Inflation and Welfare in the Laboratory

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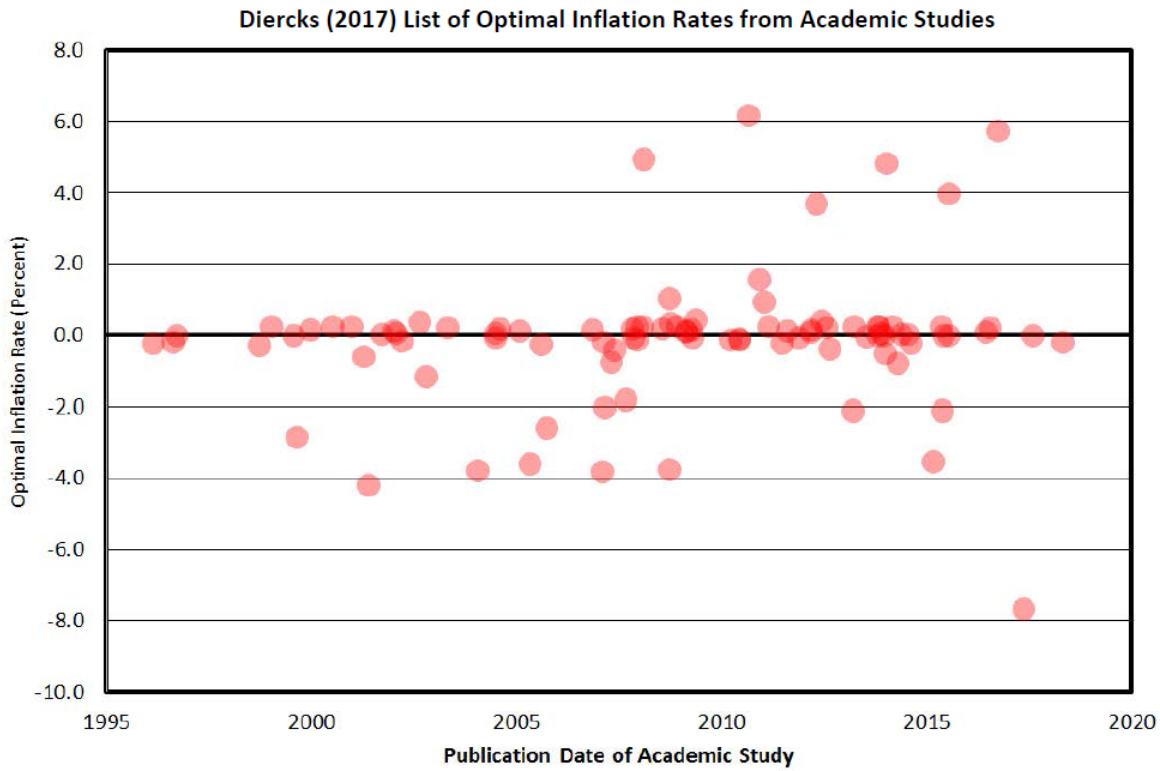
costs and benefits of inflation

- Important to evaluate costs and benefits of inflation
- Policymakers may benefit from studies on welfare implications of monetary policies



what we do

- An experimental study on the effects of inflation and monetary policy
  - Based on Lagos and Wright (2005) and Rocheteau and Wright (2005) models of monetary exchange
- Three implementation schemes for inflationary policy
  1. Govt spending using seigniorage
  2. Lump-sum transfers
  3. Proportional transfers (neutral)

what we do

- How different inflationary policies affect output traded, prices, inflation, and welfare relative to laissez-faire benchmark
- Empirical exploration of quantity theory of money
- Implications for monetary policy design, welfare cost of inflation

why a laboratory experiment?

- Monetary policy experiments in the field difficult, especially without prior wind tunnel
- Controlled testbed for effects of monetary policy through different implementation schemes
  - Are theoretical implications of monetary policies supported in the lab?
  - Do policies work as intended?
- Welfare implications of monetary policies difficult to measure and assess in the field
  - How costly is inflation in welfare terms?

preview of findings

Comparison of **laissez-faire** (Constant Money Supply) vs. **inflationary** treatments (Govt Spending, Lump Sum, Proportional)

- Quantities traded and welfare lower, prices higher with Govt Spending and Lump Sum; stronger effects with Govt Spending
  - Higher inflation associated with more detrimental effects
- Quantities traded and welfare not significantly different with Proportional transfers, relative to Constant Money, but prices higher
- Largely consistent with the theory
  - Inflation close to theoretical inflation in stationary equilibrium
  - Govt Spending has strongest impact on output and welfare

related literature

Experiments on money as a medium of exchange

- Brown (1996), Duffy and Ochs (1999, 2002), Camera, Noussair, and Tucker (2003), Berentsen, McBride, and Rocheteau (2014)
- Camera and Casari (2014), Duffy and Puzzello (2014)
- Jiang and Zhang (2018), Rietz (2018), Ding and Puzzello (2018)

Experiments on effects of monetary policy and inflation

- Marimon and Sunder (1993, 1994, 1995), Lim, Prescott, and Sunder (1993), Bernasconi and Kirchkamp (2000)
- Deck, McCabe, and Porter (2006)
- Anbarci, Dutu, and Feltovich (2015)
- Duffy and Puzzello (2017)

