Using Notional Currencies for Wireless Network Resource Allocation

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Abstract - Mobile wireless networks provide a robust capability for information sharing and play a vital role in supporting communications requirements in collaborative networks. Stimulating participation and sharing available resources are critical issues for nodes within collaborative networks. Resource allocation models that incorporate incentives enable use of available resources while, at the same time, promoting nodal participation in the network. This paper focuses on the contributory aspects of economic incentive models to resource allocation. Our capacity-based economic model encourages resource sharing amongst user entities using the control plane of a wireless mobile network. This model establishes a single currency. Rules are developed and then applied to maintain a bounded economy within a distributed collaborative environment.

Keywords: Incentives, Resource Allocation.

1.0 Introduction

A Distributed Collaborative Environment (DCE) exists within a network, such as found on many college campuses or research centers. A DCE is formed by network members to achieve self-defined goals, exchange information, and share resources. The network infrastructure ties wired and wireless environments together and provides identity of the network members. The infrastructure does not, however, attempt any centralized access control within the network.

An aspect of collaboration is that nodes participate willingly to achieve a collective goal. In a DCE, nodes contribute resources such as printing, file storage, file sharing, and processing power. Nodes that have resources contribute these to help other members but may join and depart the DCE based on internal goals and objectives [1]. While a participating member desires cooperation, it also requires that it retain ultimate authority over the resources it controlled prior to joining the DCE. Thus, we assume members are rational and self-interested entities.

While nodal mobility and dynamic membership are tremendous assets in a DCE, the environment needs to have underlying mechanics at work to share resources so that all participants can have a reasonable expectation of meeting their goals. The challenge within DCEs is that there are few effective means to force member nodes to share capabilities, behave rationally, or allow other nodes access to their resources. This situation forces designers to consider a system strategy that employs either positive or negative incentives to prompt nodal participation. Within this dynamic environment, sound incentive models can ensure that autonomous member nodes have access to distributed resources.

Because of the voluntary nature of a DCE, options for implementing negative incentives are limited. Isolation is commonly used in reputation schemes [2-5] to marginalize nodes that refuse to share or try to monopolize resources. Using isolation in a voluntary environment may be counterproductive, since the isolated nodes may control unique capabilities or resources that are necessary for the DCE to successfully achieve its desired goal. Punitive measures could encourage further negative behavior and collusion amongst marginalized nodes. This situation leads to the conclusion that punitive measures such as isolation, dismissal, or expulsion should be reserved as the course of last resort. Instead of negative incentives, we suggest that positive incentives are better means to gain and reinforce entity interaction and support resource sharing.

This paper proposes an innovative incentive model that is based upon a notional currency, in the form of *cyber credits.* Credits are used as incentives to govern use of available resources and encourage participatory behavior. The transfer of credits is implemented to yield a resource allocation decision. Although the allocation decision is important, this incentive scheme also attempts to mitigate or eliminate the negative effects of resource hoarding and free-riding.

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The rest of this paper is structured as follows. Section 2 presents the previous and related work on incentives. Section 3 introduces our team's research and system design goals for a centralized incentive system to regulate resource access. Section 4 provides suggested analytical measures for success and recommendations for simulating the system. Section 5 provides a succinct conclusion and a plan for future work.

2.0 Related Work

Incentive systems were used to stimulate cooperation and regulate access to resources in collaborative environments [4]. These objectives were met because members of the environment were motivated to possess something, in this case the incentive. Moreton and Twigg [6] classified incentive systems in two types: trust or token-based constructs. Trust systems used nodal reputations as incentives. Nodes were motivated to provide services for other network members so that they could earn or maintain a good reputation. Adams [2] demonstrated that a reputation index could be used to gauge a node's participation in the network and then isolate undesirable nodal behavior. Trust systems, by themselves, had difficulty when nodes cooperated when they needed something and then ignored the other nodes' requests when their needs had been satisfied. This was called freeloading or selfishness in the literature [7, 8] and presented a non-trivial problem.

A token system introduced a notional currency, which nodes exchanged in return for services. An example of an economy was found in the Terminodes project [9], which allowed nodes to create their own unique currency that was used to pay for services from adjacent nodes. Nodes paid to have their packet traffic forwarded by appending a certain number of "nuglets" to their traffic. Intermediate nodes accepted a nuglet for passing the traffic on to the next hop. This type of system operated like an economy, with many of the same issues found in real economies. Three issues were most important: bounding the economy, establishing prices, and exchanging currency.

