Distributing scarce jobs and output: Experimental evidence on the dynamic effects of rationing

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Abstract

How does the allocation of scarce jobs and production influence their supply? We present the results of a macroeconomics laboratory experiment that investigates the effects of alternative rationing schemes on economic stability. Participants play the role of worker-consumers who interact in labor and output markets. All output, which yields a reward to participants, must be produced through costly labor. Automated firms hire workers to produce output so long as there is sufficient demand for all production. In every period either output or labor hours are rationed. Random queue, equitable, and priority (i.e., property rights) rationing schemes are compared. Production volatility is the lowest under a priority rationing rule and is significantly higher under a scheme that allocates the scarce resource through a random queue. Production converges toward the steady state under a priority rule, but can diverge to significantly lower levels under a random queue or equitable rule where there is the opportunity for and perception of free-riding. At the individual level, rationing in the output market leads consumer-workers to supply less labor in subsequent periods. A model of myopic decision-making is developed to rationalize the results.

JEL classifications: C92, E13, H31, H4, E62

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1 Introduction

To a person living in a developed economy today, the term ‘rationing’ likely evokes images of bread lines and reinforces the failures of central planning. Such a view is grounded in truth, but it obscures the fact that rationing of many forms still arises when the gears of the economy do not turn as smoothly as hoped. Simply put, markets do not always clear in a timely and efficient manner, and when that happens it falls to market participants or policymakers to decide how to do with what is available.

Rationing has been approached using many different allocation schemes. Food rationing occurred throughout North America and Europe during the two World Wars. Rationing was undertaken in such a way that every person would receive an equal portion of food. Victory or war gardens were planted at private residences and in public parks in many countries to alleviate demand on rationed food supplies. The gardens provided households an opportunity to supplement their weekly rations with their private food production. Those who put forth more effort tending to their gardens were able to eat more, leading to millions of tons of household food production.[1] Other rationing system have been associated with panic and instability. Before the advent of deposit insurance in the United States in 1933, banks allowed depositors to withdraw their money on a first-come, first-served basis until they ran out of funds. Depositors’ expectations that others would withdraw their deposits would caused panic and a run on the bank, leading to a fragile banking system. Large price cuts on Black Friday in the U.S. or on Boxing Day in Canada often result in consumers’ waiting long hours in line and in buying frenzies for the newest tech gadgets.

The rationing of inputs into the production process, namely labor hours, has been employed in dynamic macroeconomic models to generate cyclical fluctuations of involuntary unemployment observed in the United States and Europe (Michaillat (2012)). Labor rationing has been modeled in partial equilibrium settings as the result of ef-

[1]By contrast, evidence suggests that voluntary rationing of food during World War I was ineffective at ensuring equitable allocations: “While many better-educated and more affluent Americans did observe wheatless and meatless days, immigrants and those in the working class . . . increased their food intake; beef consumption . . . actually went up during the war” (Bentley (1998)).

ficiency wages (Stiglitz 1976; Solow 1980; Shapiro and Stiglitz 1984), gift exchange (Akerlof 1984), and search costs and turnover costs (Salop 1979; Akerlof 1984), or in general equilibrium environments as a consequence of matching frictions in labor and product markets (Michaillat and Saez (2015)). Unemployment risk associated with labor rationing can lead to precautionary saving, endogenous underemployment, and potentially deep recessions (Ravn and Sterk 2013; Kreamer 2014).

The need for rationing can become even more pronounced when dealing with goods and services that are not typically sold on the open market. To deal with a very low supply of organ donations, the Israeli government implemented a policy in 2008 to give priority on organ waiting lists to those willing to sign an organ donation card. By 2011, the policy had led to a dramatic increase in the number of deceased and living donors relative to previous years (Lavee et al. 2013).

These examples demonstrate the pervasiveness of rationing across time and in all manner of countries, as well as the wide-ranging consequences that can result. They lead us to ask challenging questions about the efficiency and fairness of different rationing schemes. Standard macroeconomic models with rational agents, however, fall silent on this subject; such an agent optimally demands the amount of output associated with its labor supply, and thus no rationing is needed.

This paper seeks to step into the gap between macroeconomic methodology and the answers we seek, by way of macroeconomic laboratory experiments. It is through such experiments that we have attempted to understand how varying approaches to rationing affect welfare not only directly, but also by affecting agents' choices in other markets.

We make use of a macroeconomic setting where households supply costly labor that produces utility-yielding output. In our framework, rationing occurs either when households are unwilling to purchase all the output they wish to produce, or when they prefer to consume more than they are willing to work to produce. Rationing occurs as a consequence of aggregate household decisions, an inability for prices to adjust fully, and a lack of inventories. When agents anticipate output rationing the optimal consumption–leisure tradeoff condition predicts that their willingness to supply labor also decreases, and vice versa. We investigate whether alternative allocation schemes lead to a greater reaction to and incidence of rationing, increased spillover effects into other markets, and overall greater volatility in production. Decision-making and aggregate outcomes are compared under three non-manipulable rationing schemes: a random queue where the rationed market is distributed on a first-come, first-served basis, an equitable allocation scheme, and a priority scheme where those willing to buy what they produce (or produce what they demand) receive priority for scarce labor hours (output).

Our contribution is to provide causal evidence of the implications of rationing rules on the availability of scarce labor opportunities and output. First, unlike the predictions of standard equilibrium models, we allow for and observe rationing of jobs and output in all of our sessions, with most instances involving output rationing. We also observe that the mechanism by which the short side of the market is rationed does matter for welfare and macroeconomic stability. Participants are willing to supply high levels of costly labor if they are given priority to purchase the output they produce. Under an equitable allocation scheme, the willingness to supply labor decreases in the presence of rationing, and output volatility is considerably higher. Occasionally—and sometimes permanently—aggregate labor supply will collapse to low levels due to output rationing under random and equitable distribution schemes. Allocating scarce output and jobs according to a priority scheme, by contrast, results in significantly more stable production by reducing subjects' exposure and reaction to rationing.

The confident far-sightedness and market clearing assumptions upon which mainstream macro models rely is at odds with the strategic uncertainty agents face when the actions of others could affect the future availability of resources. The typical response to output rationing observed in our experiments is to increase output demands and decrease labor supplies. This propagates further rationing of output. To rationalize these results we develop a model of myopic decision-making in which agents focus only on maximizing current utility and pessimistically expect others in the market to possess extremely high demands. Consistent with our experimental findings, the model predicts suboptimal equilibria under equitable and random allocation schemes that involve high aggregate demand for output and low labor supply.

Our findings also provide important political economy insights into redistribution policies. In an environment where individuals are equally skilled, redistributive policies that allocate equitably or on first-come-first-serve basis and that fail to appropriately compensate individuals for their costly labor can decrease willingness to work and lead to periods of economic turmoil. Conversely, policies that minimize redistribution and enforce property rights to the fruits of one's labor creates a sufficient incentive to consistently supply labor and can foster greater macroeconomic stability.

2 Rationing in theory and experiments

Our experimental analysis is most directly inspired by substantial theoretical work that introduces non-market clearing and quantity rationing to general equilibrium settings. The disequilibrium approach was born out of the earliest work by Patinkin (1956), in which involuntary unemployment occurred because of constraints on how much could be sold. His work spans nearly two decades and aims to understand the necessary and sufficient conditions by which general equilibrium environments can persistently exist out of equilibrium.[2] We develop an environment and set of rationing schemes most closely related to Svensson (1980). Svensson, building on earlier work by Gale (1979) and Futia (1975), develops the notion of stochastic rationing, whereby a consumer must submit demands to the market before it is known whether there will be rationing or not. The extent of trade is random due to the stochastic rationing mechanism. Such rationing is in contrast to the framework of Drèze (1975) in which consumers, facing no uncertainty, simultaneously take into account the extent of rationing and their budget constraints when forming their demands.[3] More recently, Michaillat and

[2] For an excellent survey of the macroeconomic disequilibrium theory literature, see Drazen (1980).

[3] An alternative approach to rationing was developed by Clower (1965), Barro and Grossman (1971), and Benassy (1975, 1977), whereby the consumer maximizes demand for each good separately subject to her budget constraint. In forming the demand for a good, the agent disregards quantity rationing for the particular good, but optimizes as though all other demands for goods in her consumption set have faced rationing. Gale (1979) and Svensson (1980) explore the existence of disequilibria under stochastic manipulable and non-manipulable schemes.

Saez (2015), develop a tractable equilibrium model of macroeconomic rationing that sidesteps the disequilibrium approach by employing a matching function that governs the probability of trade and imposes a cost of matching on buyers. Like the Barro-Grossman framework, Michaillat and Saez's model is able to capture the spillover of demand shocks to labor markets. While the disequilibrium literature has addressed the implications of manipulable versus non-manipulable rationing rules, little attention has been paid to the behavioral responses associated with alternative allocation schemes.