Inflation and welfare in search models

- Lagos and Wright (2005), Molico (2006), Rocheteau and Wright (2009), Aruoba, Rocheteau, and Waller (2007), Craig and Rocheteau (2008)

THEORETICAL FRAMEWORK

model environment

Experiments based on version of Rocheteau and Wright (2005)

- Microfounded model of money as a medium of exchange
- Two rounds of competitive market trade
- Monetary policy formalized as growing money supply
- Testable predictions on effects of money growth through different implementation schemes

environment

- Finite population of $2N$ infinitely lived agents
- Each period has two competitive markets, A and B, opening sequentially
- Lack of commitment, no formal enforcement, private trading histories
- Two types of agents (fixed roles)
  - Type A: want to consume Good A produced in market A by Type B
  - Type B: want to consume Good B produced in market B by Type A
- Good A and B both divisible, nonstorable across periods and markets
- Fiat money is divisible and storable, grows at constant gross rate $\gamma \equiv M_{t+1}/M_t$

environment

Period utilities of type A and B agents:

$$U^A = \underbrace{u(x_A)}_{\text{market A}} - \underbrace{x_B}_{\text{market B}}$$

$$U^B = \underbrace{-x_A}_{\text{market A}} + \underbrace{x_B}_{\text{market B}}$$

Opportunity to readjust money balances + linear preferences in market B (gets rid of wealth effects) $\rightarrow$ degenerate distribution of money holdings

monetary policy

Different schemes to implement inflationary monetary policy (i.e. $\gamma > 1$)

1. **Government spending**: govt sets expenditures financed through seigniorage ($\gamma_H > \gamma_L > 1$)
2. **Lump-sum transfers**: helicopter drop of money to some agents at the beginning of market B ($\gamma_H > 1$)
3. **Proportional transfers**: transfers proportional to token holdings at the beginning of market B ($\gamma_H > 1$)

Theoretical predictions

- Policies 1 and 2 yield same stationary equilibrium where inflation constant at $\gamma_H - 1$ with quantities and welfare lower than in laissez-faire baseline regime
- Policy 3 has no real effects
- Policy 1 with different money growth rates allows for a more exhaustive exploration of the quantity theory of money

THE EXPERIMENTS

experimental design

5 treatments run at Purdue and Indiana University in 2018 and 2019

1. **Constant money growth** (CM)
2. **Government spending 15** (GS15)
3. **Government spending 30** (GS30)
4. **Lump-sum transfers 30** (LS30)
5. **Proportional transfers 30** (PR30)

setup

- Each session consists of several sequences
- Each sequence consists of an indefinite number of periods
  - Sequence continued with probability $\beta = 0.9$
  - Block random termination: subjects get feedback on termination each period only after "block" of first 10 periods (see Frechette Yuksel 2017)
  - Sessions averaged 32.3 total periods (median of 3 sequences)
- Each period consists of market A followed by market B

setup

- $2N = 8, 10$ subjects equally split between
  - Type A: consumers in market A, producers in market B
  - Type B: consumers in market B, producers in market A

- Period utilities:

$$U^A = \underbrace{A\frac{x_A^{1-\eta}}{1-\eta}}_{\text{market A}} - \underbrace{x_B}_{\text{market B}}$$

$$U^B = \underbrace{-x_A}_{\text{market A}} + \underbrace{v_0 + x_B}_{\text{market B}}$$

  where $A = 2.65$, $\eta = 0.378$, $v_0 = 5$ ($v_0 = 6$ in GS15, $v_0 = 8$ in CM and PR30)

- Mapping of production / consumption to points presented to subjects in tables (in written instructions and on computer screen)

market game

- Market game as in Shapley-Shubik (1977) as foundations for competitive equilibrium
  (see Duffy, Matros, Temzelides (2011), Duffy and Puzzello (2014, 2017))
- In both market A and B
  - Producers submit quantity to produce (x_A or x_B)
  - Consumers submit bid of tokens for Good A or B (b_A or b_B)
- In each market, price is given by