Economies were bounded when the amount of currency inside the system was known. Unbounded economies were susceptible to inflation because the supply of currency could be increased without a matching increase in production capability. Bounded economies attempted to address these issues by controlling the number of tokens in the economy. Because the number of tokens was set, a node could calculate the value of the tokens that it possessed and negotiate for the services it needed. Specific redemption schemes [10] were implemented to defeat the possibility that a node could flood the network with its own currency. An unanswered question, however, concerned the determination of the number of tokens that a system needed to operate.

Once the economy was setup with currency, nodes needed to discover how many tokens were required for a service. Buyya [10] suggested a range of applicable economic models. For example, rigid pricing models may suggest "special posted" pricing offers that were only available during off peak times. Other models considered bargaining, which allowed brokers to vie for best services at least costly rates. Auction models employed market-based concepts with an auctioneer setting the bidding rules for service providers and service seekers. The auctioneer then found a mutually agreeable price for said service. This system was similar to bid-based proportional models. Their use of the resource was proportional to the amount of their bid, which was further scaled based on the supply and demand of the available resource.

Prices and services needed to be advertised so consumers could discover resource providers. Buyya [10] proposed the concept of a node fulfilling the roles of consumer, producer, and resource broker in the grid marketplace. A consumer node interacted with his or her resource broker to access available resources. Brokers advertised their services in a directory, which tracked service pricing and availability. Zhong [11] asserted that a central authority, such as a directory or the network's key management system [12], was necessary to collect, maintain, and account for incentive charges and receipts. This type of centralized economic scheme is discussed in more detail in Section III.

Once the price was discovered, nodes decided whether or not the resource was worth the cost. Nodes that offered services for low prices might become overcommitted while higher-priced nodes sat idle or, worse, starved out nodes that could not afford their price. Odylzko [13] addressed this issue with the Paris Metro Pricing scheme. Basically, if a node did not require more than "best effort" service, it only paid x. If the node needed better service or some sort of priority, it paid $2x$. As the author pointed out, this was a simple and self-regulating system but it failed because it could not guarantee that premium service would be delivered.

The challenge of price negotiation was amplified in systems with exchange rates, as nodes had to determine the price, then calculate the exchange rate, and then negotiate for service. Levien [14] described a "Stamp Trading" network in which nodes traded stamps to acquire needed services. Nodes established exchange rates between themselves based on credibility ratings. Stamp value was recalculated at the time of each trade. As long as a trusted node behaved satisfactorily, the node's confidence factor and its stamps' exchange rate remained high. This implementation of exchange rates complemented a trust system but failed to address how to protect nodes with good reputations from being flooded with requests.

Stamp trading also failed to address situations involving monopolies or inconsistent communications. Certain nodes could have a monopoly on resources that were so critical to other members' goals that they had to be used, regardless of the resource owner's credibility. Another challenge was that the economy suffered when nodes moved away or became disconnected. The tokens they held, in this case, became lost to the rest of the DCE. Worse, other factors like connectivity or communications capacity led to an inflation scenario where certain nodes adjusted their prices in response to local supply and demand.

Finally, notional economies had currency exchange issues. In a Terminode example [9], intermediate nodes might take payment and then not render services or might overcharge and leave the message with too few tokens to arrive at its intended destination. Proposals of "ripped payments" [15] and centralized accounting [11] attempted to address this issue at the cost of increased communication overhead.

3.0 Design of a Notional Economy

An important aspect of our incentive-based economy was that all the entities were willing members of the DCE. The Central Bank (CB) system presumed that entities would share resources within their capability.

The primary focus in our CB model was that credit accounting and tracking was accomplished in a centralized location, as shown in Figure 1. DCE members had a rolling bank account that was centrally tracked. User entities accumulated cyber credits by sharing resources and responsible usage activity. Their CB accounts were funded with credits determined by the DCE's resource capacity.

The following sections introduce the CB model and describe the methods used to bound the economy, advertise services, set prices, and exchange cyber credits. The CB model's aim was to enable access, stimulate participation, and prevent resource hoarding.

