by the other country, the probability of failure will not depend on the choice of q_{0i}.

Market equilibrium In addition to π_j^R, profit i is also regulated where

$$\pi_i^R = \pi_{ii} + r\sigma q_{ji} q_{ii} + \pi_{ij}.$$

Hence for firm i, the FOCs are

$$a_i - c - \sigma(1-r)q_{ji} - 2bq_{ii} = 0, \tag{5}$$

$$a_j - c - 2\sigma q_{ij} - bq_{jj} = 0, \tag{2}$$

and for firm j, the FOCs are the same as equations (3) and (4) in the unilateral regulation case. In addition to the equilibrium in market j (q_{ij}^R and q_{jj}^R) described above, the equilibrium in market i is determined by equations (5) and (4):

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$$q_{ji}^{R} = \frac{a_i - c}{\sigma\left(3 + r\right)},$$
$$q_{ii}^{R} = \frac{\left(1 + r\right)\left(a_i - c\right)}{b\left(3 + r\right)}.$$

Environmental sustainability level For both countries, there is a chance r that the product from the other country will not be imported and hence consumer surplus is lower due to lacking product variety. Hence for $i \neq j = 1, 2$, the consumer surplus is

$$\begin{aligned} V_i^R\left(q_{0i}\right) &= \left(a_i q_{0i} - \frac{b}{2} q_{0i}^2 - p_{0i} q_{0i}\right) + \frac{b}{2} q_{ii}^2 + \sigma q_{ii} q_{ii} + \frac{b}{2} q_{ji}^2 \\ &= \left(a_j q_{0j} - \frac{b}{2} q_{0j}^2 - p_{0j} q_{0j}\right) + \frac{\left(a_j - c\right)^2}{\left(3 + r\right)^2}\left[\frac{\left(1 + r\right)\left(3 + r\right)}{2b} + \frac{b}{2\sigma^2}\right]. \end{aligned}$$

The equilibrium sustainability level is determined by maximizing SW: for $i = 1, 2$

$$V_i^R\left(q_{0i}\right) + \pi_i^R - k_i q_{0i}.$$

Hence

$$q_{0i}^{*} = \frac{1}{b}\left(a_i - p_{0i} - k_i\right).$$

The equilibrium sustainability levels are the same as free trade.

Furthermore, firm i's equilibrium profit is for $i \neq j = 1, 2$,

$$\begin{aligned} \pi_i^R &= \pi_{ii}^R + r\sigma q_{ij}^R q_{ii}^R + \pi_{ij}^R \\ &= \frac{\left(1 + r\right)^2\left(a_i - c\right)^2}{b\left(3 + r\right)^2} + \frac{\left(a_j - c\right)^2}{\sigma\left(3 + r\right)^2}. \end{aligned}$$

The equilibrium SW is: for $i = 1, 2$

$$\frac{b}{2}(q_{0i}^{*})^2 + \frac{\left(a_i - c\right)^2}{\left(3 + r\right)^2}\left(\frac{(1+r)\,(3+r)}{2b} + \frac{b}{2\sigma^2}\right) + \frac{(1+r)^2\,(a_i\text{-}c)^2}{b\left(3 + r\right)^2} + \frac{\left(a_j - c\right)^2}{\sigma\left(3 + r\right)^2}.$$

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Bilateral environmental regulations will change both firms' outputs and profits. Consumer surplus will also be changed. However, since a country's environmental sustainability level is not observable by other countries, the environmental trade regulation cannot depend on q_{0i}. Although the exporting firm's profit is affected by this regulation, this change does not vary with q_{0i} and hence has no effect on exporting country's environmental sustainability level.

5 Joining the Blockchain

We assume that if both firms form a blockchain, then each country's environmental sustainability level is recorded and broadcasted to all member countries. So all members' environmental sustainability levels are publicly known and cannot easily be changed. These records can be used to form the trade policy which regulates a foreign country's import to home country. Since a blockchain is decentralized, there is no centralized authority to determine the global optimal environmental sustainability level. However, in Section 5.3, we will compare the equilibrium to the centralized case to find out the difference between the two regimes.