The extremely stylized assumptions which make up both Real Business Cycle (RBC) and New Keynesian (NK) approaches have been put to the test in recent years as never before. Whether they concern expectations, market clearing, or utility, such assumptions make these models tractable, and yet they have been criticized for being insufficiently complex and realistic to guide our understanding of, among other things, the most recent financial crisis (Colander et al. (2008)). These overly simplified environments can yield what Caballero (2010) describes as a 'pretense-of-knowledge', in which researchers become overconfident in the accuracy and precision of their results. It is for this reason that we deem it more important to produce a logical, functioning macro environment than to maintain simplicity for its own sake.

A number of partial equilibrium experiments have explored the effects of rationing schemes on decisions. In a closely related paper, Lefebvre (2013) designs a partial equilibrium common-pool resource game to compare four rationing rules the ability of four rationing rules–proportional, constrained-equal-awards, constrained-equal-losses, and no-allocation rules—in their ability to coordinate agents to optimal levels of self-insurance, efficiency, and reliability. Under the Nash equilibrium predictions, the rationing rule should not influence aggregate usage of the common resource or self-insurance. Lefebvre finds that no-allocation and constrained-equal-awards rules lead to more efficient coordination. Welfare gains are, however, highest under the constrained-equal-awards rule. On the other hand, proportional and constrained-equal-losses rules were shown to be easily manipulable and to lead to suboptimal investment in alternative safe resources. Lefebvre argues that the success of the constrained-equal-awards rule can be attributed to its ability to fully allocate the resource and to the fact that it reduces the strategic interaction among agents.

Studying the effects of allocation rules on organ donation, Kessler and Roth (2012) observe that priority on waiting lists for registered donors leads to significantly more donations than does a first-come, first-served scheme. Buckley et al. (2012) investigate the willingness to pay for private health insurance under different public sector health-care allocation rules. They observe that the willingness to pay for private insurance is significantly higher when public health care is allocated randomly than when it is allocated on a needs or severity basis. In both these environments, the implementation of specific rationing schemes effectively reduces the excess demand for scarce resources.

While single-market experiments can enlighten our understanding of how allocations schemes influence welfare and efficiency they are limited in their ability to tell us the significance that rationing poses to the economy at large. It is the incorporation of a more complex macroeconomic framework that allows us to extend beyond simple behavioral analyses and make robust predictions of direct relevance to policymakers.

To this end we develop a laboratory production economy in which participants playing the role of worker-consumers supply the necessary labor to produce the output they later purchase and consume. Such experimental environments have been used to study the effects of money supply and monetary policy (Lian and Plott (1998); Bosch-Domènech and Silvestre (1997); Petersen (2015)), exogenous shocks (Noussair et al. (2014, 2015)), and asset price stabilization policies (Fenig et al. (2016)). While these environments all experience some degree of rationing, there has yet to be a comprehensive analysis of how the nature of rationing influences aggregate outcomes. Our experiment directly builds on Fenig et al. (2016), by systematically investigating how rationing schemes influence decision-making and economic dynamics in a laboratory macroeconomy.

3 Experimental design and implementation

The experimental design and implementation extend the baseline macroeconomy developed in Fenig et al. (2016) by considering alternative rationing schemes. The environment we consider is a dynamic general equilibrium economy with nominal rigidities and monopolistic competition. We provide a fully derived model and parametrization in Appendices A and B.[4]

3.1 Experimental economy

Groups of nine participants were assigned the roles of households and were tasked with making decisions about how much to work and consume over a number of temporally linked periods. In each period, participants gained points by buying (and automatically consuming) units of the output good, c_t, at a price of P_t, and lost points by selling labor hours, h_t, to automated firms in exchange for an hourly wage, W_t. Points in any given period were awarded according to the following formula:[5]

$$Points = 1.51c_t^{0.66} - 0.4h_t^{2.5}. \tag{1}$$

Participants received a one-time endowment of 10 units of lab money to make purchases within the sequence. Additional lab money was earned through supplying labor and earning interest on savings. Each participant also received an equal share of the firms' profits, Π_t. When subjects did not hold enough cash (lab money) to purchase output, they were able to borrow at the prevailing interest rate; similarly, if they accumulated some savings due to unspent income, they earned interest on them. Thus,

[4] Fenig et al. (2016) study household decisions in an environment with a Priority rationing scheme. The data generated from their baseline environment is employed as one treatment in this paper.

[5] There are macroeconomic experiments that involve utility for leisure and that individual household/consumers can sell their leisure for income: see Riedl and Van Winden (2007) and Lian and Plott (1998) , while others focus on disutility from labor (Noussair, Plott, and Riezman (2007); Bosch-Domènech and Silvestre (1997); Petersen (2015); Noussair, Pfajfar, and Zsiros (2015). Macroeconomic models are often framed with supplying labor as a cost to the household. We can only speculate that endowing subjects with a stock of leisure which they can sell at a cost to themselves may encourage them to over-consume leisure due to an endowment-effect story. This was observed in Lian and Plott, but not in Riedl and Van Winden

all participants faced a per-period budget constraint given by $P_t c_t + B_t = W_t h_t + B_{t-1}(1 + i_{t-1}) + \Pi_t$, where B_t are one-period bonds and i_t is the nominal interest rates which were set by an automated central bank and adjusted automatically in response to changes in current inflation. Specifically, the central bank set the nominal interest rate according to the following Taylor rule:

$$(1 + i_t) = \left((1 + \rho)(1 + i_{t-1})(1 + \pi_t)^{1.5}\right)^{0.5}, \tag{2}$$

where $\rho = 0.0363$ is the natural nominal interest rate.

At the beginning of each period, participants were asked to submit the maximum number of hours they would be willing to work (up to a maximum of 10 hours) and the maximum units of output they would be willing to purchase (up to a maximum of 100 units). Participants were allowed to submit fractions of labor supply and output demand.

Automated monopolistically competitive firms produced output using labor as their sole input: firms were able to produce 10 units of output with each hour of labor hired. After all participants submitted their output demands and labor supplies, an aggregate supply of labor ($H_t^S = \sum_{j=1}^n h_{j,t}^S$) and demand for output ($C_t^D = \sum_{j=1}^n c_{j,t}^D$) were calculated and used to determine the aggregate level of labor demand and production. If there was more labor supplied than necessary to produce the total amount of output demanded, only the necessary amount of labor would be hired and hours would be rationed. On the other hand, if there was insufficient labor to produce the total amount of output demanded, all workers would be hired to work their desired labor and output would be rationed. Thus, output was made to order; no output was produced that was not demanded and sold.[6] We parameterized the firms' probability of being unable to up-

[6] We intentionally avoided the inclusion of advanced production and inventories in our experimental design. First, the presence of inventories would alleviate the degree of rationing. Second, the underlying model of our economy assumes firms produce output made to order. Production economy experiments such as Lian and Plott (1998) and Noussair et al. (2014, and 2015) allow for advanced production but do not allow firms to carry inventories from one period to the next. With advance-production, firms inevitably face the risk that their produced unit will not be sold. To buffer themselves, firms produce inefficiently low quantities. This is a plausible explanation for the low production levels in Lian and

date their prices to $1-\omega=0.1$. Such nominal rigidities prevented firms from adjusting prices sufficiently in response to aggregate demand.

Wages, prices, and the central bank's nominal interest rate evolved based on aggregate outcomes. Specifically, prices were determined by the evolution of inflation:

$$\Pi_t = 1 + 0.0016(c_t^{med} - c^{SS}) + 0.0744(h_t^{med} - h^{SS}) \tag{3}$$

where c^{SS}, and h^{SS} are consumption and labor steady state (SS) values, respectively. The nominal wage and the output price were then calculated using median realized labor supply, h_t^{med}, and output consumed, c_t^{med}, as[7]

$$P_t = P_{t-1}\Pi_t, \text{ and} \tag{4}$$

$$W_t = P_{t-1}\Pi_t \left(h_t^{med}\right)^{1.5} \left(c_t^{med}\right)^{0.33}. \tag{5}$$

Importantly, we assumed that the firms' pricing rule did not take into consideration the extent of rationing. Wages and prices were unable to adjust fully to accommodate excess aggregate labor supply or output demand. This was an important design decision that increased the occurrence of rationing when aggregate behavior was inconsistent with the predictions of a rational utility-maximizing framework.