$$P = \frac{\text{Total Tokens Bid}}{\text{Total Amount Produced}}$$

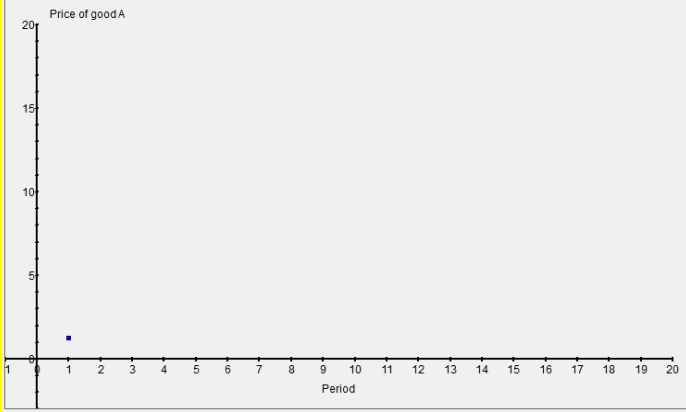
schedule of token increases

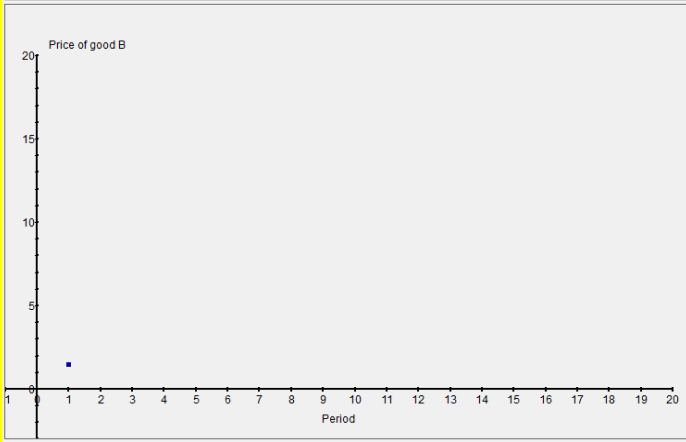
- Type A endowed with 5 tokens each at start of new sequence
- In Constant Money Supply, token supply fixed at 25
- Otherwise, token supply increased by 15% or 30% in market B each period (all schemes publicly known)
  - In GS15 and GS30, "robots" in market B create and use new tokens to buy Good B
  - In LS30, Type B get lump-sum tokens at the start of each market B
  - In PR30, all types get 30% transfer at the start of each market B

Period	Total Tokens	Total Token Increase
1	25.00	7.50
2	32.50	9.75
3	42.25	12.68
4	54.93	16.48
5	71.40	21.42
6	92.82	27.85
7	120.67	36.20
8	156.87	47.06
9	203.93	61.18
10	265.11	79.53
...*	...	...

sample screenshot

Your ID: 1 Sequence 1 Period 2





Your Roles

You are a CONSUMER in market A, and a PRODUCER in market B.

Tradeoff You Face

In each producer-consumer cycle, you face the following tradeoff.

Production cost in market B: you incur a cost of xB points from producing xB units of good B.

Consumption benefit in the next market A: if the sequence continues to the next market A, then you use your sales revenue of xB*pB tokens in market B to buy and consume xB*pB/pA additional units of good A in the next market A.

Your cost from producing good B and benefit from consuming good A are listed in the table on the right.

We are in **market A,** and you are a CONSUMER.

Your current token holdings are 4.50

The amount of tokens you would like to spend on good A

(Please choose a number between 0 and 4.50)

(Up to 2 decimal points are allowed.)

OK

Table: Your cost of producing xB and benefit of consuming xA measured in points

xA or xB	cost producing xB	benefit consuming xA
0	0	0
1	1	4.27
2	2	6.58
3	3	8.46
4	4	10.12
5	5	11.62
6	6	13.01
7	7	14.32
8	8	15.56
9	9	16.74
10	10	17.88
11	11	18.97
12	12	20.02
13	13	21.04
14	14	22.04
15	15	23.00
16	16	23.94
17	17	24.86
18	18	25.76
19	19	26.64
20	20	27.50
21	21	28.35
22	22	29.18
23	23	30.00
24	24	30.80
25	25	31.60
26	26	32.38
27	27	33.14

session summary

- Sessions lasted 2 hours (instructions + quiz + experiment)
- Point totals from all sequences converted to cash at exchange rate 1 point = \$0.15

Treatment	Session	Date	Location	Subjects	Sequence
Constant Money Supply, CM	1	8/3/2018	Purdue	8	9,15
	2	8/24/2018	IU	10	6,8,2,16
	3	8/29/2018	IU	10	13,10,5
	4	9/5/2018	Purdue	10	5,6,4
Government Spending 15, GS15	1	3/27/2019	Purdue	10	9,15
	2	3/27/2019	Purdue	10	6,8,2
	3	3/27/2019	IU	10	13,10
	4	3/27/2019	IU	10	5,6,4,1
Government Spending 30, GS30	1	7/25/2018	Purdue	10	9,15
	2	8/27/2018	IU	10	6,8,2,16
	3	9/19/2018	Purdue	10	13,10
	4	9/4/2018	Purdue	10	5,6,4,1
Lump Sum Transfers 30, LS30	1	9/26/2018	Purdue	10	9,15
	2	9/27/2018	Purdue	10	6,8,2
	3	10/10/2018	Purdue	10	13,10,5
	4	10/23/2018	Purdue	10	5,6,4
Proportional Transfers 30, PR30	1	11/27/2018	Purdue	10	9,15
	2	11/27/2018	Purdue	10	6,8,2
	3	12/7/2018	Purdue	10	13,10
	4	12/7/2018	Purdue	10	5,6,4

main predictions

Treatment	x_A	x_B	m_t	$p_{b,t}$	Inflation	Welfare Ratio
1. CM	10	10	5	0.5	0	0.98
2. Govt Spending 15	6.91	7.95	$5 \times 1.15^{t-1}$	1.15^{t-1}	15%	0.91
3. Govt Spending 30	5	6.5	$5 \times 1.3^{t-1}$	1.3^{t-1}	30%	0.82
4. Lump Sum 30	5	6.5	$5 \times 1.3^{t-1}$	1.3^{t-1}	30%	0.82
5. Proportional 30	10	10	$5 \times 1.3^{t-1}$	1.3^{t-1}	30%	0.98

- First-best output in market A is $x_A^* = 13.2$
- Welfare ratio defined as sum of individual surpluses in market A over first-best surplus

$$\frac{\sum_i [u(x_{A,i}) - x_{A,i}]}{N[u(x_A^*) - x_A^*]}$$

hypotheses

Hypothesis 1. Inflation and prices are higher in GS15, GS30, LS30, and PR30 than in CM.