Since each member's environmental sustainability levels are publicly known, we consider two possible schemes that these records can be used to regulate international trade. These schemes are decentralized, and we will later show that each country's environmental sustainability level could resemble the one in centralized scheme. Specifically, the first scheme assumes that a country's export to the other country is positively related to this country's environmental sustainability level. That is,

$$\begin{aligned} q_{ji} &= \rho_j q_{0j} \quad \text{if } \rho_j q_{0j} < q^*_{ji}, \\ &= q^*_{ji} \qquad \text{if } \rho_j q_{0j} \geq q^*_{ji}. \end{aligned}$$

where ρ_i could be a summary of country i's environmental history, and q^*_{ji} is the equilibrium export from country j to country i.

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The second scheme assumes that a country's profit in the other country is positively related to this country's environmental sustainability level. That is, firm j's profit in market i is:

$$\phi_j q_{0j} * \pi_{ji},$$

where π_{ji} is firm j's profit in market i under free trade. ϕ_j could be a summary of country j's environmental history. We will address the impact of each scheme below.

5.1 Proportional Output

In what follows, we use the superscript "1" to indicate the first scheme with proportional output. First, given that $q^1_{ji} = \rho_j q_{0j}$, then in market i, from firm i's best reply function:

$$q^1_{ii} = \frac{1}{2b}\left(a_i - c - \sigma\rho_j q_{0j}\right),$$

and hence the price in market i is:

$$p^1_i = \frac{1}{2}\left(a_i + c - \sigma\rho_j q_{0j}\right).$$

Hence firm i and j's profits in market i are:

$$\pi^1_{ii} = \frac{1}{2}\left(a_i - c - \sigma\rho_j q_{0j}\right) q_{ii},$$
$$\pi^1_{ij} = \frac{1}{2}\left(a_j - c - \sigma\rho_i q_{0i}\right) \rho_i q_{0i}.$$

Therefore, firm i's total profit and consumer surplus in market i are:

$$\pi^1_i = \frac{1}{4b}\left(a_i - c - \sigma\rho_j q_{0j}\right)^2 + \frac{1}{2}\left(a_j - c - \sigma\rho_i q_{0i}\right)\rho_i q_{0i},$$

$$V^1_i = \left(a_i - p_{0i}\right) q_{0i} - \frac{b}{2} q^2_{0i} + \frac{1}{8b}\left[(a_i\text{-}c)^2 + (a_i\text{-}c)\,(2b\text{-}2)\,\sigma\rho_j q_{0j} + \left((2b\text{-}1)\,\sigma^2 + 4b^2\right)\left(\rho_j q_{0j}\right)^2\right].$$

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Environmental sustainability level The optimal sustainability level is determined by maximizing country i's SW:

$$\max_{q_{0i}} V_i^1 + \pi_i^1 - s_i q_{0i},$$

where s_i is country i's marginal cost for maintaining the sustainability levels and recording them on blockchain. s_i is higher than k_i. The F.O.C shows

$$a_i - bq_{0i} - p_{0i} - s_i + \frac{\rho_i}{2}(a_j - c - 2\sigma\rho_i q_{0i}) = 0,$$

which implies

$$q_{0i}^1 = \frac{1}{(b + \sigma\rho_i^2)}\left[a_i - p_{0i} - s_i + \frac{\rho_i}{2}(a_j - c)\right].$$

Therefore, the SW under proportional output scheme is

$$\begin{aligned} & V_i^1\left(q_{0i}^1\right) + \pi_i^1\left(q_{0i}^1\right) - s_i q_{0i}^1 \\ &= \frac{1}{8b}(a_i - c - \sigma\rho_j q_{0j})(3a_i - 3c + (2b-3)\sigma\rho_j q_{0j}) + \frac{b}{2}(\rho_j q_{0j})^2 + \frac{\sigma}{2}(\rho_i q_{0i})^2 + \frac{b}{2}q_{0i}^2. \end{aligned}$$