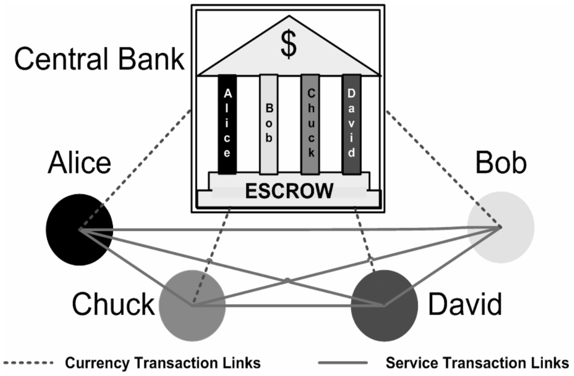

Figure 1. Central Bank Incentive Model

3.1 Central Bank Model

The CB model created a single source for cyber credit and economic accountability. The CB polled DCE members at the beginning of each economic cycle to compile an inventory of available resources. The updated inventory represented the current DCE capacity and membership. The CB tracked each entity's cyber credits, which were employed as a form of payment for services rendered. In this banking system, no tokens, stamps, etc. were physically exchanged between entities, since that activity contributed to additional system traffic and overhead. Instead user entities negotiated with the service providing nodes and were then billed directly through the CB.

3.2 Bounding the Economy

At the beginning of each economic cycle, the CB calculated an amount of cyber credits relative to the current DCE members' resource capabilities. These credits were disbursed as a part of the cyclic stipend. The impact of nodes that joined or departed the DCE during an economic period was not realized until the next economic period's membership poll. This adjustment allowed the economy to expand and contract in a controlled manner. Figure 2 is an example of a single economic cycle.

Figure 3 presents an eight-node DCE. The nodes joined, participated, and periodically departed the DCE throughout seven economic cycles. Resource capacities in terms of cyber credits were calculated for each node to demonstrate the expansion and contraction of the total economic capacity. Cycle 1 commenced with four member nodes. The membership poll for cycle 2 identified the addition of node 5, increasing the economy's bound to include that node's resource capacity. In the cycle 3 membership poll, nodes 1 and 2 had departed so the DCE's resource capacity and economic bound decreased accordingly. In cycle 4's

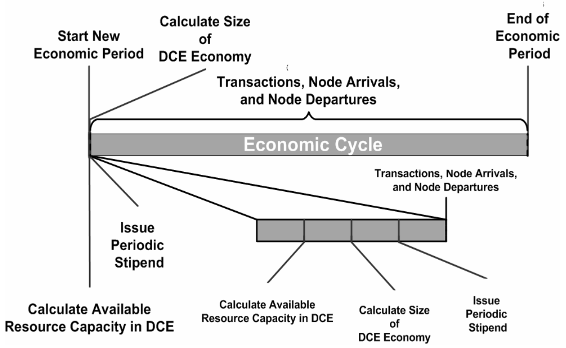

Figure 2. Example of One Economic Cycle

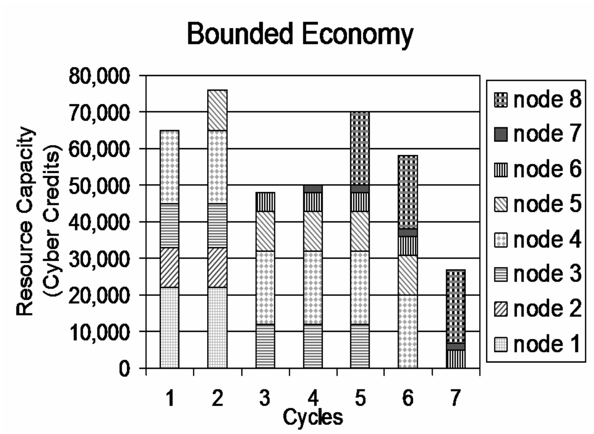

Figure 3. Bounded Economy Example

membership poll, node 7 was identified as a new entity that brought limited resources to the DCE. Membership polls in cycles 5, 6, and 7 indicated the arrival of node 8 and departures of nodes 3 and 4, respectively, with the CB adjusting the economy's bounds accordingly.

Upon joining the economy, new entities were issued enough credit to conduct initial operations and use basic services. If the new arriving entity had services to offer, then it advertised those capabilities. This encouraged the entity to provide services by receiving cyber credit from the CB and spend cyber credit for needed services.