Hypothesis 2. Output and welfare in market A are lower in GS30, GS15 and LS30 relative to CM and PR30.

Hypothesis 3. Output and welfare in market A are the same across GS30 and LS30.

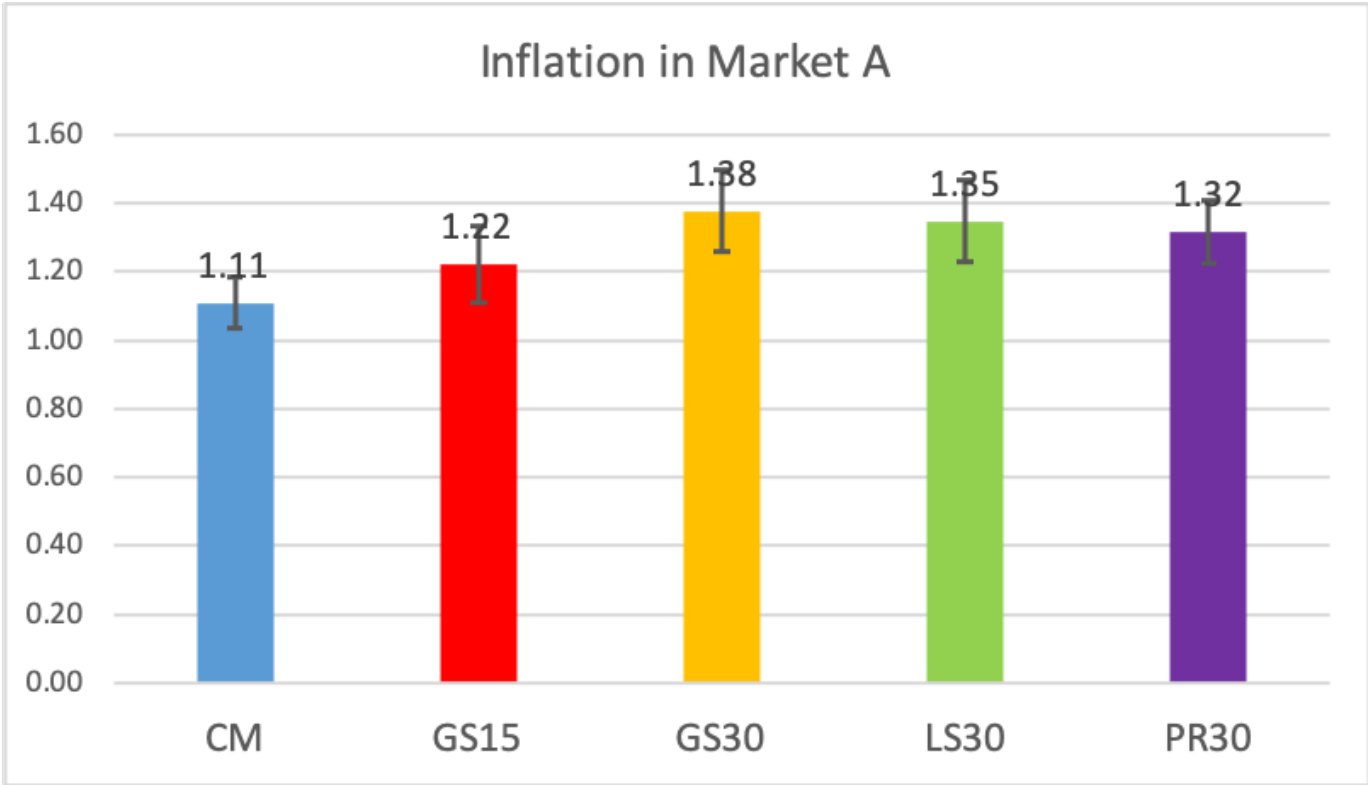
Hypothesis 4. Output and welfare in market A are the same across CM and PR30.

Hypothesis 5. Changes in prices correspond to changes in the money supply.

