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OPTIMAL PUBLIC MONEY

BY CYRIL MONNET

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Abstract

In most countries, the supply of paper money is controlled by a state institution. This paper provides an explanation for why such an arrangement is typically chosen. I use a deterministic matching model with a continuum of agents where enforcement is limited and where some agents produce public goods. Agents can also, at a cost, produce a distinguishable, intrinsically useless but perfectly durable good: *notes*. I call a note *public* if it is printed by an agent who produces public goods. In this framework, I prove that the socially optimal allocation is only implemented by a pattern of trade in which exchanges are effected using public notes.

J.E.L. Classification: D8,E5

Keywords: Money, Limited Commitment

Non Technical Summary

Menger (1892) concludes his seminal paper *On the origin of money* stating that "money has not been generated by law. In its origin it is a social and not a state-institution". Nonetheless, money became a state-institution in most societies. In conjunction, money became more abstract, in the sense that means of payments were developed using technologies that allowed increasingly more flexible management of the stock of money.

So there appears to be a close relation between the ease with which paper money can be produced and controlled for and the State monopoly over its production. However, it might be difficult to uncover this relation directly. Instead, one can ask why paper money or any other abstract forms of money - as electronic money - should be provided solely by the State or a state-institution and not privately.

More abstract technologies used for the creation of money might distort incentives of all agents having access to them. Because they increase the flexibility in supplying money, agents are able to take more opportunistic behaviors. In this sense, increased abstraction in technologies used to produce money strengthens enforcement problems. Hence, I place enforcement problems at the center of my argument.

The main result of the paper is that when enforcement is limited it is socially optimal that a state institution provides the (abstract) means of payment.

1 Introduction

In most countries, the supply of paper money is controlled by a state institution. In this paper, I provide an explanation for why such an arrangement is typically chosen. Menger (1892) concludes his seminal paper *On the origin of money* stating that "money has not been generated by law. In its origin it is a social and not a state-institution". Nonetheless, money became a state-institution in most societies. In conjunction, money became more abstract, in the sense that means of payments were developed using technologies that allowed increasingly more flexible management of the stock of money. So there appears to be a close relation between the ease with which paper money can be produced and controlled for and the State monopoly over its production. However, it might be difficult to uncover this relation directly. Instead, one can ask why paper money or any other abstract forms of money - as electronic money - should be provided solely by the State or a state-institution and not privately.

More abstract technologies used for the creation of money might distort incentives of all agents having access to them. Because they increase the flexibility in supplying money, agents are able to take more opportunistic behaviors. In this sense, increased abstraction in technologies used to produce money strengthens enforcement problems. Hence, I place the lack of enforcement at the center of my argument. Also, I adopt a somewhat naive view of the State, limiting its actions to its core responsibility of pure public good provision. The main result of the paper is that when enforcement is limited it is socially optimal that a state institution provides the (abstract) means of payment. In other words, optimally there is a natural complementarity between the production of public good and the provision of paper money.

To present the argument I use a deterministic version of the model of Kiyotaki and Wright (1989, 1993). There is a finite number of types of agents and a continuum of agents in each type. One type of agents produces a public good and the other types of agents produce excludable consumption goods. All types of agents produce a different good. In addition to goods, every agent can produce, at a cost, *notes* which are distinguishable across types. I call a note *public* if an agent who produces public goods prints it. Notes are intrinsically useless but perfectly durable objects. Because of limited enforcement and an absence of a double coincidence of wants, these notes are necessary in order to achieve any non-autarkic allocation.

In this environment, I describe a general class of mechanisms where notes can be produced and exchanged. I consider mechanisms where agents have the choice to walk away from any exchange. This lack of commitment is also reinforced by the possibility given to some agents to make offers to their trading partner. Within this class of no-commitment mechanisms, I consider all allocations for which agents have no incentive to walk away or make offers. I call these allocations *incentive feasible*.

Then I consider the problem of a social planner whose aim is to find incentive feasible allocations that maximize social welfare. I call these allocations *optimal*. I prove that the unique optimal allocation only features exchanges that are effected using public notes. In this sense public money is optimal.

The intuition for the results is simple. In an environment where no contract can be enforced, each agent has an incentive to refuse to deliver goods to any bearer of his notes. This is because it is less costly to print new notes than to produce goods. Hence, agents' notes are used as means of payment only if society finds an *endogenous* device that allows agents to commit to their future actions. However, the implementation of devices designed to provide the proper incentive is costly.

This cost can be avoided with the use of public money because the State will never be offered its notes. The State only produces goods of *social* value: once produced, all agents benefit from these goods even if they did not pay for their production. Since every agent can free ride, no one is willing to voluntarily pay for the provision of public goods. Hence no agent willingly makes payments to the State in any form of money. A commitment device is therefore unnecessary for public money to circulate. In this sense, public money is more cost efficient than private money because there is no need to set up such a costly device.

State money also plays a significant role in facilitating the provision of public goods. In an environment where the government *cannot* force agents to produce the intermediate goods necessary for the production of public goods, the State has to buy these goods. Public money is the natural candidate means of payment for such purchases. Without public money, agents would again free ride by deliberately not producing the intermediate goods necessary to the production of public goods. When public money is an accepted means of payment, however, private agents are willing to produce for the State in exchange for its money. Since agents cannot produce it, they cannot afford to refuse payments denominated in public money for the production of their good without suffering future losses. In this case, public goods are supplied.

To summarize, public money is optimal because, contrary to agents' money, its use does not distort incentives of the State or of agents.

This paper has two main contributions. First, there is a consensus in the literature that the use of private money is more efficient than the use of State money (see among others Cavalcanti and Wallace 1999, Williamson 1999 and Azariadis, Bullard and Smith 2001). But every analysis assumes, at least implicitly, the existence of an enforcement technology that is costless to operate. For instance, Cavalcanti and Wallace (1999) assume trading histories of money providers are public information: defections are known and can then be punished. Therefore the knowledge of past histories constitutes a form of monitoring of redemption. In this paper, I show that the opposite result is obtained when enforcement is endogenous and costly. Second, this paper shows that explicit monitoring of redemption is not necessary for money produced by agents in the economy to be used as means of exchange. This is a new contribution to the literature, that so far has always assumed the existence of a specific institution - a clearinghouse system or a record keeping device as in Cavalcanti, Erosa and Temzelides (1999) - that regulates the redemption process.