The economy was bounded by total resource capacity. In our system, services were requested in blocks of resources. The price for each block was proportional to the capacity of the specific service. For example, one credit equated to a printed page. Thus, if a single printer could print eight pages per minute, the available capacity associated with that printer equated to 11,520 credits in an economic cycle. Other examples of resources and their associated capacities were shown in Table 1. This relationship between resources and available credits kept the economy bounded.

The CB was able to bound the economy because it had knowledge of available resources relative to available cyber credit. Importantly, the CB kept account of the credits such that the economy never exceeded available resources during DCE growth or contraction.

3.3 Resource Advertising and Pricing

Standard 802.11 advertising and association were used to request and provide services between nodes. Resource providing nodes advertised their services through their beacon signal. Consumers listened to the beacons and selected the provider that advertised the resource they desired. If multiple providers were available, a wireless consumer selected the provider that had the highest signal strength. If the consumer had wired access to the DCE, the signal strength criterion was replaced by bandwidth.

Table 1. Example Resource Pricing

Service	Unit	Max	Price / Unit
Printing	8 ppm	11,520	1 credit / page
File Storage	1 MB	Available Space	1 credit / MB
File Sharing	1 MB File	Available BW	1 credit / MB
Processing	100 MHz	CPU Speed	1 credit / 100 MHz

Once the consumer located the desired resource, it used a capacity rate-pricing scheme to purchase the resource. The pricing was directly related to the capacity computation the CB performed in order to bound the economy as described above.

There were two restrictions to the capacity rate scheme. The first was that a resource provider (e.g., Bob) was allowed to increase his price to prevent over committing his resource. In this case, he could increase his price to two or even three credits per page if demand for printing was outpacing his capacity. The second restriction was that consumers had to request resources in set blocks. In the case of Bob's printer, a consumer (e.g., Alice) had to request service in eight-page blocks. This restriction allowed Bob to gauge the demand on his printer and prevented Alice from monopolizing his resource. Alice could print as much as she could afford but she had to make print requests in blocks, thus allowing others the chance to request Bob's printer.

So far, the discussion has used printing as an example. At this point, it is worthwhile to examine how the system's pricing structure works with other services. File storage required that a consumer rented disk space from a provider for a specific amount of time. Storage was requested in megabyte blocks but the request was not fulfilled unless the producer could provide all of the blocks required for the file. We required that the rent be paid at the start of each economic cycle to prevent malicious or unintended hoarding of storage resources by storing large unneeded files.

File sharing was assumed to be a pull operation. A producer advertised that they had files to share. Consumers then requested a list of these files and chose to receive one or more for their personal use. The producer was paid based on the file size.

Finally, processing power was purchased based on CPU time. Producers offered blocks of access time to their CPUs. Consumers purchased the number of blocks they estimated would allow their process to complete. If the consumer purchased too few blocks, the producer notified him that the job was incomplete. If the consumer purchased too many blocks, the producer refunded the cost of unused whole blocks minus the unused blocks' reservation cost to discourage resource hoarding. Of all the services offered in a DCE, this service placed the most emphasis on the consumer trusting the producer to run their job. A malicious producer might run the job but still claim that the process failed to complete in the time purchased. The only solution we could devise was having the process benchmark itself to allow the consumer to gauge the job's completion and gain an appreciation for how much time the job required.

3.4 Currency Regulation

Credit management was critical to maintaining a stable economy. One method used was regulating the accumulation of cyber credit by employing an expiration period. Applying an expiration time for cyber credits capped runaway buildup of incentives, keeping the economy in balance. It also had the added benefit of allowing the economy to reset itself cyclically.

Another technique used to maintain a stable economy was ensuring that each node could participate in the DCE. There were some nodes that did not provide any services to the DCE but had requirements to consume services. It was imperative that these nodes be issued credits in order to complete these transactions. To do this, we estimated a basic subsistence rate predicated on the size of the economy. Each member was given an initial stipend, proportional to the total economy. For example, if there were *x* credits and *n* members, then the stipend was *x/n*. Because of the method we used to calculate capacity, *x/n* was greater than a member's basic requirement. Since the economy was recalculated at the beginning of each economic period to adjust *x* and *n*, the resulting stipend amount changed accordingly.