To induce exponential discounting within an infinite horizon environment, we generated indefinite length sequences that ended randomly with a probability of 3.5%.[8] This implied an average length of 28 periods. To make this salient to subjects, in each period we drew a marble from a bag containing 193 blue marbles and 7 green marbles. If a green marble was drawn, the sequence ended and a new one began.[9]

Plott (1998).

[7] We use the median, rather than the average, of participants' labor and consumption decisions because latter may be biased due to decisions that were not submitted on time or by extreme outliers.

[8] This procedure was first implemented by Camerer and Weigelt (1993), and has been used by Lei and Noussair (2002) and Crockett and Duffy (2015) among others. Alternatively, one could shrink the utility points associated with consumption and labor as in Noussair, Pfajfar, and Zsiros (2014).

[9] Stationary repetition allows us to control for learning and is especially important in macroeconomic experiments. In our environment, subjects carry cash balances and debt from one period into the next. At the beginning of an experiment, it is not unreasonable for subjects to experiment with their decisions

Subjects did not earn or lose points for their savings or borrowing within a sequence, except for the case of the last period. When a sequence ended, participants would have either a positive or a negative cash balance in their bank account. If they had a positive balance, the participants would be required to buy up output and would be credited the points received for that final consumption. On the other hand, if the participants had a negative balance, they would be required to work the necessary hours to pay off their debt, and points would be deducted accordingly. To make this discounting salient, we provided participants with a hypothetical adjusted score assuming that the previous period was the last period of a sequence.

Participants had extensive information at their disposal to make decisions. First, the interactive computer interface enabled subjects to experiment with different combinations of labor and output decisions for both themselves and the average person in the economy, in order to derive predictions about their own potential points and bank account balances as well as aggregate wages, prices, and interest rates. We believe this dramatically facilitated learning of what would otherwise be a relatively complicated payoff function. Second, participants had access to all historical information up to the current period for a given sequence. They could toggle between personal history and market history to receive detailed information about past outcomes. Finally, we informed all participants what the steady state values of labor and consumption were and explained that if everyone in their group were to play such values for an extended amount of time, wages and prices would stop adjusting and the interest rate would converge to its steady state level. We provided such detailed information because the model is derived under the assumption that agents have full information about the data-generating process and the steady state values of the economy.[10]

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or make decision errors that will influence their bank account balances. Bank account balances, however, have important implications for optimal consumption and labor decision-making, and errors during learning can potentially bias subjects' behavior.

[10] We find little evidence that information about the steady state values biased subjects' initial decisions. When we consider the first round of play, we find no subject selects the equilibrium decision or rounds up or down to the next 0.1 value. Moreover, a very small proportion of subjects are within 1 (0.5) unit of the equilibrium value for output demand (labor supply). Of those subjects that submitted a decision, 5/51 in the Random treatment, 2/62 in the Equitable treatment, and 0/54 in the Priority

The desire to avoid unnecessary complexity in experimental design is still a very justifiable one, for the sake of both ensuring understanding amongst the participants and allowing clear interpretation and analysis after the fact. It is for these reasons that we removed a number of these moving parts to reduce a full DSGE framework into the simplest possible environment for answering these sorts of questions. Among other simplifications, firms were automated to follow specific production and pricing rules to make their behavior predictable, rationing schemes were exogenously imposed rather than being voted on as in some experiments, the production environment used only one input (labor) to produce only one output good, induced preferences/payoff functions were identical across subjects, and stationary repetition and many periods of play were used to address any possible confusion about the environment. Where we required complexity was in the dispersed interactions among agents and the rationing that occurred as a result of their own decisions. We see these two aspects of complexity as being absolutely necessary in order to study rationing.

3.2 Testable hypotheses under the assumption of homogeneous utility maximization

We now outline our testable hypotheses formed under the assumption that participants behave consistently with the predictions for a representative utility-maximizing household with rational expectations.

Hypothesis 1a *Household-consumers will individually supply* $h_{i,t} = h^{SS} = 2.24$ *hours of work and demand* $c_{i,t} = c^{SS} = 22.4$ *units of output.*

In the steady state, individuals consume 22.24 units of output and work 2.24 hours. This is the equilibrium solution to the model in Appendix A.

treatment chose a number in the range [21.37,23.37]. When it comes to labor supply decisions, we observe 10/51 in the Random treatment, 10/62 in the Equitable treatment, and 6/54 in the Priority treatment chose values in the range [2,2.5]. The full distribution of first-round decisions can be found in Appendix E.

Hypothesis 1b *The average labor supply will be* $H_t/n = h^{SS} = 2.24$ *and the average output demand will be* $C_t/n = c^{SS} = 22.4$ *units.*

If Hypothesis 1a holds then Hypothesis 1b will hold also. This is a weaker hypothesis that tests whether the economy converges on average to the steady state even if some individuals deviate from equilibrium consumption and labor.

Hypothesis 2 *There will not be rationing in labor or consumption.*

This is a consequence of Hypothesis 1a. If consumption demand and labor supply are symmetric among individuals, then there will not be rationing.

Hypothesis 3 *The allocation scheme will not affect participants' behavior.*

If Hypothesis 1a holds then Hypothesis 3 will also hold. Labor supply and output demand decisions should not be influenced by the different allocation rules.

3.3 Rationing rules

Note that in the above model, agents are assumed to optimize their labor and output decisions identically and have no reason to form expectations about future rationing. Thus, as Hypothesis 3 states, the equilibrium predictions should be unaffected by the choice of a specific rationing rule.

In our environment, n households simultaneously submitted their desired labor supply and output demand. Given aggregate output demand (C_t^D) and labor supply (H_t^S), individual actual consumption ($c_{i,t}$) and labor ($h_{i,t}$) in the experiment were allocated according to one of three scenarios at any point in time:

1. If $C_t^D = H_t^S$, neither output nor labor was rationed, $c_{i,t} = c_{i,t}^D$ and $h_{i,t} = h_{i,t}^S$.
2. If $C_t^D > H_t^S$, subjects obtain the hours of work they requested, $h_{i,t} = h_{i,t}^S$, and output was rationed, $c_{i,t} = \min\left(\theta_{ci,t}^R, c_{i,t}^D\right)$.
3. If $C_t^D < H_t^S$, subjects obtain the output they requested, $c_{i,t} = c_{i,t}^D$, and labor was rationed, $h_{i,t} = \min\left(\theta_{hi,t}^R, h_{i,t}^S\right)$.

Where $\theta_c^R(\theta_h^R)$ is the individual consumption (hours) when output (labor) is rationed according to a specific rule R. Note that households never obtained more than their desired consumption and labor.

A household that supplied the equilibrium level of labor but faced rationing in terms of output would experience an increase in its money balance. As noted by Barro and Grossman (1971), the household's best response to frustrated demand is to increase its output demand and/or decrease its labor supply over the following periods. All else equal, both will generate further excess demand. Likewise, following involuntary unemployment or underemployment relative to consumption, the household's best response is to smooth its consumption over the horizon by increasing its labor supply and/or reducing its output demand. Thus, involuntary unemployment can further increase excess labor supply in the future. This leads us to our fourth testable hypothesis:

Hypothesis 4 *Excess output demands and labor supplies are persistent.*

In this paper, we explicitly test whether different rationing rules influence economic stability and welfare. We focus on rationing rules for which realized outcomes for an individual i are a function of her own effective supplies and demands, as well as the aggregate effective supply and demand on the market. The rules are similar in that no individual is forced to trade more than she likes and only the market with excess supply/demand is rationed. Moreover, all the rationing rules are efficient: the aggregate output produced is consumed by all agents and the total hours of hired work are allocated among them. Below we describe in detail the rationing rules we considered in our experiments.

1. Random Queue (Random): In each period households were assigned a random position in a queue. Households at the front of the queue had priority for the scarce hours or output. When there was excess output demand, expected consumption was given by

$$
\begin{aligned}
E(c_{i,t}) = \quad & \underbrace{\frac{1}{n}\min\left\{ZH_t^S, c_{i,t}^D\right\}}_{\text{First Position}} + \underbrace{\frac{1}{n}\min\left\{\max\left\{ZH_t^S - \sum_{q=1}^{1}\left[c_{j,t}\right]_q, 0\right\}, c_{i,t}^D\right\}}_{\text{Second Position}} + \\
& \ldots + \underbrace{\frac{1}{n}\min\left\{\max\left\{ZH_t^S - \sum_{q=1}^{n-1}\left[c_{j,t}\right]_q, 0\right\}, c_{i,t}^D\right\}}_{\text{Last Position}},
\end{aligned} \tag{6}
$$

while in instances of excess labor supply, expected labor was

$$
\begin{aligned}
E(h_{i,t}) = \quad & \underbrace{\frac{1}{n}\min\left\{\frac{C_t^D}{Z}, h_{i,t}^S\right\}}_{\text{First Position}} + \underbrace{\frac{1}{n}\min\left\{\max\left\{\frac{C_t^D}{Z} - \sum_{q=1}^{1}\left[h_{j,t}\right]_q, 0\right\}, h_{i,t}^S\right\}}_{\text{Second Position}} + \\
& \ldots + \underbrace{\frac{1}{n}\min\left\{\max\left\{\frac{C_t^D}{Z} - \sum_{q=1}^{n-1}\left[h_{j,t}\right]_q, 0\right\}, h_{i,t}^S\right\}}_{\text{Last Position}},
\end{aligned} \tag{7}
$$

where $\left[c_{j,t}\right]_q$ and $\left[h_{j,t}\right]_q$ denote consumption and hours of work of agent j where $j \neq i$, respectively, and $q \in \{1, n\}$ is the position in the queue.