Therefore, limited commitment is implicitly acknowledged as a problem for the circulation of inside money. The effect of limited commitment on the choice of a means of payment has recently been addressed in Kiyotaki and Moore (2000). They stress the importance of agents' ability to make a binding contract with a large number of trading partners for their money to circulate as means of payment. Using their own words "The power of one agent to make a multilateral commitment can substitute for another agent's lack of commitment". The present paper goes a step further by asserting that state-institutions do not *need* to commit to their actions for their money to circulate because no agent wishes to exchange money for public goods.

Finally, few papers have analyzed the reasons why a state institution is generally providing means of payment. One notable paper is Ritter (1996) who shows, in a random matching model, that a coalition of agents - the government - can provide a uniform means of payment that will be valued by other agents. The government money is valued *because* “It has the ability to limit the production of money by individual members”. One weakness of Ritter’s result is that he assumes the government has this ability. In the present environment public agents do not tend to overissue notes. The reason is they can only buy a bounded amount of goods from private agents and it is optimal that they always buy the maximum amount from private agents. The present paper also differs from Ritter’s in its use of a framework where all kinds of money (public and private) can be valued. The comparison of monetary system is then non-trivial. In parallel to Ritter’s findings, I find that the crucial characteristic of a government that makes its money optimal is its specialization in the production of public goods.

The paper proceeds as follows. In Section 2, I present the basic structure and in Section 3, I describe a class of no-commitment mechanisms that use notes. Within this class of mechanisms, I define incentive feasible allocations. In Section 4, I show that the use of public money is optimal. In Section 5, I discuss this result and its robustness to possible modifications of the environment. Finally, I conclude in Section 6.

2 The Environment

2.1 Preferences and Production Technologies

I consider an economy with a measure 3 of infinitely lived agents with a measure 2 of private agents and a measure 1 of public agents. There are two types of private agents, labelled 1 and 2, that have equal measure. Public agents are labelled g.

Private agents are endowed with a production technology. Type 1s can only operate the technology in even periods. They can produce perishable goods which consumption only gives utility to type 2s. Inversely, type 2s can only operate the technology in odd periods and produce perishable goods desired only by type 1s. Hence, in odd periods agents of type 1 will be called consumers while agents of type 2 will be called producers, inversely in even periods. Private agents can produce either 0 or 1 unit of good. Producers bear a cost c to produce one unit of good, but consumers enjoy utility 1 from consuming it.

Consumers are also endowed with one unit of a special good, ω. If consumed, this good gives consumers a utility $\gamma \geq 0$.

Public agents are endowed with a transformation technology that can be used in each period. It takes 1 unit of ω to produce 1 unit of public good. Production costs public agents c units of utility. The good produced by public agents is public in the following sense. If a measure $\lambda \in [0, 1]$ of public agents produce 1 unit of public good, then private agents receive utility $\lambda\mu$, where $\mu \geq 0$. Public agents get utility 1 from operating the technology. In this sense, public agents are benevolent. Note that γ is the opportunity cost for consumers of getting the public good.

Private and public agents can also produce *notes*. A note is a durable and worthless good. Agents of type 1 and 2 produce private notes of type 1 and 2 respectively. Public agents produce public notes. While the production of notes is unrestricted, each note costs $\varepsilon > 0$ to produce. The three types of notes are perfectly distinguishable. I do not impose any upper bound on note holdings. I call the note holdings of an agent, his *portfolio*.

Each period $t = 1, 2, ...$ is divided in 2 sub-periods. First, consumers are each randomly matched with a public agent. Then consumers are each randomly matched with a producer. Meetings are physically and informationaly separated. Consumers are first matched with a public agent and then with a producer. Although within a period consumers are of the same type, I will denote for notational simplicity the consumer meeting a public agent by c' and the consumer meeting a producer by c. Hence a match involving a public agent and a consumer is denoted (g, c') and a match involving a producer and a consumer is denoted (p, c), where p stands for producer. The structure of meetings is represented in Figure 1.

Agents discount utility by factor δ, $0 < \delta < 1$. The parameters δ, γ, c and ε are common knowledge and satisfy the following assumptions.

Assumption 1.

(A.1) $c > \varepsilon$; (A.2) $\mu \geq \gamma/2$; (A.3) $1 - \delta^2 > \gamma$; (A.4) $\delta - c > \delta(\gamma + \varepsilon)$.

In A.1, I assume the cost of goods production is higher than the cost of notes production. Also, A.2 implies it is socially beneficial to produce the public good. I further impose two constraints that guarantee agents are willing to trade off the consumption of ω for the consumption of private goods. First A.3 implies a producer would rather consume today than to consume ω forever after. Second, according to A.4 producing today to consume the private good tomorrow is better than consuming ω tomorrow, even if a note must be produced to consume the private good.

3 Mechanisms with Note Production

3.1 Definition

In this subsection, which borrows from Kocherlakota (1998a,b) and Kocherlakota and Wallace (1998), I describe a general class of mechanisms pertaining to the environment with note production. I focus on the class of no-commitment trading mechanisms.

A *trading mechanism* is a description of a finite stage game in each match. More precisely, it specifies a sequential action set and an outcome function for each match.

Given that agents of any type are endowed with a note production technology, the sequential action set allows the production of notes. The note production of a given agent is secret and is not observed by other agents. Moreover if notes circulate each agent has a note portfolio at the time they enter each match. I let w_t be the portfolio of an agent in period t. Since there are 3 types of agents, there are 3 types of notes so that $w_t \in \mathbb{N}_+^3$.

I adopt the following principle: all notes vectors (portfolios and transfers) will have notes of type 1 and 2 as their first and second component respectively and public notes as their third component.