Proposition 6 *The environmental sustainability level under the proportional output scheme in blockchain is higher than those under free trade and trade regulations.*

Proof. The FOC for sustainability level under free trade and trade regulations is: $a_i - bq_{0i} - p_{0i} - s_i = 0$. Compared to the FOC under scheme 1, the LHS for the FOC under scheme 1 is greater (by $\frac{\rho_i}{2}(a_j - c - 2\sigma\rho_i q_{0i})$). If the marginal cost s_i is not too high, the LHS of the above equation is higher than that of free trade case. Since profit function needs to be concave, the level of q_{0i}^1 is higher than q_{0i}^*. ■

As for the welfare comparison among trade on blockchain, free trade and regulated trade, we can only make remarks for specific cases. First, if q_{0j} is sufficiently high such that $\rho_j q_{0j} \geq q_{ji}^*$ (the equilibrium under free trade), then since q_{ji}^1 is bounded above by q_{ji}^*, firms' equilibrium profits are the same as free trade. However, as described by Proposition 6, the environmental

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sustainability level under blockchain is higher, so we can conclude that the social welfare is higher under blockchain.

Next, when comparing free trade and regulated trade, Proposition 6 describes that higher environmental trade regulations can increase a country's social welfare and profit, while decreasing the other country's welfare and profit, but have no effect on the equilibrium sustainability levels. This suggests that if q_{0j} is sufficiently high such that $\rho_j q_{0j} \geq q^*_{ji}$ (then q^1_{ji} is bounded above by q^*_{ji}), then under blockchain, the country that imposes the regulation will have a smaller profit, while the regulated country will have a higher profit compared to the regulated trade. However, since for both countries, the social welfare is higher due to higher environmental sustainability level, there is no conclusive results for the overall welfare.

5.2 Proportional Profit

The second scheme assumes that a country's profit in the other country is positively related to this country's environmental sustainability level. That is, firm j's profit in market i is:

$$\phi_j q_{0j} * \pi_{ji},$$

where π_{ji} is firm j's profit in market i under free trade. ϕ_j could be a summary of country j's environmental history.

In what follows, we use the superscript "2" to indicate the second scheme with proportional profit. First, each firm maximizes the total profits from two markets, where

$$\max_{q_{ii},q_{ij}} \pi_i^2 = \pi_{ii} + \phi_i q_{0i} \pi_{ij}. \tag{3}$$

Since the FOCs will be the same as those in free trade, we have for $i \neq j = 1, 2$

$$q^2_{ii} = q^*_{ii} \quad \text{and} \quad q^2_{ij} = q^*_{ij}.$$

Therefore firm i's equilibrium profit is:

$$\pi_i^{*2} = \pi^*_{ii} + \phi_i q_{0i} \pi^*_{ij}.$$

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Environmental sustainability level Given that the outputs are the same as free trade, the representative consumer's utility is the same as free trade (except for q_{0i}).

$$V_i^2(q_{0i}) = V_i^*(q_{0i}) = a_i q_{0i} - \frac{b}{2}q_{0i}^2 - p_{0i}q_{0i} + \frac{b}{2}\left(q_{ii}^{*2} + q_{ji}^{*2}\right) + \sigma q_{ii}^* q_{ji}^*$$
$$= a_i q_{0i} - \frac{b}{2}q_{0i}^2 - p_{0i}q_{0i} + \left(\frac{3}{18b} + \frac{b}{18\sigma^2}\right)(a_i - c)^2 .$$

Hence, country i's social welfare is given by

$$V_i^2(q_{0i}) + \pi_{ii}^* + \phi_i q_{0i}\pi_{ij}^* - s_i q_{0i}. \tag{2}$$

The FOC of maximizing social welfare (SW) is:

$$a_i - bq_{0i} - p_{0i} + \phi_i \pi_{ij}^* - s_i = 0.$$

Thus, country i's environmental sustainability level is:

$$q_{0i}^2 = \frac{1}{b}(a_i - p_{0i} - s_i + \phi_i \pi_{ij}^*).$$

Proposition 7 *(1) The environmental sustainability level under the proportional profit scheme in blockchain is higher than those under free trade and trade regulations. (2) The sufficient condition for* $q_{0i}^2 > q_{0i}^1$ *is* $\frac{\rho_i}{\phi_i} < \frac{2}{9\sigma}(a_j - c)$.