2. Equitable rule (Equitable): All households equally shared the rationed hours or output up to their desired demand. Households obtained $c_i = \min\left\{\frac{ZH^S}{n}, c_i^D\right\}$ when there was excess output demand, and $h_i = \min\left\{\frac{C^D/Z}{n}, h_i^S\right\}$ when there was excess labor supply. Any undesired hours of work or units of output were allocated in equal shares among those with excess demands for labor hours or output.

3. Priority rule (Priority): Households were given priority to purchase the output they personally produced: $c_i = \min\{Zh_i^S, c_i^D\}$. Similarly, if labor hours were rationed, participants were given priority to work the hours associated with their purchased output, $h_i = \min\{c_i^D/Z, h_i^s\}$. Any undesired hours of work or units of output were randomly allocated among those with unsatisfied demands for labor hours or output.

Table 1 presents an example of how resources are allocated in a four-household economy under each of the rationing rules. The subjects' numbers reflects their spot in a queue. In the example, output is rationed due to excess demand. Columns 2 and 3 display the desired labor and consumption. In column 4, the assigned hours are shown; they are the same as the desired hours. Finally, since total output produced is lower than the desired output, columns 5, 6, and 7 show how output is allocated under each rule.

To gain some intuition about the relative effects of the different rationing schemes on allocations and subsequent decisions, consider the following example of excess output demand.[11] Suppose eight participants are demanding output and supplying labor in a manner consistent with the model predictions ($h_i^s = 2.24$ and $c_i^s = 22.4$), while the ninth participant supplies the same amount of labor but demands more output ($c_i^s = 22.4 + j$, where $j > 0$). Aggregate labor supply is $H = 20.16$ and output demand is $C = 201.6 + j$.

If rationing is conducted according to the Priority rule, one person's demands for an excessive amount of output has no effect on the allocations for the other eight participants. The first eight participants will receive their requested labor hours and units of output, while the excess demander receives her requested labor hours and is rationed on output, where her realized consumption is $c_i = 22.4$. Increasing j has no additional effect on any participant's final allocations.

Under the Equitable rule, the scarce output will be distributed equally among all participants up to their desired demand. Given that the excess demander also supplies $h_i^s = 2.24$, the output allocations will be identical to that observed under a Priority rule, $c_i = 22.4$. In this case, output rationing should have no effect on other participants' decisions. If, however, output rationing were due to a single participant supplying less labor than would be predicted by the optimizing model ($h_i^s = 2.24 - k$ and $c_i^s = 22.4$), aggregate labor supply and output demand would be $H = 20.16 - k$ and $C = 201.6 - 10k$. Each participant would receive $c_i = 22.4 - (10/9)k$, which is less than her original demand. As k grows large, the impact of one person's reduction in labor supply on others' output allocations grows large. Furthermore, all participants will spend less than they desired, resulting in an increase in cash balances. In the following period,

[11] The intuition for excess labor supply follows a similar thought experiment.

participants will best respond to this excess cash balances by either lowering their labor supply or increasing their output demands—both of which may generate even more rationing of output.

Under a Random Queue rule, the opportunity for the excess demander to influence others' allocations of output will depend on her position in the queue. Unless she is at the end of the queue, at least one other participant will experience a reduction in her output allocation. As the amount by which the participant overdemands output, j, grows large, an increasing number of participants will be unable to receive their desired output. The alternative scenario, in which a single participant undersupplies labor, resulting in excess demand, will have similar effects. For the participants who experience output rationing, their best response in the next period will be to undersupply labor or increase their demand for output.

Thus, for the same amount of excess output demand generated by a reduction in labor supply by $k = 1$, leading to a 10-unit reduction of total production, $c_i^{Equitable} = 21.28$ for all participants while $c_i^{Random} = 22.4$ for all participants except the last person in the queue, who receives $c_i^{Random} = 12.4$. The extent to which labor supplies will decrease in the next period depends on how much participants smooth their unanticipated increases in their cash balances. Under the Equitable rule, the increases in individual cash balances due to under-consumption are relatively modest, as they are spread equally among all participants. By contrast, the increase in individual cash balances are quite large and isolated to a single participant under the Random Queue rule. In general, the reduction in the following period's aggregate labor supply will be larger under a Random Queue rule.[12] This leads us to our fifth testable hypothesis:

Hypothesis 5 *The size of the adjustment in labor supply in response to past output*

[12]Note that nominal wages and prices are more likely to respond minimally to rationing under an Equitable rule, as the median participant will also be changing her output demands and/or labor supplies. By contrast, under a Random Queue rule, the median participant in the initial stages of rationing will be unaffected by small amounts of labor shading. Under a Priority rule, wages and prices are unaffected by a single participant deviating from the representative agent prediction, regardless of the size of the deviation.

rationing varies by rule, as follows: Random Queue > Equitable > Priority.

3.4 Experimental procedures

The experiment was conducted at the CRABE Laboratory at Simon Fraser University. Subjects were undergraduate participants recruited from a wide variety of disciplines. We conducted six sessions of the Random and Priority treatments and seven of the Equitable treatment. All sessions consisted of inexperienced participants interacting in a single treatment. Most sessions involved groups of 9 subjects interacting together, with a few exceptions: RQ3 and RQ6 had 7 and 8 subjects, respectively, while UT7 had 8 subjects. At the beginning of each session we conducted a 35-minute instruction phase that involved a discussion of the game, the rationing rule and four periods of guided practice through the visual interface.[13] Payoffs, including a $7 show-up fee, ranged from $10 to $38.[14]

4 Aggregate findings

In this section, we summarize our findings across treatments. Our analysis includes decisions made by all participants over all periods of play. The data from all sequences are treated as one time series, unless otherwise noted.

4.1 Decisions, production, and rationing

Cumulative distributions of median and individual labor supply and median output demand decisions are presented in Figures 1 and 2 for each treatment, respectively. The dashed vertical line is the steady state predicted individual labor supply of 2.24 hours and output demand of 22.4 units. Histograms of labor supply, output demand, and realized consumption are provided in Figure 3.

[13] Screenshots of the computer interface can be found in Figures 4,5 and 6 in Appendix F.
[14] The instructions can be found in Appendix G and Appendix H.

Mean labor supply under the Priority treatment is 2.76 hours (SD = 1.83), while it is modestly higher in the Random treatment, with participants supplying an average of 2.91 hours (SD = 2.17). By contrast, mean labor supply is lower in the Equitable treatment, with 2.58 hours (SD = 1.93). Signed-rank tests reject the null hypothesis that the session-level mean labor supply is equal to the equilibrium prediction in the Priority and Random treatments ($p = 0.046$ and $p = 0.028$, respectively), but detect no significant differences from equilibrium behavior in the Equitable treatment ($p = 0.3980$). Two-sided Wilcoxon rank-sum tests are unable to reject the null hypothesis that session-level mean labor supplies are identical across treatments ($p > 0.31$ for each pairwise comparison). Labor supply in the Priority treatment is heterogeneous but largely centered around the steady state. By contrast, labor supply in the Random treatment exhibit greater heterogeneity and a distribution closer to bipolar. Participants facing rationing according to a random queue have a tendency either to work very little or to work a lot. In the Equitable treatment, we observe considerably lower labor supplies across the entire distribution, with a large mass of decisions on hours below the steady state.