In a match (i, j) - for $(i, j) = (g, c')$ or (c, p) - in period t, the sequential action set for an agent of type j with portfolio w_t is denoted by $A^j(w_t, t)$. If there are M stages, $A^j(w_t, t) = \prod_{m=1}^{M} A^j(w_t, t, m)$. Each chosen action is common knowledge to both party.

The mechanism specifies an *outcome function* f that depends on the match (i, j), the period t and the actions of both types of agents chosen at each stage. For a consumer matched with a public agent in period t, the outcome function states the realized transfer to the public agent of $x_t \in \{0,1\}$ unit of ω. For a producer matched with a consumer, it states the realized production and transfer of $y_t \in \{0,1\}$ unit of good to the consumer. Also, for agent $i \in \{c, c', p, g\}$, the outcome function states the realized production of notes $n_t^i \in \mathbb{N}$ and the realized transfer of notes $z_t^i \in \mathbb{N}^3$.[1] Given his preferences, I assume that a public agent always produces as long as $x_t = 1$, i.e. whenever ω is transferred.

Given a mechanism, all agents have a *private history* and a *public history* when they enter a new meeting. The public history is the realization of the public good production for the given period and all past periods. This history is public because all agents have the same knowledge of this history. Along the finite stage game, the private history of each agent is updated with their action and the observable action of their current trading partner.

I let h_t^i be the history of an agent of type i in period t. In the match (i,j) in period t, the *sequential action choice* for an agent of type i with portfolio w_t and history h_t^i is denoted by $\alpha_t^i \equiv \alpha^i(w_t, h_t^i) \in A^i(w_t, t)$.

An *allocation* is a vector $(n, x, y, z) = \{\{n_t^i, x_t, y_t, z_t^i\}_i\}_{t=1}^{\infty}$ that only depends on time, the type of match and the portfolio of both agents. The vectors $((n_t^g, z_t^g), (n_t^{c'}, x_t, z_t^{c'}))$ and $((n_t^p, y_t, z_t^p,), (n_t^c, z_t^c))$ are outcomes of the game, hence $f(\alpha_t^g, \alpha_t^{c'}, t) = ((n_t^g, z_t^g), (n_t^{c'}, x_t, z_t^{c'}))$, and $f(\alpha_t^p, \alpha_t^c, t) = ((n_t^p, y_t, z_t^p,), (n_t^c, z_t^c))$. I will only consider symmetric allocations. An allocation is *symmetric* if two agents of the same type with the same portfolio in the same type of match receive the same allocation.

A *no-commitment trading mechanism* is a trading mechanism where private and public agents can choose to remain in autarky in any match and where consumers can make a take-it or leave-it offers when they meet a producer. More precisely for any match (i,j) in period t, for any action of agent j in $A^j(w_t^j, t)$, there exist actions in $A^i(w_t^i, t)$ such that an agent of type i does not produce notes of type i, she does not transfer or receive notes, she does not consume the good of type j and she does not produce the good of type i. Also, for any match

[1] In order to ease notation, and if there is no possibility of confusion, each n_t^i can be either (a) a scalar or (b) a 3 elements vector with n_t^i notes of type i and all other elements being zero.

(p, c) in period t, for any action of agent p in $A^p(w_t^p, t)$, there exist actions in $A^c(w_t^c, t)$ which allow the consumer to offer a vector $((\tilde{n}_t^p, \tilde{y}_t, \tilde{z}_t^p), (\tilde{n}_t^c, \tilde{z}_t^c))$. If the producer leaves the offer, the outcome is autarky. If he accepts the offer, the outcome of the game is the accepted offers.

The use of no-commitment mechanisms allows a role for notes, as producers cannot abide to promises. However, I consider a class of trading mechanisms where the enforcement problem is made stronger than having autarky as the only outside option. The crucial feature of these mechanisms is that consumers are allowed to bid a lower price than the posted price. For example, if consumption requires a consumer to transfer two notes to the producer, the enforcement technology is such that the consumer can propose instead one note for the good. The reasons why private money is inefficient are starker under this assumption.

Because agents have no information on the outcome of a game in which they are not involved, I confine the analysis to Bayesian Markov perfect public equilibria. The state variables of an agent when engaged in a match in period t is his portfolio and the measure of public good last produced. Therefore an equilibrium is a collection of strategies in which:

1. Each agent's choice of action only depends on the agent's state variables at each stage of the game.
2. Given the state variables and beliefs, no agent can gain by deviating from his strategy after any history of play.
3. Beliefs are updated using Bayes' rule whenever possible.

Definition 1. *An allocation (n, x, y, z) is incentive feasible if it is a Bayesian Markov perfect public equilibrium outcome of a no-commitment mechanism in the environment with note production.*

3.2 Partial Characterization of Incentive Feasible Allocations

In this section, I prove well known results in the random matching literature which also apply to my deterministic matching environment. In order to partially characterize incentive feasible allocations, it is useful to first specify the payoff for each agent V^i of an incentive feasible allocation (n, x, y, z).

$$\begin{aligned} V_t^g &= x_t(1-c) - n_t^g\varepsilon + \delta V_{t+1}^g, \\ V_t^{c'} &= [x_t\mu + (1-x_t)\gamma] - n_t^{c'}\varepsilon + V_t^c, \\ V_t^c &= y_t - n_t^c\varepsilon + \delta V_{t+1}^p \\ V_t^p &= x_t\mu - y_t c - n_t^p\varepsilon + \delta V_{t+1}^{c'}. \end{aligned} \tag{3.1}$$

The public agents' payoff in period t, V_t^g, is determined as follows. They get $x_t(1-c)$ from the production of the public good, they have to pay $n_t^g\varepsilon$ for the production of n_t^g public notes and they also get the next period payoff discounted at a rate δ. The payoff of a consumer c' in period t is determined similarly. They receive utility $x_t\mu$ from the public good if $x_t = 1$ or $(1-x_t)\gamma$ from the consumption of ω if $x_t = 0$, and they have to pay $n_t^{c'}\varepsilon$ to produce their notes. Then they will become consumer c and get this payoff. The payoff of consumer c is constituted of the utility 1 from consuming the private good only if it is produced ($y_t = 1$) and the cost of note production. Then a consumer c becomes a producer in the following period and get the respective discounted payoff. The payoff of a producer, V_t^p in period t is the utility from getting the public good, $x_t\mu$ in addition to the disutility of producing the private good $y_t c$ or notes and the discounted payoff of being a consumer c' in the following period.