The purpose of the stipend was to provide member entities enough startup credits to enable participation during each economic period. Once the initial distribution of credits was complete, entities provided services to earn more credits, which were then spent to consume other services as necessary.

The system adapted to nodes that entered after the beginning of an economic period. The CB accepted the risk of inflation for the remainder of the economic period and issued the new node that period's stipend amount. Because demand did not reach the DCE's capacity, the throttling effect of the *x/n* stipend protected the economy until the next recalculation.

3.5 Service Request and Payment Scheme

In the CB system, negotiation for the service was conducted between the two transaction participants. As shown in Figure 4, the assumption in a centralized economy was that the CB conducted all credit transfers during the transaction. A resource-providing node (e.g., Bob) joined the DCE, notifying the CB that it owned a printer that it was willing to share. At the same time, a consumer node (e.g., Alice) had a file to print.

If Alice had sufficient funds and the service was available, then the transaction exchange began as shown in Figure 4. At that time, *x* credits were placed into a transaction escrow account. Of those credits, *x/2* credits were considered as a reservation fee while the service transaction processed. If the consumer did not complete the transaction, then the reservation credits were transferred to the service provider's account and the remaining escrowed credits were returned to the consumer's account. If the transaction successfully completed, then the full balance of escrowed credits was transferred to the service provider's account. However, if Alice had insufficient funds or Bob was busy, then Alice's request was denied. In either case, she could return later with sufficient funds or when the service provider was not busy to complete the transaction.

It is important to note that the system's service request and payment scheme was considered vulnerable at three points marked by stars in Figure 4. Special rules were in place to address these vulnerabilities and prevent Alice from undermining the system or tying up resources.

1. If Alice failed to confirm the transaction initiation with the CB, Bob's printer waited. To prevent Bob's printer from being monopolized, we allowed Bob to discard Alice's request after a set amount of time. Alice could issue another request later, restarting the process.

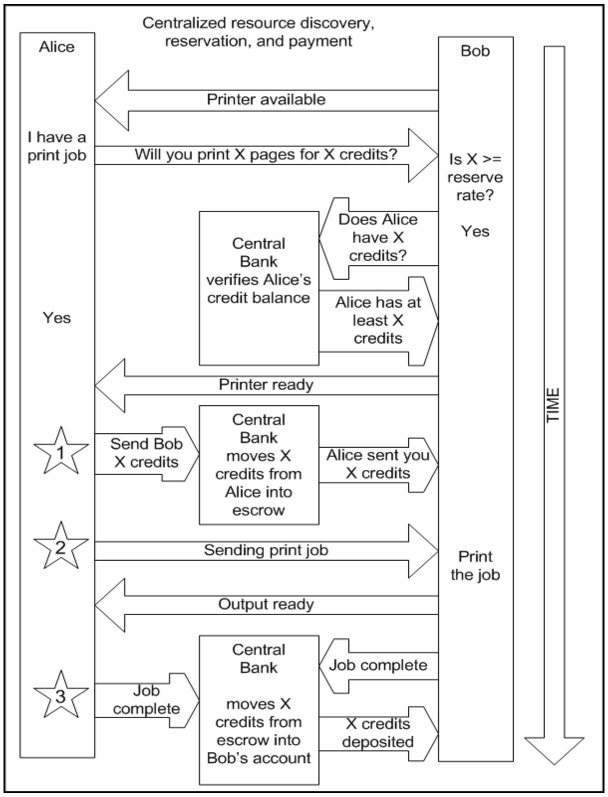

Figure 4. Centralized Incentive System

2. If Alice failed to send Bob the print job, Bob waited a predetermined amount of time and then considered Alice to be in default. The CB transferred the reservation credits to Bob's account in payment for the time he waited. The CB then notified Alice of the debit to her account.

3. If Alice failed to confirm the transaction completion, Bob waited a predetermined amount of time and then considered Alice to be in default. The CB transferred the entire escrowed amount to Bob's account and notified Alice of the debit to her account.

In this situation, Bob had nothing to gain by subverting the process; since he could not receive any credits until the transaction was completed, it was in his best interest to play by the rules.

4.0 Evaluation of the Economy

An evaluation must be performed to determine the economy's impact on DCE operations. This evaluation should include all of the areas mentioned previously: resource utilization, hoarding, and free-riding. After the appropriate metrics are identified, they must be analyzed through simulation. Below we discuss the metrics and potential options for simulation.