Proof. (1) From the definitions of q_{0i}^2 and q_{0i}^*, we know that there is additional term $\phi_i \pi_{ij}^*$ in q_{0i}^2. Hence the environmental sustainability level under the proportional profit scheme in blockchain is higher than those under free trade and trade regulations. (2) Recall that

$$q_{0i}^1 = \frac{1}{(b + \sigma\rho_i^2)}\left[a_i - p_{0i} - s_i + \frac{\rho_i}{2}(a_j - c)\right].$$

Comparing q_{0i}^2 with q_{0i}^1, we can see that the denominator of q_{0i}^1 is greater than the denominator of q_{0i}^2. Thus the sufficient condition for $q_{0i}^2 > q_{0i}^1$ is

$$\phi_i \pi_{ij}^* \geq \frac{\rho_i}{2}(a_j - c).$$

By using the definition $\pi_{ij}^* = \frac{1}{9\sigma}(a_j - c)^2$, this condition turns to $\frac{\phi_i}{9\sigma}(a_j - c)^2 > \frac{\rho_i}{2}(a_j - c)$, or alternatively, $\frac{\rho_i}{\phi_i} < \frac{2}{9\sigma}(a_j - c)$. ■

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Corollary 8 *If $\phi_i = \rho_i$, then the sufficient condition for $q_{0i}^2 > q_{0i}^1$ is $\sigma < \frac{2}{9}(a_j - c)$.*

5.3 Comparison to the Centralized Coalition

Finally, we compare the environmental sustainability level under the two schemes under blockchain with the level under a *centralized* coalition. First, the environmental sustainability levels are determined by an authority to maximizes the joint welfare of the coalition: $TW(q_{0i}, q_{0j})$, where

$$TW(q_{0i}, q_{0j}) = V_i(q_{0i}) + V_j(q_{0j}) + \tau V_i(q_{0i}) V_j(q_{0j}) + \Pi_i(q_{0i}) + \Pi_j(q_{0j}) - k_i(q_{0i}) - k_j(q_{0j}).$$

The coalition's joint welfare is the sum of two countries welfare plus a term to capture the positive cross-country externality $\tau V_i(q_{0i}) V_j(q_{0j})$, with $\tau > 0$. This can also be interpreted as the social norm effect or the consumers' consciousness,

Second, the FOC is $\frac{\partial TW}{\partial q_{0i}} = 0$, which gives:

$$q_{0i}^C = \frac{1}{b}(a_i - p_{0i}) - \frac{k_i}{b(1 + \tau V_j(q_{0j}))},$$

or alternatively,

$$q_{0i}^C = \frac{1}{b}[a_i - p_{0i} - k_i + \frac{k_i}{\left(1 + \frac{1}{\tau V_j(q_{0j})}\right)}].$$

The superscript "c" indicates the centralized coalition.

Compare q_{0i}^C with q_{0i}^2, where

$$q_{0i}^2 = \frac{1}{b}(a_i - p_{0i} - s_i + \phi_i \pi_{ij}^*).$$

We have the following results.