From these payoffs, a first property of incentive feasible allocations where goods are produced can be stated. The following lemma concerns allocations (n, x, y, z) such that the private good is produced in period t or the public good is produced in period $t+1$. It states that such allocations are incentive feasible only if the private good is produced in the future.

Lemma 1. *If the allocation (n, x, y, z) is incentive feasible and $y_t = 1$ or $x_{t+1} = 1$ then it must be the case that $y_s = 1$ for some $s > t$.*

Proof. For an allocation to be incentive feasible, it must be that agents do not choose autarky in any match. Now suppose by way of contradiction that $y_t = 1$ and $y_s = 0$ for all $s > t$. Then the lifetime payoff of the producer in period t is the discounted sum of utility from the public good from $t+1$ onward. If a producer chooses autarky in period t, this continuation payoff is not affected. This is due to the restricted flow of information and the continuum of public agents: they imply that the measure of public good produced will not change in each future periods whatever the action of a producer in period t is. Therefore a producer will choose autarky if $y_s = 0$ for all $s > t$. Using the same argument, we must have $y_s = 1$ for some $s > t$ if $x_{t+1} = 1$. □

Therefore if private or public goods are to be produced in a period, it must be the case that private goods are also produced in the future because of incentive problems. As is well known from e.g. Kocherlakota (1998) these incentives problems are generated by the absence of commitment and the lack of information. The following lemma describes how these incentives constraints can be relaxed using transfers of notes in this deterministic matching environment.

Lemma 2. *If the allocation (n, x, y, z) is incentive feasible and $y_t = 1$ then $z_t^c > \mathbf{0}$. Similarly, if $x_t = 1$ then $z_t^g > \mathbf{0}$.*

Proof. Suppose $y_t = 1$ and $z_t^c = \mathbf{0}$. I will show that in period t, producers will choose autarky. Given the information constraint and $z_t^c = \mathbf{0}$, choosing autarky does not modify the state variables of the producer in t becoming consumer in date $t+1$, or of any other agents at $t+1$ with whom he will be matched. Hence, this consumer at $t+1$ can make the same choice as if he did not deviate when a producer. Given the allocation is incentive feasible, the choice after the deviation remains optimal. Therefore, the producer will choose autarky. A contradiction. The same argument applies to the case where $x_t = 1$. □

The important aspect of the use of notes, as illustrated by the proof of Lemma 2, is that the producer's portfolio is affected by notes transfers from the consumer. In other words, it is crucial that the continuation payoff of the producer in any game is decreased if notes are not being transferred - i.e. if the producer chooses autarky. A similar consideration holds for consumers who would not transfer ω to public agents.

In the rest of this paper, I will consider only allocations where the private good is produced in every period. This clarifies the exposition and is a characteristic of the optimal allocation, as defined in the next section. I now turn to the fundamental question posed at the start of this paper: should private trades be implemented using private or public money ?

4 Private versus Public Money

In this section I will first show that allocations where the private good is traded in every period can be implemented using private money *only*. In other words, I will show that private money can be valued. Then I will show that it is possible to implement these allocations using one note produced by the public agent. Finally, I will define, characterize and comment on the optimal allocation.

4.1 Private Money

In this section, I show that allocations where the private good is traded in every period can be implemented using private notes only. The key element is that notes are costly to produce.

In the first period of this economy, since only private notes are used, type 1 notes must be produced by type 1 consumers and transferred to type 2 producers. These producers then become consumers. If type 2 consumers transfer type 1 notes to type 1 producers, then the latter have an incentive to choose autarky. The reason is that they can produce the types of notes that are being transferred to them. In order to solve the incentive problem, type 1 notes must be produced in such a quantity that type 1 producers will not choose autarky. The following lemma further states that this incentive problem can be solved if private notes are produced in a sufficient amount at least once every two periods.

Lemma 3. *If the allocation (n, x, y, z) is incentive feasible with $y_t = 1$ for all t and uses only private notes, then*

1. $n_1^c \geq c/\delta\varepsilon$, $z_t^{c,1} \geq c/\delta\varepsilon$ *for all t and*

2. $n_{t-1}^p/\delta + n_t^{c'} + n_t^c + 1 \geq (\delta - c - \delta x_t \gamma)/\delta\varepsilon$, *for all $t \geq 3$ odd.*

Proof. Suppose the allocation (n, x, y, z) is incentive feasible with $y_t = 1$ for all t and uses only private notes. By Lemma 2 we know that $z_t^c > \mathbf{0}$ for all t. Suppose $z_1^{c,1} < c/\delta\varepsilon$.

First consider an allocation where only notes of type 1 are transferred. I will show that in period 2, producers are better off choosing autarky, thus contradicting incentive feasibility.

In period 2, consumers have a portfolio constituted of $z_1^{c,1} < c/\delta\varepsilon$ notes of type 1. Since only these notes are used at most $z_1^{c,1}$ can be transferred. Producers are of type 1. If one producer chooses autarky, she can produce the amount of untransferred notes the next period. In this way, her state variable is unchanged and she can consume in period 3, as if she did not choose autarky in period 2. In this case, her (period 2) payoff is at least $-n_2^p\varepsilon + \delta V_3^{c'} - \delta z_1^{c,1}\varepsilon$. This has to be compared with the allocation (period 2) payoff which is $-c - n_2^p\varepsilon + \delta V_3^{c'}$. As $z_1^{c,1} < c/\delta\varepsilon$ she will prefer autarky, a contradiction.