FINDINGS

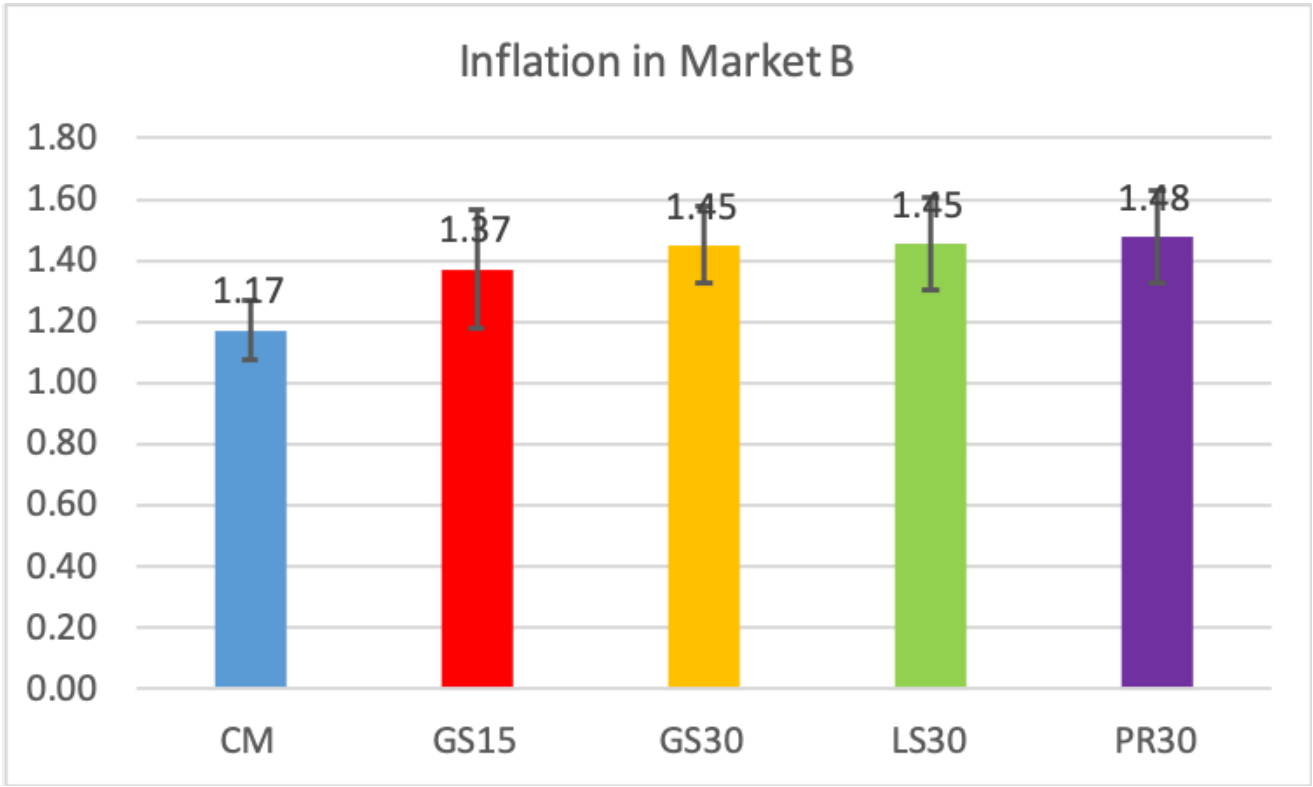
market A inflation

hypothesis 1: **inflation**



market B inflation

hypothesis 1: **inflation**



hypothesis 1: **inflation**

Partial support for hypothesis 1

- Market A inflation magnitudes in line with theoretical predictions

VARIABLES	(1) CM	(2) GS15	(3) GS30	(4) LS30	(5) PR30
Period	0.0371***	0.132***	0.241***	0.207***	0.225***
	(0.00396)	(0.00283)	(0.00314)	(0.00476)	(0.00315)
Constant	-1.375***	-0.923***	-0.822***	-1.070***	-1.298***
	(0.0272)	(0.0209)	(0.0233)	(0.0329)	(0.0190)
Observations	1,290	1,290	1,340	1,180	1,080
R-squared	0.072	0.628	0.821	0.646	0.817

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

hypothesis 1: **inflation**

Partial support for hypothesis 1

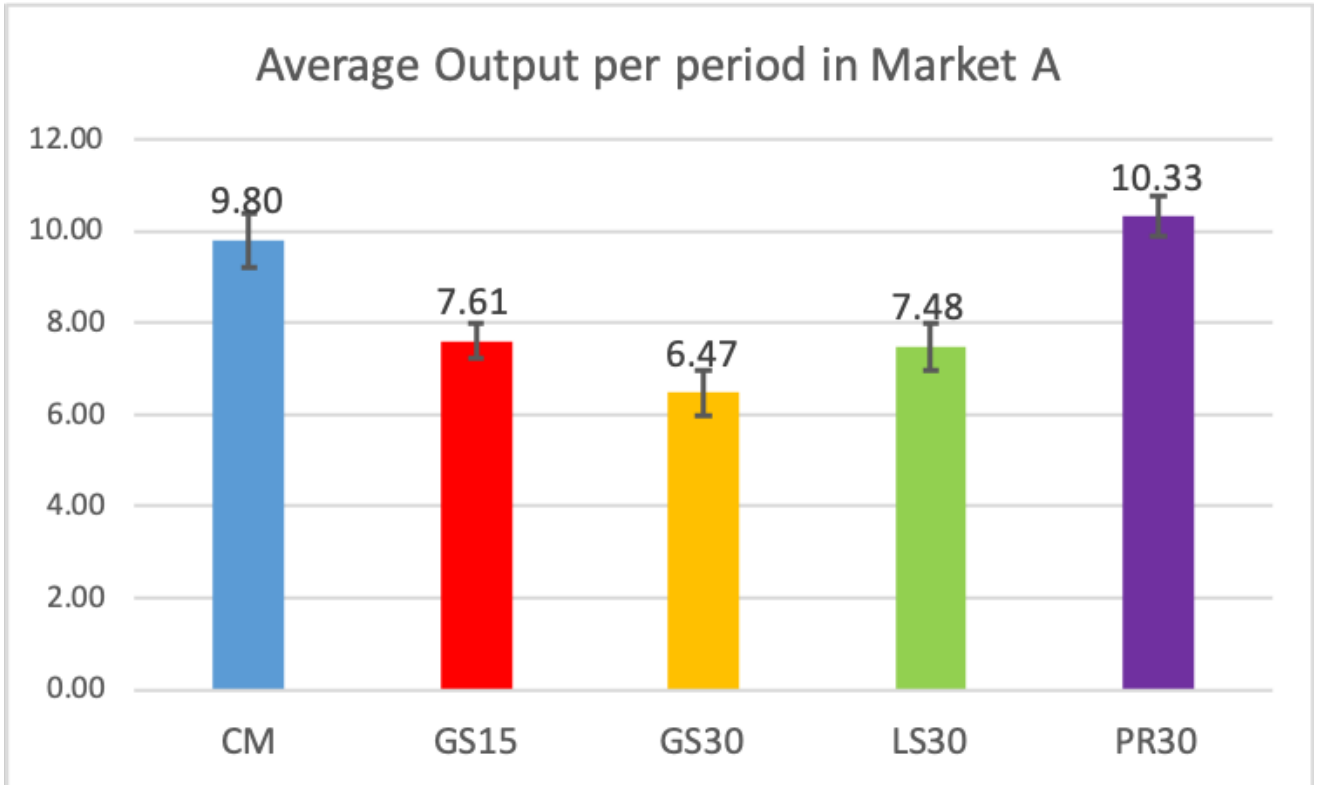
- Market B inflation magnitudes in line with theoretical predictions