Output demand differs more clearly across treatments. We observe the highest average demands under the Priority treatment (mean = 48.13, SD = 9.12), followed by the Equitable treatment (mean = 42.66, SD = 7.31) and the Random treatment (mean = 38.97, SD = 4.12). Median demands follow a similar order. Mean output demands in all treatments are significantly above the equilibrium prediction ($p < 0.028$ in all cases). While the session-level mean output demands are not significantly different between the Random and Equitable treatments ($p = 0.317$) or the Equitable and Priority treatments ($p = 0.253$), the differences are significant between the Random and Priority ($p = 0.055$). Output demands in the Random treatment stochastically dominate at first order the output demands in the Priority treatment. Output demands are also considerably lower in the Equitable treatment than in the Priority treatment for most of the distribution. From the histograms of the distribution of output demands, we see that approximately 8% of Random decisions, 12% of Equitable decisions, and 14% of Priority decisions are for the maximum allowed (100 units).[15]

The differences in labor supply and output demand do not translate into significantly different levels of mean production across treatments. Table 2 presents the session-level summary statistics, with two-sided Wilcoxon rank-sum tests provided to denote statistical differences between treatments. Mean total output produced is lowest in the Equitable treatment at 219.09 units (SD = 54.51), and is relatively higher in the Random with 238.44 units (SD = 45.11) and Priority with 241.68 (SD = 43.44). While mean production is above the steady state prediction in all treatments, the differences are statistically significant only in the Random and Priority treatments. Moreover, the treatment differences in mean production at the session level are not statistically significant, with $p > 0.39$ in all pairwise comparisons.

Rationing occurs in all periods of play and we confidently reject Hypothesis 2. We observe high frequencies of output rationing in all treatments, occurring on average between 80% and 87% of the time. Rationing of labor hours occurs minimally in five of six sessions of the Random treatment (the exception is in Random2, in which labor rationing never occurs), in four of seven Equitable sessions (Equitable1, Equitable3, Equitable5, and Equitable7), and in only two of six sessions of the Priority treatment (Priority4 and Priority6).

Rationing of both output and labor is highly persistent over time. Figure 4 plots, for all periods and sessions, the relationship between the quantity of lagged and current output and labor rationed. The green 45-degree line denotes observations in which the aggregate quantity of output or labor rationed remains constant across two consecutive periods. Observations above (below) the diagonal line denote instances of rationing increasing (decreasing) in the following period. The solid red line denotes a local polynomial smoothed line. The vast majority of periods in which rationing occurs is followed by further rationing of the same market. More than 91% of output rationing and 61% of labor rationing are followed by further rationing in the following period. However,

[15]The frequency of subjects submitting the maximum levels of consumption and labor was extremely low. Only 0.6% (23/3928) of submitted decisions in the Random treatment, 0.1% (6/4723) in the Equitable treatment, and 0.3% (14/4177) in the Priority treatment were for $c^D_{i,t} = 100$ and $l^S_{i,t} = 10$.

the quantity of output rationed increases in the following period roughly half the time across all treatments, while the quantity of labor rationed increases between 28% and 41% of the time.[16]

Observation 1 *Output demands are significantly higher than the steady state equilibrium in all treatments.*

As output is typically the rationed market, labor supplies are the key driver of production in most sessions. Mean labor supply and realized production is on average higher than the steady state equilibrium in all treatments, and significantly higher in the Priority and Random treatments. Hypothesis 1a is rejected completely in the Priority and Random treatments, and for output demand decisions in the Equitable treatment.

Observation 2 *Both output and labor rationing are persistent.*

While labor rationing tends to subside in the following period in the Equitable and Priority treatments, it worsens on average in the Random treatment. Output rationing worsens in half of the following periods consistently in all treatments.

Production volatility is influenced by the form of rationing. The lowest levels of volatility are observed in the Priority treatment (mean = 0.20, SD = 0.02), whereas volatility increases in the Equitable treatment (mean = 0.25, SD = 0.10, $p = 0.333$) and significantly increases in the Random treatment (mean = 0.25, SD = 0.03, $p = 0.037$).

In terms of average points earned, all subjects earn significantly less than the steady state equilibrium prediction of 8.625. Equitable subjects earn the highest with 5.04 points, followed by Priority subjects at 4.26 points, and Random subjects at 1.01 points. There is no statistical difference between earnings in the Equitable and Priority treatments. Participants in the Random treatment, however, receive significantly less output and earn significantly fewer points on average than both Equitable and Priority participants. Figure 5 presents the wealth distribution for each treatment. The solid black line

[16] We also compute a session-level measure of the likelihood of worsening output and labor rationing given past rationing. Wilcoxon signed-rank tests reject the null hypothesis that output rationing remains constant in favor of increased output rationing in all treatments ($p < 0.027$). Only in the Random treatment does output rationing significantly worsens in the following period ($p = 0.06$).

is a reference line of perfect equality among subjects. As expected, the highest levels of equality are observed in the Equitable treatment, where output is equally distributed up to individual demands. The fact that the Equitable treatment exhibits some inequality is due to heterogeneity in participants' preferences for labor and output, as well as to fluctuating decisions and outcomes over time. Inequality worsens under the Priority rationing rule. When participants are largely responsible for their points, as they are in the Priority treatment, the heterogeneity in labor supply decisions leads to significantly different levels of output and points received. Finally, the greatest inequality is observed when output is allocated according to a random queue. In the Random treatment, 50% of the participants receive, on average, less than 10% of the points earned. The inequality in the Random treatment is driven by consumers demanding the highest levels of output each period in the hopes of being at the front of the queue. Such impulses leave little output remaining for other participants later in the queue, especially in later periods, when labor supply and, consequently, production fall significantly.

4.2 Convergence

As in most dynamic experimental environments, the main macroeconomic variables in our economies do not immediately reach their steady state values. However, one would expect that after some learning, subjects would become familiarized with the environment and their choices would gradually converge to the equilibrium predictions. In this section we analyze whether median labor supply and output demand converged to the equilibrium predictions, and if so how fast the process was. We first contrast behavior across treatments graphically. Figures 6.a and 6.b show box-plots of the average median labor supply and output demand for each sequence, while Figure 6.c and 6.d depict the aggregate outcomes. Figure 7 contrasts the time series of average labor supply and output demand across treatments. The horizontal red lines in these figures represent the corresponding steady state levels of labor and output.

Median and aggregate labor supplies appear to be converging toward the steady state after many stationary repetitions. In the Random treatment, there is considerable heterogeneity in both median and aggregate labor supplies, where some sessions experience very high levels of labor supply. By contrast, in the Equitable treatment, labor supplies in some sessions become quite low after a few repetitions. In terms of output demand, there is little convergence, either at the median or aggregate level, to the steady state. Over time, we see that the differences in output demand become quite stark under the Random and Priority rules, with average demand often 10 units higher under the Priority rule.

We next identify the period of convergence following Bao et al. (2013). In each session, we calculate the absolute deviation of median labor supply and output demand from the steady state. We then claim that convergence occurs in the first period in which the absolute deviation from the steady state is less than 1 in the case of labor supply and less than 10 for output demand, and this is preserved until the end of the session.[17] The second column of Table 3 shows the number of periods before convergence for the median labor supply. It takes only 22 periods on average for labor supply to converge to the steady state in the Priority treatment, whereas in the Random and Equitable treatments it takes almost three times as many periods (64 and 62, respectively). There is less difference across treatments in terms of the number of periods it takes for output demand to converge (74, 64, and 74 periods on average for the Random, Equitable, and Priority treatments, respectively).

Finally, we formally test convergence, following the regression model of Noussair et al. (1995). They were the first to propose this econometric procedure to study convergence of experimental panel data. The regression model for each treatment is the following:

$$y_{st} = \frac{1}{t}\sum_{s=1}^{S}\alpha_s D_s + \beta\frac{t-1}{t} + \varepsilon_{st}, \tag{8}$$

where y_{it} is the dependent variable (in this case, median labor supply/output demand), $s = 1, 2, ..., S$ is the session, D_s is a dummy variable for each of the sessions within

[17]If at period t, $\left|h_t^{med} - h_{ss}\right| > 1/ : (\left|c_t^{med} - c_{ss}\right| > 10)$, where h_t^{med} and c_t^{med} are median labor supply and median output demand at period t, respectively, we still count it as a converging period only if convergence is restored in the following period, $\left|h_{t+1}^{med} - h_{ss}\right| < 1/ : (\left|c_{t+1}^{med} - c_{ss}\right| < 10)$.

a treatment, and ε_{st} is an error term. The α_s coefficients capture the initial value of the variable of interest at the beginning of the sessions, and β represents the value of the variable y to which each of the treatments converge. Table 4 shows the generalized least squares (GLS) estimates of α_s and β. For median labor supply, $\hat{\beta}$ is not significantly different than the steady state value in the Random and Priority treatments; thus there is evidence of asymptotic convergence. However, median labor supply in the Equitable treatment converges to a value that is significantly lower than the predicted one. Median output demand converges to values above the theoretical predictions in all the treatments.