Now, assume $n_2^p/\delta + n_3^{c'} + n_3^c + 1 < (\delta - c - \delta x_3\gamma)/\delta\varepsilon$. I will show that the allocation is then not incentive feasible. Producers should reject any offer from consumers of a price lower than the allocation price. Hence, in period 2 producers should reject a price of $z_1^{c,1} - 1$ (or lower). If they accept such an offer, they will have to produce one note in the next period (period 3) so as to have an unchanged state variable. In this case, they get at least $-c - n_2^p\varepsilon + \delta V_3^{c'} - \delta\varepsilon$. However, if they reject, they are not transferred any notes. Furthermore, the argument in the first paragraph of this proof implies that they will not find profitable to produce the missing $z_1^{c,1}$ notes in period 3. Hence, they will not have a portfolio allowing them to consume in period 3. In such a situation they might also find optimal to defect on the public agent. Therefore, they get at most $\delta(x_3\mu + \gamma) + \delta^2 V_4^p$. Given the definition of $V_3^{c'}$ and $n_2^p/\delta + n_3^{c'} + n_3^c + 1 < (\delta - c - \delta x_3\gamma)/\delta\varepsilon$, producers in period 2 will accept such offers. A contradiction.

The above two points imply that consumers in period 3 transfer at least $z_1^{c,1}$ notes to producers. Moreover, since $\delta - c > \delta(\gamma + \varepsilon)$, further notes must be produced. That is, either $n_2^p \geq 1$ or $n_3^{c'} \geq 1$ or $n_3^c \geq 1$. Hence, replicating the argument above for all t, we have that $z_t^{c,1} \geq c/\delta\varepsilon$ for all t and $n_{t-1}^p/\delta + n_t^{c'} + n_t^c + 1 \geq (\delta - c - \delta x_t\gamma)/\delta\varepsilon$ for all t odd.

Now consider an allocation where type 2 notes are also transferred. In this case, we can apply the arguments above. If producer 2 chooses autarky in period 1, producers in period 2 should not accept any offers constituted only of type 2 notes. That is, it must be that they are worse off producing $z_1^{c,1}$ notes and accepting the offer than rejecting it. Similarly, producers in period 2 should not accept any offer constituted of type 2 notes and less than $z_1^{c,1}$ notes of type 1. $\square$

Due to limited commitment, the use of private notes imposes a non trivial cost to society.

Given Assumption 1, $z_t^{c,1} \geq 2$ and $n_{t-1}^p + n_t^{c'} + n_t^c \geq 1$ grow to infinity when ε decreases to zero. Furthermore, it is easy to verify that the total cost of notes production does not decline as ε diminishes.

When it uses private money, society trades off information acquisition with incentive constraints. In other words, while it eliminates the information asymmetry, the use of private money in the absence of commitment induces a severe incentive problem. In period 2, the producer has the technology to create any note that the consumer would transfer him. The production of the good being more costly than the production of a note, the producer might not produce the good to acquire the notes he needs from the consumer. Rather, he might prefer producing the notes himself. The producer is willing to trade whenever it would cost him more to produce the notes instead of acquiring them through the production of his good. In this sense, the production of additional private notes represents the *endogenous* device that allows the implementation of an equilibrium with private money. However, this device is costly to set up because private agents have to suffer the cost of producing notes.

I now prove that, although it is costly, private notes can be used in order to implement trades among private agents. I will call the following type of allocation a *private allocation*.

1. $V_t^g \geq 0, V_t^{c'} \geq \gamma/(1-\delta^2), V_t^c \geq \delta^2\gamma/(1-\delta^2)$ and $V_t^p \geq \delta\gamma/(1-\delta^2)$,
2. $n_1^c \geq c/\delta\varepsilon$, $n_t^c \geq (\delta - c)/\delta\varepsilon - 1$ for $t \geq 3$ odd,
3. $n_t^g = n_t^p = n_t^{c'} = 0$ for all t, $n_t^c = 0$ for all t even,
4. $x_t = 0$, $y_t = 1$ for all t,
5. $z_t^c = (\sum_{s=1}^t n_t^c, 0, 0)$ and $z_t^g = z_t^p = z_t^{c'} = \mathbf{0}$ for all t.

In a private allocation, all agents are willing to participate (condition 1). Also, only private goods are produced but in each period (condition 4). Moreover, the purchase of this good is financed by private notes of type 1 only (conditions 2,3 and 5).

Lemma 4. *Given Assumption 1 a private allocation exists.*

Proof. Consider the above allocation, where notes production and transfers are set to the lowest integer greater than the required number. I will show that this allocation satisfies conditions 1. It is clear that $V_t^g = 0$ for all t. Also, since the public good is not produced and $n_t^{c'} = 0$, $V_t^{c'} = V_t^c + \gamma$ for all t. Now, $V_{t+1}^c > V_t^c$ for t odd, as the consumer in period $t+1$ does not produce notes and producers incur the same cost whether in period $t+1$ or $t+2$. This implies that $V_{t+1}^p > V_t^p$ for t even. Hence, we have to show $V_t^c - \delta^2\gamma/(1-\delta^2) \geq 0$ for t odd, $V_t^p - \delta\gamma/(1-\delta^2) \geq 0$ for t even, and $V_1^p - \delta\gamma/(1-\delta^2) \geq 0$. The first two inequalities are satisfied if $-c+\delta[1-n^c\varepsilon] \geq -c+\delta[1-(\delta-c)\varepsilon/\delta\varepsilon] \geq 0$, which is the case. $V_1^p - \delta\gamma/(1-\delta^2) \geq 0$ if $\delta > c$ - which is true by assumption - and $V_t^p \geq \delta\gamma/(1-\delta^2)$, which is verified. □

Proposition 1. *Any private allocation is incentive feasible.*

Proof. To prove incentive feasibility, associate to any private allocation (n, x, y, z) the following game.

The choice set is as follows. In a match (g, c') and (p, c) in period t the game is constituted of the choice set $\{$*accept,reject,offer*$\}$ for public agents g and consumers c, only if the transfer of notes is physically feasible (i.e. the portfolio of notes includes the notes that an agent has to transfer but cannot produce). If the note transfer is not physically feasible, then the choice set for these agents is $\{$*offer*$\}$. For agents c' and p, the choice set is $\{$*accept,reject*$\}$ if the transfer of notes is physically feasible, and $\{$*reject*$\}$ otherwise.