4.1 Defining the Metrics

The first metric for consideration was resource utilization. Utilization could be measured by calculating the ratio between resource allocation and resource requests. This was done for each node for multiple reasons. First, the CB already knew what transactions occurred based on the exchange of credits that it managed. This knowledge allowed for an analysis of which nodes were most and least active. Second, determining the utilization of resources provided insight to how efficiently the DCE was able to meet its resource requirements. For example, if utilization was high, it indicated that the pricing scheme was effective and not in need of change. However, low utilization indicated problems like resource hoarding or free-riding, requiring further analysis.

Utilization was not the only metric to help identify these problems. Resource hoarding was assessed by counting the number of credits that expired at the end of each period. Expiring credits indicated that nodes were holding on to their credits and not using resources across the DCE. There were numerous explanations for this phenomenon. The first was that nodes did not need to use resources during the time period and, as a result, their credits expired. Second, nodes might have held the credits intentionally to limit the number of credits available within the DCE. This option was called *credit hoarding* and was the specific reason that the CB model included credit expiration. Third, a node might attempt to monopolize a resource to limit its availability to other nodes. This *resource hoarding* was addressed by requiring a node to request resources in blocks. Finally, *free-riding* occurred when a node refused to share its resources while requesting use of other nodes' services.

Two other metrics that could be used to identify credit or service hoarding were the rate at which credits were spent and the time at which the credits were spent based on the CB's internal clock. If the spend rate was low, this indicated that there was either a lack of demand or credit hoarding as described above. A high spend rate indicated the desire to tie up a specific resource for a long time thereby preventing other nodes from using the service.

The timing of credit spending was also a concern. Holding credits until the later portion of the expiration period could result in an excessive demand a specific service. If successful, this demand might overwhelm resource providers and keep consumer nodes from meeting their requirements. These examples represented some of the resource hoarding possibilities. Combining utilization with the number of expiring credits, the spending rate, and the redemption time could identify credit and service hoarding problems.

Identifying free-riding nodes was considered trivial if a new node was honest and, upon arrival, told the CB that it could provide no services to the DCE but would have some requirements. Identifying these nodes became more difficult if the incoming node either misrepresented its capabilities or chose not to share the services it possessed. The utilization metric identified which nodes were using which services. Resource providing nodes that consumed services without sharing known resources were identified as possible free-riders.

The economy's metrics produced indications of participation, free-riding, and hoarding. These indicators were passed to the DCE's control plane for appropriate action.

4.2 Simulation Development

In the future, we plan to construct an OPNET simulation that will model the information exchange processes within a DCE. OPNET was chosen as a platform because of its availability and ready-made application and user profiles. It also allows us to simulate the hybrid DCE communications (in terms of wired and wireless links of varying capacities) with ease. A CB activity will be included in designated nodes, allowing us to capture the metrics described above.

Simulated member nodes will enter, participate, and leave the DCE dynamically. Members will be either static or mobile. Through a set of transactions, based on the resources described in Table 1, members will interact to test the bounds and mechanisms of the economy. The number of members and resources will be changed to test the assumptions made about efficacy of the proportional stipend.

Deliberate insertion of non-participating or free-riding nodes will test the system's success in discouraging these types of undesirable activity. The economy will also be monitored, using the metrics described previously, to determine the appropriate length of an economic period that mitigates credit and service hoarding.

5.0 Conclusion and Future Work

Notional currency systems could be used to stimulate participation and discourage a number of undesirable activities in a DCE. A CB accounted for credits in an economy based on resource capacity, thus eliminating communications overhead found in other incentive systems. This centralized accounting bounded the economy, distributing a portion of the DCE's credits to each member.

Stimulating participation and sharing available resources were critical issues for nodes within a DCE. Our economic model encouraged resource sharing amongst user entities. Currency in the form of centrally accounted cyber credits metered the use of available resources. Furthermore, this use of incentives discouraged free-riding and hoarding.

Our design work indicated that the implementation of incentives in a capacity-based economy were effective in a DCE. Future work will be conducted to define the operational boundaries and constraints using simulation. The results of these simulations will demonstrate the effectiveness of notional currencies as part of DCE measures.

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