Proposition 9 *(1) The environmental sustainability level under the centralized coalition is higher than those under free trade and trade regulations. (2) The sufficient condition for $q_{0i}^2 > q_{0i}^C$ is $(a_j - c)^2 > \frac{9\sigma k_i}{\phi_i}$.*

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Proof. (1) From the definitions of q_{0i}^C and q_{0i}^*, we know that there is additional term $\frac{k_i}{(1+\frac{1}{\tau V_j\left(q_{0j}\right)})}$, so $q_{0i}^C > q_{0i}^*$. (2) If $k_i = s_i$, then $q_{0i}^2 - q_{0i}^C = \frac{1}{b}[\phi_i \pi_{ij}^* - \frac{k_i}{(1+\frac{1}{\tau V_j\left(q_{0j}\right)})}]$. Thus the sufficient condition for $q_{0i}^2 > q_{0i}^c$ is $(a_j - c)^2 > \frac{9\sigma k_i}{\phi_i}$. ■

In other words, when the size of foreign market (a_j) is sufficiently big, then the environmental sustainability level under proportional profit scheme under blockchain is higher than that of the centralized coalition. Intuitively, when the market size of foreign market becomes larger, the profit from foreign market is higher, so $\phi_i \pi_{ij}^*$ is higher. On the other hand, $\frac{k_i}{(1+\frac{1}{\tau V_j\left(q_{0j}\right)})}$ is not related to a_j. So, if the size of foreign market is sufficiently large, the proportional profit scheme under blockchain can induce higher environmental sustainability level.

Table1. Summary of market equilibria and environmental sustainability levels.

Equilibrium for $i \neq j = 1, 2$	q_{ii}^*	q_{ji}^*	q_{0i}^*
Free Trade	$\frac{a_i - c}{3b}$	$\frac{a_i - c}{3\sigma}$	$\frac{a_i - p_{0i} - k_i}{b}$
Bilateral Regulation	$\frac{(1+r)(a_i - c)}{b(3+r)}$	$\frac{a_i - c}{\sigma(3+r)}$	$\frac{a_i - p_{0i} - k_i}{b}$
Proportional Output	$\frac{a_i - c - \sigma\rho_j q_{0j}}{2b}$	$\rho_j q_{0j}$	$\frac{a_i - p_{0i} - s_i + \frac{\rho_i}{2}(a_j - c)}{b + \sigma\rho_i^2}$
Proportional Profit	$\frac{a_i - c}{3b}$	$\frac{a_i - c}{3\sigma}$	$\frac{a_i - p_{0i} - s_i + \phi_i \pi_{ij}^*}{b}$
Centralized Coalition			$\frac{a_i - p_{0i} - \frac{k_i}{1+\tau V_j(q_{0j})}}{b}$
Unilateral Regulation	q_{ii}^*, q_{jj}^* $\frac{a_i - c}{3b}, \frac{(1+r)(a_j - c)}{b(3+r)}$	q_{ji}^*, q_{ij}^* $\frac{a_i - c}{3\sigma}, \frac{a_j - c}{\sigma(3+r)}$	$\frac{a_i - p_{0i} - k_i}{b}$

Table1 provides the summary of equilibrium quantity among different situations. Except for unilateral regulation, all other frames derive symmetric equilibrium between the foreign and the home market. So, we use $i \neq j = 1, 2$ at the position of the first column and the first row to indicate it. The equilibrium sustainability level in a centralized coalition could derive from joint profit maximization, so we leave the optimal equilibrium quantity blank in the table. Again, we see a bigger optimal sustainability level in the blockchain scheme compared to free trade and regulation situations.

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6 Concluding Remarks

The blockchain technology has several important features including distributed, Immutable and decentralized. With the usage of blockchain-applied methodology to improve international trade efficiency, countries will be willing to form a decentralized or grand coalition based on their incentives. Several preliminary policy concepts have been proposed. We attempt to contribute to this line of literature by proposing a global environmental scheme that the blockchain technology can be used to record member countries' environmental sustainability levels. These records will be broadcasted to all members of the blockchain and will be used to determine the level of exports to other countries. We analyze each country's incentive to join this scheme and show that the levels of environmental sustainability are higher than those obtained by considering welfare externalities across countries.