If both agents g and c' accept then the allocation $((n_t^g, z_t^g); (n_t^{c'}, x_t, z_t^{c'}))$ is the outcome of the match and agents proceed to the next match. If both agents p and c accept, then the allocation $((n_t^p, y_t, z_t^p); (n_t^c, z_t^c))$ is the outcome for the match and agents proceed to the next match. If one of the agent in a match rejects, then the outcome is autarky and the agents proceed to the next match, unless one of the agents made an offer. If either g or c makes an offer then agents c' or p can either accept or reject it. If they accept, then the offer becomes the outcome of the match. Otherwise, the outcome is autarky.

I will now describe the strategy that implements a private allocation (n, x, y, z).
(1) g and c' accept. If g offers $((\tilde{n}_t^g, \tilde{z}_t^g); (\tilde{n}_t^{c'}, \tilde{x}_t, \tilde{z}_t^{c'}))$, where $\tilde{z}_t^g < z_t^g$ or $\tilde{z}_t^{c'} > z_t^{c'}$, then c' rejects.
(2) p and c accepts. If c offers $((\tilde{n}_t^p, y_t^p, \tilde{z}_t^p); (\tilde{n}_t^c, \tilde{z}_t^c))$, where $\tilde{z}_t^c < z_t^c$ or $\tilde{z}_t^p > z_t^p$, then p rejects.
I abstract from multiple deviations, or deviations that are unprofitable to the defector. First, note that all payoffs are positive and greater than the value they would be in autarky. Hence all agents are willing to participate in the game. Second, observe that transfers of notes are

such that it is enough to consider the effects of a deviation on the first two periods only: 3 periods after a deviation, portfolios of agents are identical to the one when they did not defect. So, consumers always prefer to accept when they can. Also, since $y_t = 1$ for all t, and $\delta(1 - n_t^c\varepsilon) > c$ producers prefer to accept, since otherwise they lose consumption in the next period. This follows from arguments in lemmas 2 and 3. Beneficial offers allow the consumer to make a lower net transfer of notes. Given the allocation considered, any other offers are not beneficial. However, from lemmas 2 and 3, rejection of these offers is optimal. □

Therefore in this economy private money is "valued", in the sense that it can be used to implement beneficial trades. This depends crucially on the assumption that notes are costly to produce. Otherwise the argument used in Lemma 3 would not apply. However, private money is valued for all ε strictly positive. Note that the cost of private note production is at least $c/\delta + \delta^2(\delta - c - \delta\varepsilon)/(1 - \delta^2)$, which tends to a positive constant when ε tends to zero.

In the next section I analyze the case of public money. In particular, I will show that all allocations where the private good is traded in all periods can be implemented using public notes only.

4.2 Public Money

In this section, I show that the exchange of private goods from producers to consumers can be implemented using public notes only. In particular, I will show that using *one* public note is enough to implement trades.

I first define a *public allocation* as any allocation (n, x, y, z) such that for all t:

1. $V_t^g \geq 0, V_t^{c'} \geq \gamma/(1 - \delta^2), V_t^c \geq \delta^2\gamma/(1 - \delta^2)$ and $V_t^p \geq \delta\gamma/(1 - \delta^2)$,
2. $n_1^g = 1 \geq n_t^g \geq 0$, $n_t^{c'} = n_t^c = n_t^p = 0$,
3. $x_1 = 1$, $x_t > 0$ whenever $n_t^g > 0$,
4. $y_t = 1$,
5. $z_t^g = (0, 0, n_t^g)$, $z_t^c = (0, 0, \sum_s^t n_s^g)$ and $z_t^{c'} = z_t^p = \mathbf{0}$.

A public allocation is an allocation where the public good is produced in at least the first period, and where the private good is always produced. The purchase of any of the goods are financed using public notes only.

Lemma 5. *Given Assumption 1 a public allocation exists.*

Proof. Set $n_t^g = 0$ for all $t > 1$. The existence follows from $1 > \gamma$, $1 - c/\delta > \gamma + \varepsilon$ and the arguments in Lemma 4. □

Public allocations differ from private allocations in that they (1) use only public money but also (2) the public good is produced. Whenever the public good is not produced, the public agent will prefer autarky to producing public notes. Hence, given public notes are costly to produce, one has to compensate the public agent for their production.

Proposition 2. *Any public allocation is incentive feasible.*

Proof. Consider the game and strategies specified in the proof of Proposition 1. Since $1-c > \varepsilon$, public agents are willing to produce the public good. Private agents are willing to give up ω as $1 - c/\delta > \gamma$. The difference with the proof of Proposition 1 is that we cannot appeal to the proof of Lemma 3 since only public notes are produced. However, because producers do not produce the public notes, we do not need to use this particular point. Indeed, producers have no incentive to chose autarky *even if* a single public note is transferred by consumers.

However, since the public good is produced, private agents gain μ but lose γ in exchange for public notes. Hence, consumers might prefer defecting on producers and piling up public notes. This might allow them to defect in later meetings with public agents while still being able to consume the private good. However, given $1 - \delta^2 > \gamma$, such a strategy is not optimal. The rest of the proof follows exactly the proof of Proposition 1. □

4.3 Optimal Allocation

In this section, using the class of mechanisms defined above, I characterize the incentive feasible allocation that optimizes a welfare function for this economy. This allocation exhibits the property that only public notes are used. I first define the optimal allocation and then characterize it.

The basic problem this economy faces is to find the allocation that will maximize a social welfare function subject to being incentive feasible. I choose a welfare function that gives every type of agent in the economy equal weight.

Definition 2 (Optimal Allocation). *An optimal allocation* (n, z, x) *solves the social planner problem:*

$$\max_{(n,x,y,z)} \quad V_1^g + V_1^p + V_1^{c'} \text{ subject to } (n, x, y, z) \text{ is incentive feasible.}$$

The rest of the section deals with the characterization of the optimal allocation.