VARIABLES	(1) CM	(2) GS15	(3) GS30	(4) LS30	(5) PR30
Period	0.0502***	0.156***	0.252***	0.242***	0.276***
	(0.00466)	(0.00343)	(0.00320)	(0.00403)	(0.00415)
Constant	-1.341***	-0.859***	-0.752***	-0.793***	-1.176***
	(0.0277)	(0.0211)	(0.0253)	(0.0266)	(0.0274)
Observations	1,290	1,290	1,340	1,180	1,080
R-squared	0.096	0.608	0.823	0.763	0.787

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

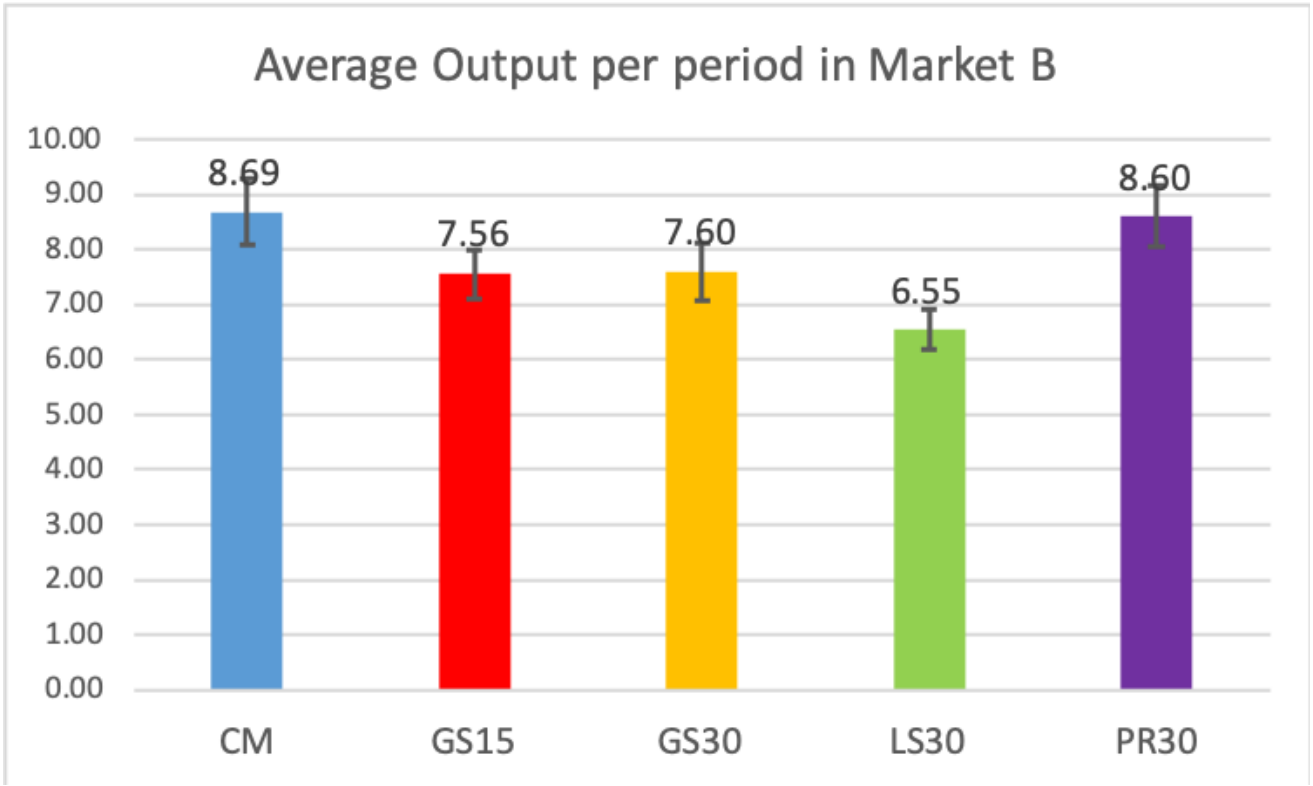
market A output

hypotheses 2-4: **output** and welfare



market B output

hypotheses 2-4: **output** and welfare

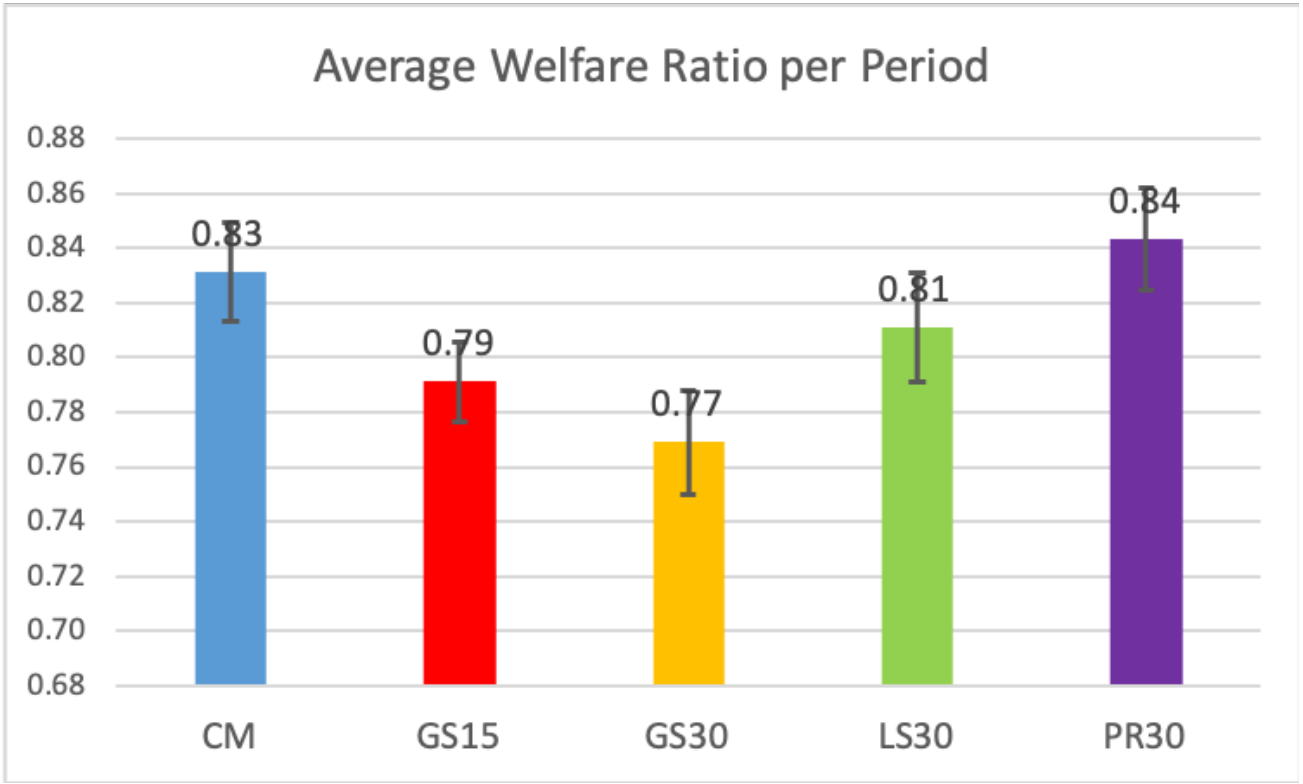


welfare

Treatment	Average Welfare Ratio		
	1st Half	2nd Half	All
1. CM	0.91	0.90	0.91
2. CM	0.79	0.71	0.75
3. CM	0.91	0.88	0.89
4. CM	0.86	0.85	0.85
Avg. 1-4	**0.87**	**0.83**	**0.85**
1. GS15	0.82	0.76	0.79
2. GS15	0.90	0.83	0.87
3. GS15	0.79	0.73	0.76
4. GS15	0.80	0.75	0.77
Avg. 1-4	**0.83**	**0.77**	**0.80**
1. GS30	0.85	0.80	0.82
2. GS30	0.83	0.80	0.82
3. GS30	0.83	0.77	0.80
4. GS30	0.70	0.65	0.68
Avg. 1-4	**0.80**	**0.76**	**0.78**
1. LS30	0.93	0.79	0.86
2. LS30	0.69	0.68	0.68
3. LS30	0.86	0.86	0.86
4. LS30	0.90	0.80	0.85
Avg. 1-4	**0.84**	**0.78**	**0.81**
1. PR30	0.92	0.84	0.88
2. PR30	0.86	0.80	0.83
3. PR30	0.82	0.74	0.78
4. PR30	0.91	0.85	0.88
Avg. 1-4	**0.88**	**0.81**	**0.84**

welfare

hypotheses 2-4: output and **welfare**



hypotheses 2-4: **output** and welfare

Partial support for hypotheses 2-4

- Market A output significantly lower in Govt Spending and Lump-Sum treatments than in Constant Money. Market A output not significantly different between Proportional and Constant Money.