5 A model of myopic decision-making

A pattern of overworking and overdemanding was observed in the Random Queue and Equitable treatments. Our subjects were willing to incur debt to acquire high levels of output. This is inconsistent with the assumptions of the standard optimizing representative agent model. One way to rationalize the observed behavior is by assuming that subjects maximize their utility myopically without regard fo their intertemporal budget constraints. In what follows, we develop a framework incorporating these feature and show how they can lead to low levels of labor supply and consequently output rationing in the Random Queue and Equitable treatments.

Suppose that there are n agents in the economy. The labor supply and output demand of agent $i \in \{1, ..., n\}$ is denoted by $h_i^S \in \{0, 10\}$ and $c_i^D \in \{0, 100\}$, respectively, whereas hours worked and output purchased are denoted by h_i and c_i, respectively. Agent i chooses n_i^S and c_i^D to maximize:

$$\max_{c_i^D, h_i^S} U\left(c_i, h_i\right) \tag{9}$$

subject to

$$c_i = \min\left\{c_i^D, \theta_{ci}^R(C_{-i}^D, H^S)\right\},\ h_i = h_i^S \quad \text{if} \quad C^D > ZH^S \tag{10}$$

$$c_i = c_i^D,\ h_i = \min\left\{h_i^S, \theta_{hi}^R(C^D, H_{-i}^S)\right\} \quad \text{if} \quad C^D < ZH^S, \tag{11}$$

where $U(c_i, h_i) = \left(\frac{1}{1-\sigma}\right) c_i^{1-\sigma} - \left(\frac{1}{1+\eta}\right) h_i^{1+\eta}$, and $\theta_c^R(\theta_h^R)$ is the individual consumption (hours) when output (labor) is rationed according to a rule, R, which is either Random, Equitable, or Priority. Aggregate output demand and labor supply are denoted by $C^D \equiv \sum_{i=1}^n c_i^D$ and $H^S \equiv \sum_{i=1}^n h_i^S$, respectively. We can compare the symmetric equilibrium for labor supply under the different rationing rules.[18]

Random Queue: Under a random queue rationing scheme, the probability of obtaining output depends on the quantity of excess output demanded. Increasing one's own labor supply raises the probability of consuming, but it is costly in terms of utility. As long as aggregate labor supply is positive, at least the first individual in the queue will be able to purchase a positive amount of output. To simplify the analysis, suppose that agents demand the same amount of output, $c_1^D = c_2^D = \ldots = c_n^D = \bar{c}$. Agent i chooses how many hours to work to maximize her expected utility:

$$\max_{h_i^s} \frac{1}{n}\left[U\left(\min\left\{c_i^D, \left[\theta_{ci}^{Random}\right]_1\right\}, h_i^s\right) + U\left(\min\left\{c_i^D, \left[\theta_{ci}^{Random}\right]_2\right\}, h_i^s\right) + \ldots + U\left(\min\left\{c_i^D, \left[\theta_{ci}^{Random}\right]_n\right\}, h_i^s\right)\right],$$

where $\left[\theta_{ci}^{Random}\right]_q = \max\left\{ZH^S - (q-1)\bar{c}, 0\right\}$, and $q \in \{1, \ldots, n\}$ is the position of individual i in the queue. Positions are randomly assigned, and there is a $\frac{1}{n}$ probability of obtaining each one of the spots.

The maximization problem can be solved numerically. There are multiple Nash equilibria for labor supply. The equilibrium depends on output demand. Assuming that there are nine agents, if $\bar{c} \geq 48$ then $\left(h_i^S\right)^{Random} = 0.471$. For $\bar{c} < 48$, the equilibrium

[18] We consider the excess output demand case. Whenever there is excess labor supply, agents would find it profitable to deviate by cutting their hours of work, up to the point at which there would be excess output demand.

range is $\left(h_i^S\right)^{Random} = [0.471, 0.65]$.

Equitable rule: Under the assumption of excess output demand production only depends on labor. Agents' individual demand for output does not influence the allocation. On the equitable allocation scheme, each agent receives an equal share of the total production, $\theta_{ci}^{Equitable} = \frac{ZH^S}{n}$, up to her specified demand. The first order condition with respect to h_i^S from equation (9) is

$$\left(\frac{Z}{n}\right)^{1-\sigma} (H^S)^{-\sigma} = \left(h_i^S\right)^{\eta}. \tag{12}$$

In a symmetric equilibrium, $H^S = nh_i^s$. Thus, each agent will choose to work

$$\left(h_i^S\right)^{Equitable} = \left(\frac{1}{n^{\frac{1}{\eta+\sigma}}}\right) Z^{\frac{1-\sigma}{\eta+\sigma}}. \tag{13}$$

With $n = 9$, the Nash equilibrium labor supply is 0.699.

Priority rule: Under a priority rationing scheme, c_i depends on h_i^S. Specifically, $\theta_{ic}^{Priority} = Zh_i^S$. The first order condition with respect to h_i^S from equation (9) is given by the following equation:

$$Z^{1-\sigma} \left(h_i^S\right)^{-\sigma} = \left(h_i^S\right)^{\eta}. \tag{14}$$

Thus, the Nash equilibrium labor supply is

$$\left(h_i^S\right)^{Priority} = Z^{\frac{1-\sigma}{\eta+\sigma}}. \tag{15}$$

Under the parameterization of the experimental environment, the Nash equilibrium labor supply is 2.32.[19]

There are two important conclusions from the above analysis. First, unlike under the Equitable rule and the Random rule, under the Priority rule equilibrium labor supply

[19] Given that this is the equilibrium solution for the static model, labor supply is higher than in the steady state. However, for the dynamic case, the Nash equilibrium labor supply and the implied consumption do not maximize individuals' lifetime utility because they imply a positive level of indebtedness.

does not depend on the number of agents. Under the Equitable rule and the Random rule, as the number of agents increases, the optimal labor supply decreases. The subjects' best response when aggregate labor increases is to cut their own labor supply; that is, labor supply is a strategic substitute. Second, optimal labor supply under myopic decision-making is highest under the Priority rule, followed by the Equitable rule, and lowest under a Random rule.

While average labor supply, measured at the session level, is not significantly different across treatments, the myopic model does predict extreme outcomes in our data. We observe that the minimum aggregate labor supply observed at the session level is significantly lower in the Random Queue treatment (mean = 11.77, SD = 4.14) than in the Priority rule (mean = 15.05, SD = 3.48, $p = 0.078$). Aggregate labor supplies also reach very low levels in the Equitable treatment (mean = 10.49, SD = 6.46), but are not significantly different from that observed in the Random Queue ($p = 0.668$). While the average minimum aggregate labor supply is lower under an Equitable rule than under a Priority rule, the difference is not statistically significant (p=0.153).

6 Discussion

In this paper we present original experimental evidence that the nature of rationing has important implications for macroeconomic stability. Equilibrium models with representative agents and market clearing abstract away from these important issues and consequently miss out on important, realistic dynamics driven by market spillovers. However, in our experimental economies populated with heterogeneous participants, distribution schemes are shown to play an important role in preserving economic stability. Our findings suggest that convergence to the steady state equilibrium depends significantly on the presence of property rights and on the opportunity for free-riding. Under random queue and equitable allocation rules, consumer-workers are not obliged to supply costly labor in order to purchase output and can instead rely to some extent on others to do the work for them. Such behavior results in greater incentives to free-ride on others' costly labor. In turn, hard-working individuals may respond to others' excess consumption by reducing their labor supply, which leads the aggregate production to fall to extremely low levels. The presence of property rights in a priority system allows individuals to confidently supply labor with the expectation that they will be able to purchase at least what they have produced. Likewise, these individuals can purchase output with minimal uncertainty about their employment opportunities. In this case, aggregate production is significantly less volatile, and quickly and consistently converges to the steady state.

We must be cautious not to claim that the undersupplying of labor in our environments is entirely a consequence of free-riding. If an individual faces rationing of output and cannot spend her money balances sufficiently, she should optimally reduce her labor supply in an effort to smooth her utility over time. Such reductions in labor supply lead to further output rationing and the potential for a downward spiral in production. Similarly, pessimistic employment expectations motivate optimizing individuals to reduce their consumption demands and can result in self-fulfilling recessions and job rationing. It is not unreasonable for some participants to perceive the consumption-smoothing behavior of other market participants as free-riding and reciprocate by cutting their own labor supplies. We emphasize that such low-production outcomes are more likely to occur under rationing rules where there are minimal or nonexistent property rights to workers' production.