Characterization 1 (C1). *Consider the allocation* (n, x, y, z) *where for all* $t = 1, 2, ..$*:*

1. $n_t^{c'} = n_t^c = n_t^p = 0$, $n_t^g = 1$,
2. $x_t = 1$, $y_t = 1$,
3. $z_t^g = (0, 0, 1)$, $z_t^c = (0, 0, t)$ *and* $z_t^{c'} = z_t^p = \mathbf{0}$.

The first item states that no notes should ever be produced but public notes, and a single public note is produced in all periods. The second item states that private and public goods are produced in every period. The third item refers to note transfers. Public notes are transferred from public to private agents and from consumers to producers in each period. Each agent always transfers its entire holdings of public notes. This allocation is represented in Figure 2.

Theorem 1. *Under Assumption 1 the allocation* (n, x, y, z) *characterized in C1 is the unique optimal allocation.*

Proof. It is straightforward to check that the allocation in C1 is a public allocation. Hence according to Proposition 2 it is incentive feasible.

It remains to check that this allocation maximizes welfare among the set of incentive feasible allocations. Disregarding incentive problems, Assumption 1 guarantees that the production of public and private goods in each period is socially beneficial. $\mu \geq \gamma/2$ implies that the social benefit of public goods is higher than the private opportunity cost it generates.

Furthermore, $\delta > c + \delta\varepsilon$ implies that public agents benefit from the production of the public good, even if they have to produce one note.

Given incentive problems, Lemma 2 implies that at least one note has to be transferred from public to private agents. Lemma 3 and Proposition 1 imply that it is not optimal that such a note is a private note. From Lemma 3, the use of private notes creates further incentive problems that can only be solved by producing additional notes. However from Proposition 1 such incentive problems do not exist when public notes are used. Hence, a public note must be transferred from public to private agents. Now transferring one note each period is the cheapest possible transfer. Using available public notes in order to implement trade among private agents is optimal as it does not create additional costs or distortion. However, because of existing incentive problems, transferring the entire note holdings is necessary.

Introducing transfers from private to public agents increases the cost of notes production. These transfers would have to be smaller than what the public agent transfers to private agents, otherwise the latter would prefer autarky. Finally, transfers would have to take place at least one period before the notes are effectively used by public agents. Hence notes would have to be produced at least one period before they become useful. Discounting implies that this is not optimal for society. □

5 Discussion

5.1 Public Agents

I model public agents so as to capture the core responsibilities of the State. This choice has the advantage of clearly underpinning the important feature of public notes as the optimal means of payment. Public agents share all the characteristics of private agents, but they provide public goods. Their specialization in the production of public goods explains why their notes are used.

To solve incentive problems due to the lack of information and commitment, private notes must be given to agents who can produce them. However, these notes have little value to these agents thus creating additional incentive problems. On the other hand private agents prefer to free ride on the production of public good rather than paying for it. Hence, public notes used by private agents are never transferred to public agents. Therefore, the incentive problems created by the use of private notes do not exist. In this sense there is a natural complementarity between the production of public goods and the production of money.

In an environment with no enforcement but where the State *can* force agents to produce their goods, money is unnecessary to the production of public goods. However, even in this case, the use of State money is still optimal because it circumvents the aforementioned distortion associated with the use of agents' notes. A similar concern might arise when taxation is allowed. One might conjecture that public money then is not needed for the purchase of private goods. This is true. However, the use of private money by the State reinforces and does not solve the distortions associated with private money.

Finally, public agents do not tend to overissue notes. The reason is the limited amount of ω that private agents can sell. In the present environment, the only way overissue can arise is to assume ω is in infinite supply. In itself this does not appear a very appealing assumption.

5.2 Matching Structure

Deterministic matching allows for the circular pattern of note transfers. This permits type 1 agents to monitor actions of type 2 agents and inversely. The possibility for such a circular pattern is the most important feature of the environment and gives the core results of this paper. Corbae *et al.* (2000) show that random matching is not necessary for money to be valued and I exploit here this characteristic.

It is critical that matching is deterministic. Because meetings are set deterministically, agents know *the history* of encounters. If matching is random, notes cannot communicate appropriately past actions of the holder because it is always possible (although with decreasing probability) that a type i only met another type i in past meetings, so that the former type i agent has no notes $j \neq i$. As a consequence if type i agents are producers, they will always deviate and pretend they did not meet a consumer.

The reasoning used in the derivation of the results are not affected by the matching order. Indeed, the proofs of the lemmas are not using the specified ordering. However, the optimal allocation is of course modified by a change in the matching structure. Suppose private agents are matched with public agents in their last meeting of any given period. Then it might be optimal to use private notes in the first periods. However, the social planner minimizes the cost associated with these private notes by removing them from the economy as soon as possible once public notes are in circulation (i.e. in the second period). The way to do this is to require the transfer of the private notes to public agents in exchange for a transfer of one public note. This is incentive feasible and, provided ε is low enough, maximizes social welfare.

5.3 Social Weights

The analysis uses a social welfare function with equal weights to any agents in the society. Results are robust to the degenerate case where public agents are not given any social weight. If the consumption of a measure λ of public good gives $\lambda\mu$ utiles to private agents, then the results hold. The social benefit of having the public good being produced is $2\mu > \gamma$. Is it still robust if the consumption of a measure λ of public good gives less than $\lambda\gamma/2$ utiles to a private agent? In this situation, the social planner may wish to stop the complete production of the public good because the net benefit for each private agent of having the public good being produced is negative. However, the social planner faces a crucial tradeoff. Either private agents produce private notes forever, or they produce for public agents in the first period and then use public notes. From Lemma 3 and the implied cost of private note production, the social planner will prefer to have public notes being produced only in the first period and having private agents use public notes forever after if the discount factor is large enough. Hence the results are robust to a change in social weights.

5.4 Goods Divisibility

Irrespective of the production level, the use of private notes implies additional incentive problems that are non-existent if only public notes are used. Hence using public notes in implementing goods exchange is always more efficient than using private notes, whether or not goods are divisible. Goods divisibility is only an issue for the implementation of a certain level of production.