VARIABLES	(1) Market A output	(2) Average Market A Output
GS15	-2.080*	-2.193***
	(1.225)	(0.358)
GS30	-3.213***	-3.326***
	(1.222)	(0.389)
LS30	-2.206*	-2.319***
	(1.203)	(0.397)
PR30	0.642	0.529
	(1.512)	(0.375)
Constant	9.687***	9.800***
	(0.817)	(0.303)
Observations	3,090	623
R-squared	0.051	0.218

Robust standard errors in parentheses, clustered at subject level in (1)
*** p<0.01, ** p<0.05, * p<0.1

hypotheses 2-4: output and **welfare**

Partial support for hypotheses 2-4

- Welfare lower in Govt Spending than in Constant Money. Welfare in Lump-sum not significantly lower than in Constant Money. Welfare in lump-sum not different than in Govt Spending. Welfare in Proportional not significantly different than in Constant Money.

	(1)	(2)
VARIABLES	Welfare	Welfare Ratio
GS15	-0.322***	-0.0402***
	(0.0944)	(0.0118)
GS30	-0.500***	-0.0625***
	(0.106)	(0.0132)
LS30	-0.162	-0.0203
	(0.109)	(0.0136)
PR30	0.0962	0.0120
	(0.105)	(0.0131)
Constant	6.656***	0.831***
	(0.0737)	(0.00921)
Observations	623	623
R-squared	0.066	0.066

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

conclusions

An experimental study on the effects of monetary policy through different implementation schemes for inflation. Insights from the experiments

- Inflation in experimental economies close to theoretical predictions
- Money growth via LS and GS leads to lower output and welfare, especially in GS treatment
- Money growth via PR is neutral
- Results largely consistent with theory, but welfare loss from inflation lower than predicted

conclusions

- Results different from Duffy and Puzzello (2017) where inflation *increases* output
  - But many different design choices: trading protocol, probability of continuation, fixed roles, timing of lump-sum implementation, block...
- To do: more comparison across implementation schemes, e.g., dispersion of money holdings, consumption and production

future work

1. Effects of monetary policy on currency competition
   - Framework with two currencies where monetary policy affects rate of return on each currency (as in Zhang 2014)
   - Currency substitution, dollarization in response to inflation
2. Other implementation schemes for monetary policy
   - Open market operations (as in Rocheteau, Wright, Zhang 2018)
   - Inflation targeting
3. Role of different trading institutions
   - Competitive pricing, bargaining, directed search, market participation (as in Rocheteau Wright 2005)
   - Optimal trading mechanism (as in Hu, Kennan, Wallace 2007, Bajaj, Hu, Rocheteau, Silva 2017)

fraction tokens spent

Treatment	Average Spend Ratio Market A				Average Spend Ratio Market B			
	1^{st} Half	2^{nd} Half	All	St. Dev.	1^{st} Half	2^{nd} Half	All	St. Dev.
1. Baseline	0.72	0.72	0.72	0.094	0.91	0.98	0.94	0.08
2. Baseline	0.86	0.94	0.90	0.102	0.76	0.75	0.75	0.1
3. Baseline	0.70	0.73	0.72	0.068	0.61	0.69	0.65	0.11
4. Baseline	0.52	0.66	0.59	0.131	0.73	0.75	0.74	0.11
Avg. 1-4	**0.70**	**0.78**	**0.74**	**0.10**	**0.74**	**0.77**	**0.76**	**0.10**
Eq. Predictions	-	-	1	-	-	-	1	-
1. Govt Spending	0.9	0.79	0.84	0.099	0.71	0.78	0.75	0.13
2. Govt Spending	0.86	0.83	0.84	0.070	0.85	0.82	0.84	0.1
3. Govt Spending	0.77	0.79	0.78	0.043	0.56	0.54	0.55	0.08
4. Govt Spending	0.78	0.77	0.78	0.063	0.66	0.61	0.63	0.07
Avg. 1-4	**0.83**	**0.80**	**0.81**	**0.068**	**0.71**	**0.70**	**0.71**	**0.089**
Eq. Predictions	-	-	1	-	-	-	1	-
1. Lump Sum	0.57	0.61	0.59	0.090	0.60	0.57	0.58	0.18
2. Lump Sum	0.6	0.54	0.57	0.090	0.71	0.69	0.7	0.08
3. Lump Sum	0.53	0.54	0.54	0.089	0.82	0.83	0.83	0.074
4. Lump Sum	0.85	0.86	0.85	0.067	0.77	0.72	0.75	0.108
Avg. 1-4	**0.64**	**0.64**	**0.64**	**0.084**	**0.74**	**0.71**	**0.73**	**0.102**
Eq. Predictions	-	-	1	-	-	-	1	-
1. Proportional	0.76	0.76	0.76	0.067	0.68	0.53	0.61	0.142
2. Proportional	0.82	0.85	0.84	0.106	0.75	0.70	0.72	0.087
3. Proportional	0.75	0.71	0.73	0.087	0.81	0.80	0.81	0.075
4. Proportional	0.70	0.73	0.72	0.065	0.76	0.84	0.80	0.097
Avg. 1-4	**0.76**	**0.77**	**0.77**	**0.082**	**0.75**	**0.73**	**0.74**	**0.099**
Eq. Predictions	-	-	1	-	-	-	1	-

Table 4: Average Spend Ratio