Rationing schemes have important implications for inequality. Inequality is significantly greater when jobs and output are distributed on a first-come, first-served basis, as in the Random treatment. A tendency to work many hours or buy up as much output as possible when given an opportunity to do so leads to less work and output for others at the end of the queue. Considerable inequality exists when participants are allocated output based on their willingness to work. Heterogeneity in participants' willingness to work and save results in a wide range of payoffs in the Priority treatment. As expected, equality is the highest (though still not perfect) when policies are in place to provide equally up to individual demands, as is the case in the Equitable treatment. This equality and increased welfare, however, comes at the risk of rationing and increased instability and may lead to periods of significantly lower individual and aggregate welfare.

Despite the historical evidence and the results that we have shown, core macro models have moved almost uniformly to market-clearing assumptions. The RBC model (and the NK model as money is not an essential ingredient) ignores the presence of cash, with the representative agent being paid in the production resulting from the labor they supply. This production is automatically consumed by the household-worker. There is no opportunity for stockpiling cash or rationing; accordingly, there is very little theoretical work on the subject. Current NK models assume that markets clear despite assumptions of nominal rigidity, an awkward state of affairs justified by perfectly rational, market-clearing behavior by households. Our model of myopic decision-making helps to provide a behavioral justification for questioning this outcome. That said, rationing is slowly being brought into fashion with models that incorporate matching frictions (e.g. Michaillat (2012); Michaillat and Saez (2015)) whereby the degree of rationing influences the probability an agent is able to access scarce jobs or output. Beyond this probability of matching mechanism, however, there is little discussion about alternative rationing rules. As Michaillat and Saez note, disequilibrium not only raises the difficult question as to how to ration markets, but also limits model tractability. These conclusions are a distressing sign of how such research is perceived; by relaxing the assumptions of a cashless economy with no opportunity for borrowing or savings, the behavior exhibited in our experiments shows that an environment with sustained disequilibrium should not be overlooked due to its apparent complexity. Empirical evidence on the impact of different rationing schemes on aggregate outcomes will likely be instructive in the development of further theory as well as a necessary discussion of how rationing should take place. This is precisely why our research here is needed; it helps to move the discussion on rationing forward and provide clarity to macroeconomists as to the consequences of the approach they take to modelling such processes. Our work demonstrates that rationing does occur, despite the amount of (unrealistic) information provided to subjects, when prices cannot fully adjust. Furthermore, such rationing can reverberate across markets and potentially have wide-reaching consequences. It should be clear to any macroeconomist that, given these results, the choice of rationing mechanism should not be taken lightly.

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Tables and figures

Table 1: Rationing rules example

Subject	h_i^S	c_i^D	h_i	c_i		
				Random[I]	UT	Priority[II]
1	2	100	2	100	30	20+x
2	5	80	5	20	30	50+y
3	1	50	1	0	30	10+z
4	4	30	4	0	30	30
Aggregate	12	260	12	120	120	120

(I) Here it is assumed that subject $i \in 1, 2, 3, 4$ has the ith position in the queue.
(II) $x + y + z = 10$.

Table 2: Session-level statistics on production, rationing and welfare[I]

Treatment	Sessions	Statistic	Total Output Produced	Freq. Excess Labor Supply[II]	Output Volatility	Avg. Points
Steady State Equilibrium			200.16	0	0	8.625
Random	6	mean	238.44**	0.20**	0.25**	1.01**
		SD	45.11	0.25	0.03	3.38
Equitable	7	mean	219.09	0.19**	0.25**	5.04**
		SD	54.51	0.24	0.10	1.88
Priority	6	mean	241.68**	0.13*	0.20**	4.26**
		SD	43.44	0.22	0.02	1.58
Random vs. Equitable		p-value	0.391	0.943	0.253	0.015
Random vs. Priority		p-value	0.749	0.333	0.037	0.025
Equitable vs. Priority		p-value	0.567	0.389	0.317	0.475

(I) Summary statistics for the following session-level results from all periods of play are presented: total output produced, frequency of excess labor supply, output volatility, and the average points earned in a period by subjects for consumption and labor decisions. All variables are adjusted to account for only submitted decisions in a given round.
(II) All sessions in all treatments exhibit rationing of either output or labor. The asterisks in this column indicate whether session-level rationing is significantly different from zero.

Table 3: Number of periods before convergence[I]

Sessions	No. of Periods Before Convergence: Med. Labor Supply	No. of Periods Before Convergence: Med. Output Demand	Total No. of Periods
Random1	76	74	79
Random2	Never	Never	90
Random3	66	Never	79
Random4	1	62	69
Random5	Never	65	73
Random6	80	63	84
Equitable1	Never	84	97
Equitable2	38	Never	75
Equitable3	49	Never	70
Equitable4	Never	Never	72
Equitable5	41	Never	81
Equitable6	Never	40	79
Equitable7	61	26	74
Priority1	6	Never	77
Priority2	9	Never	78
Priority3	34	Never	84
Priority4	10	66	100
Priority5	3	65	70
Priority6	Never	Never	71

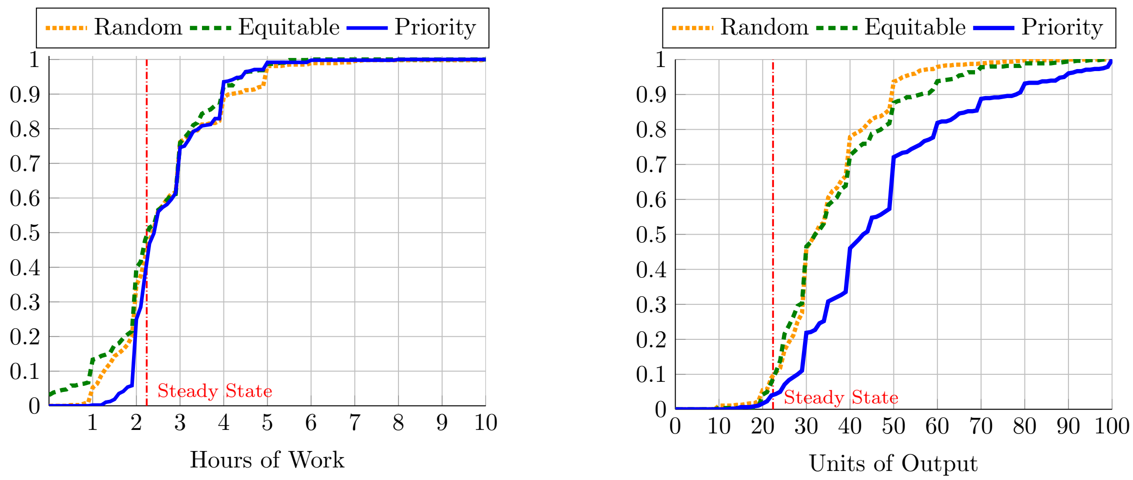
(I) In each period t, we compute $\left|c_t^{med} - c_{ss}\right|$ and $\left|h_t^{med} - h_{ss}\right|$. We then claim that convergence occurs in the first period in which $\left|c_t^{med} - c_{ss}\right| < 10$ $(\left|h_t^{med} - h_{ss}\right| < 1)$, and this is preserved until the end of the session. If at period t $\left|c_t^{med} - c_{ss}\right| > 10$ $\left|(h_t^{med} - h_{ss}\right| > 1)$, we still count it as a converging period if convergence is restored in the following period, $\left|c_{t+1}^{med} - c_{ss}\right| < 10$ $\left|(h_{t+1}^{med} - h_{ss}\right| < 1)$.

Table 4: Convergence model estimates[I]

Treatment	Dependent Variable	$\hat{\alpha}_1$	$\hat{\alpha}_2$	$\hat{\alpha}_3$	$\hat{\alpha}_4$	$\hat{\alpha}_5$	$\hat{\alpha}_6$	$\hat{\alpha}_7$	$\hat{\beta}$	Model Prediction	ρ
Random	med N_t	2.29 (0.76)	2.75 (0.82)	3.86 (0.94)	1.71 (0.48)	3.61 (1.91)	2.90 (0.71)		2.34 (0.10)	2.24	0.75
	med C_t	22.41 (9.11)	44.38 (9.00)	27.21 (13.04)	18.77 (8.62)	45.56 (9.88)	28.88 (11.20)		33.73 (0.81)	22.37	0.81
Equitable	med N_t	1.73 (0.47)	2.12 (0.58)	3.43 (1.46)	2.22 (1.12)	4.49 (0.82)	2.59 (0.59)	3.79 (0.97)	2.13 (0.10)	2.24	0.66
	med C_t	17.31 (11.15)	43.12 (10.87)	41.75 (11.05)	61.28 (16.90)	41.93 (12.39)	33.24 (7.45)	33.11 (9.61)	32.48 (0.83)	22.37	0.43
Priority	med N_t	2.87 (0.50)	2.36 (0.84)	1.58 (0.78)	3.30 (0.58)	4.34 (0.47)	3.60 (1.12)		2.43 (0.07)	2.24	0.47
	med C_t	41.73 (12.33)	76.14 (25.85)	23.33 (12.69)	38.83 (15.49)	56.14 (12.95)	37.36 (14.63)		43.03 (1.33)	22.37	0.55

(I) Standard errors are in parentheses. The $\hat{\alpha}_s$ coefficients capture the initial values for each session; while the $\hat{\beta}$ coefficient captures the value of the variable labor supply (output demand) to which each treatment converges. Following Noussair, Plott, and Riezman (1995) the standard errors are corrected for heterosedasticity and first order autocorrelation (where ρ is the correlation parameter).