For instance, If producers could produce a perfectly divisible good in $[0, 1]$, then the result would not be modified if the optimal allocation requires the production of 1 unit of private good. As only consumers are able to make offers, they would never ask for less. However, if the production that maximizes welfare irrespective of incentive problem requires the production of $y < 1$ units of private goods, then consumer could make an offer where the producer has to produce slightly more. Hence it is likely that this allocation is not incentive feasible.

6 Conclusion

I considered an environment with three crucial characteristics. First, no agent is able commit to his actions. Second, money is essential to achieve a non-autarkic allocation. Third, agents can produce their own, perfectly distinguishable, means of payment at a cost. In this environment I prove that public agents who are specialized in the production of public goods issue the optimal means of payment..

The main reason for this result is that while private agents cannot commit to deliver goods to the bearer of their notes, public agents do not need to commit: because all private agents free ride, public notes are never used to buy public goods. Therefore, while a costly commitment device is necessary in the case private money is used, no such device is necessary if only public money is used. In this sense, public paper money is more efficient than private paper money.

It is daring to draw implications from such a simple model. However, I believe the trade-off between information acquisition and incentives will survive any generalization of the present framework. Therefore, in a world where the abstraction in the means of payment increases enforcement problems, unless there is an important shortage of liquidity and potentially substantial gains from the introduction of private means of payment, they shall only be introduced with caution, if at all.

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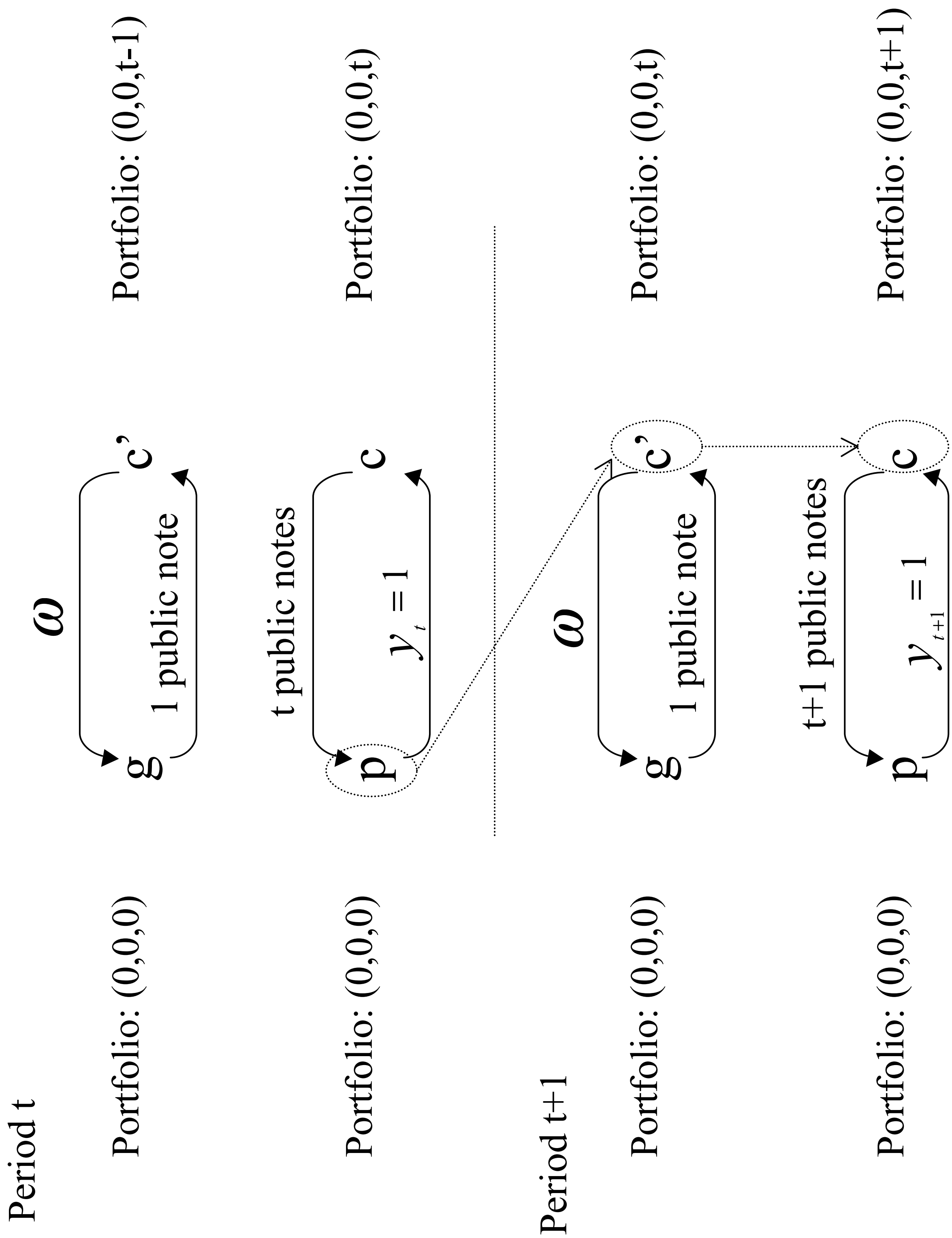
Period t
Portfolio: (0,0,0)
ω
1 public note
g
c'
Portfolio: (0,0,t-1)
t public notes
Portfolio: (0,0,0)
p
$y_t = 1$
c
Portfolio: (0,0,t)
Period t+1
Portfolio: (0,0,0)
ω
1 public note
g
c'
Portfolio: (0,0,t)
t+1 public notes
Portfolio: (0,0,0)
p
$y_{t+1} = 1$
c
Portfolio: (0,0,t+1)

t= 1	(g , 1)	
	(2 , 1)	
t= 2	(g , 2)	generically, (g , c’)
	(1 , 2)	in each period: (p , c)
t= 3	(g , 1)	
	(2 , 1)	
…		

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