Our results show that (i) environmental trade regulations have no effect on optimal sustainability choices, but will increase home country's profit and welfare while decrease other country's welfare. (ii) Both proportional output and profit schemes applied to blockchain derive a higher sustainability level compared to free trade and regulation trade. (iii) The larger market scope of the foreign market is the sufficient condition for the sustainability level of proportional profit to be bigger than that of proportional output. (iv) The centralized decision at the sustainability level will be smaller than that decentralized blockchain outcome, and the potential expression will be a social norm effect in a grand coalition.

Harford (1987) concluded little sensitivity between real pollution reported by firms and under-reporting regulation parameters, considering a linear relationship assumption between standard infringement and excess pollution. Our findings suggest similar results with no significant effect on the influence of optimal sustainability by regulation. Both of the schemes other than free and regulation trade reach higher environmental sustainability.

The optimal sustainability level would decrease under network effect consideration. The

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social sanctions in norms provided intrinsic environmental effects to trigger members to comply with reciprocal cooperation (Lai et al., 2003). People followed social norms under internalized ethical principles influenced by the whole society (Nyborg, 2018). Hence, considering the social norms through a network route would raise the marginal benefit of one more unit of sustainability level.

Finally, our analysis of product trading finds that collateral enhances the probability of trading. With the different ownership of the key to unlock the hash function, sellers will decide whether to continue or stop in the last stage. In Xu et al. (2021), collateral could improve the transaction success rate and prevent adverse behavior in token swapping. Han et al. (2019) viewed the exchange process as an American option in that the issuer had the right not to give the key to its counterparty. Collateral was a mechanism to trigger both parties into a fairer position.

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Appendix

Proof of Lemma 2

After manipulation, equation (2) can be rewritten as:

$$p^3\text{-}\left(b\text{-}Q+a+\frac{1}{2}(b\text{-}a)\right)p^2+\left(\frac{1}{2}(b+a)^2\text{-}Q(b\text{-}a)\text{-}2bQ+ab\text{-}Q^2\right)p$$
$$+(\frac{(b\text{-}a)^2}{\delta}+(Q+a)(b\text{-}a))\left(\frac{1}{2}(b\text{-}a)+Q\right)-(b+Q)(\frac{(b\text{-}Q)(b\text{-}a)}{2}+Q(Q\text{-}a))\leq 0.$$

Assuming a=0, b=1 and $\delta = 1$, then this inequality can be simplified to

$$p^3+(\frac{-3}{2}+Q)p^2+[-Q^2-3Q+\frac{1}{2}]p+Q(Q+1)(Q+\frac{1}{2})\leq 0. \tag{A1}$$

Suppose we can decompose this polynomial as

$$\left[p^2+xp-Q(Q+1)\right](p\text{-}(Q+\frac{1}{2}))\leq 0. \tag{A2}$$

Spelling out this equation gives

$$p^3\text{-}(Q+\frac{1}{2})p^2+xp^2\text{-}x(Q+\frac{1}{2})p\text{-}\left(Q^2+Q\right)p+Q(Q+1)(Q+\frac{1}{2})\leq 0. \tag{A3}$$

Equation (A3) needs to be the same as equation (A1). In particular, the parameters of p^2 and p need to be the same, i.e.,

$$x-Q-\frac{1}{2}=\frac{-3}{2}+Q,$$
$$xQ+\frac{x}{2}+Q^2+Q=-Q^2-3Q+\frac{1}{2}.$$

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Alternatively,

$$x = (2Q - 1),$$

$$4Q^2 + 4Q - 1 = 0.$$

In other words, with these two conditions satisfied, equation (A2) becomes

$$\left[p^2 + (2Q\text{-}1)\, p\text{-}Q\,(Q{+}1)\right](p\text{-}(Q{+}\frac{1}{2})) \leq 0. \tag{A2}$$

That is, for $p \leq Q{+}\frac{1}{2}$, equation (A2) is satisfied. Moreover, if we solve the polynomial $4Q^2 + 4Q - 1 = 0$, we have $Q = \frac{-1+\sqrt{2}}{2}$ and hence $p^* {=} Q + \frac{1}{2} = \frac{\sqrt{2}}{2}$.

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