Figure 1: Cumulative Distribution Functions of Median Labor Supply and Output Demand

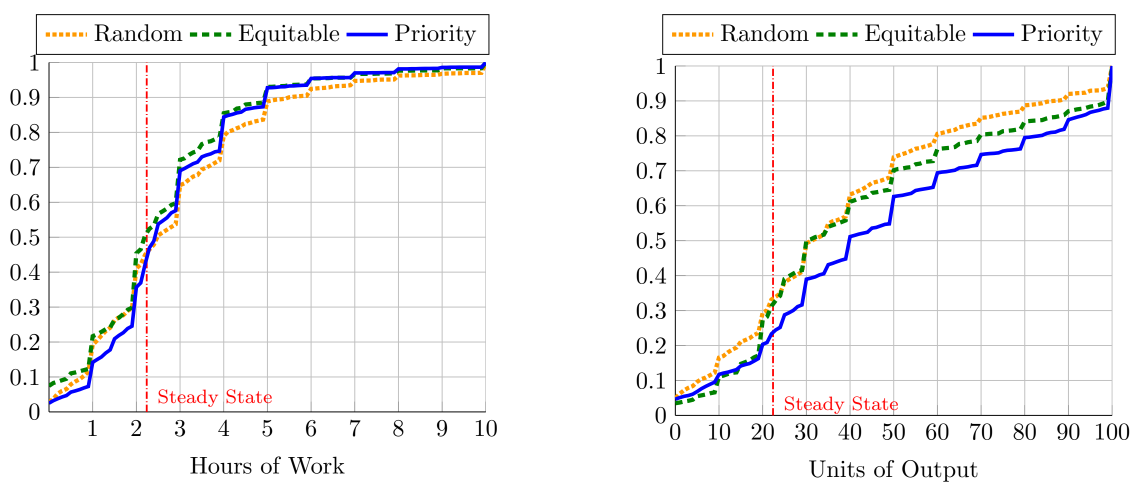


(a) CDF Median Labor Supply

(b) CDF Median Output Demand

Note: These figures display median labor supply and median output demand starting from period 1. To calculate the medians we excluded observations for which subjects did not submit their decisions on time (when this was the case the decisions were recorded as zero units of labor requested and zero units of output requested).

Figure 2: Cumulative Distribution Functions of Individual Labor Supply and Output Demand

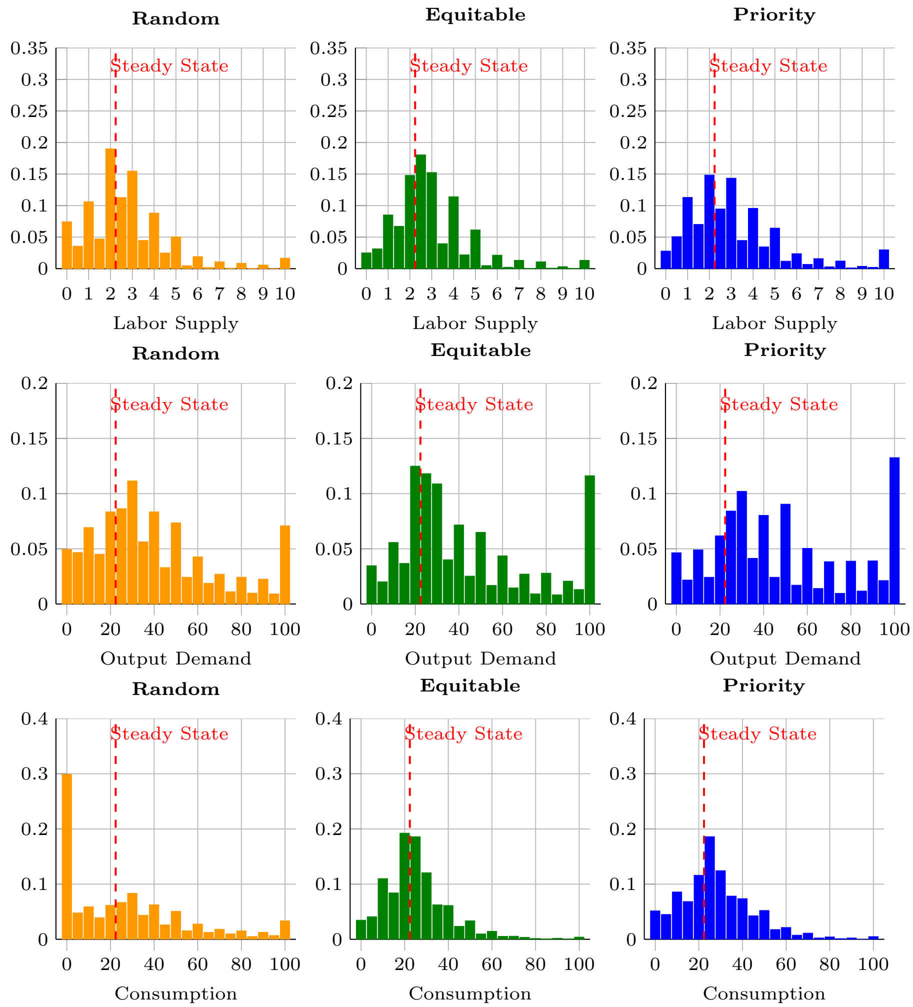


(a) CDF Individual Labor Supply

(b) CDF Individual Output Demand

Note: These figures display labor supply and median output demand for each subject/period starting from period 1. We excluded observations for which subjects did not submit their decisions on time (when this was the case the decisions were recorded as zero units of labor requested and zero units of output requested).

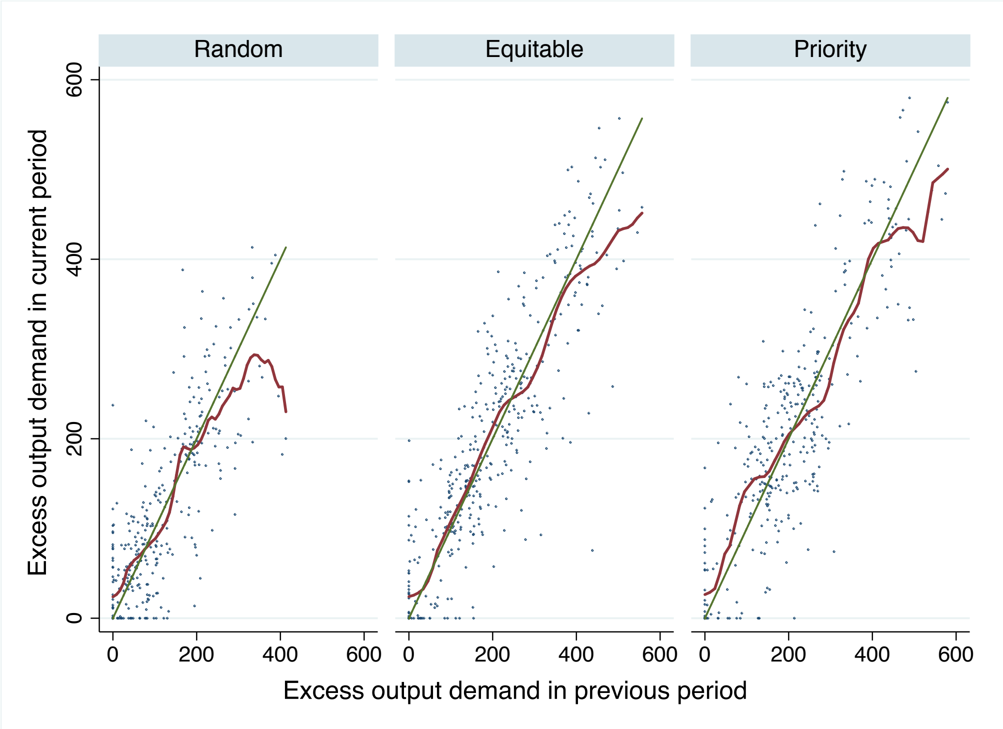
Figure 3: Relative Frequency (First Row: Labor Supply, Second Row: Output Demand, Third Row: Consumption)



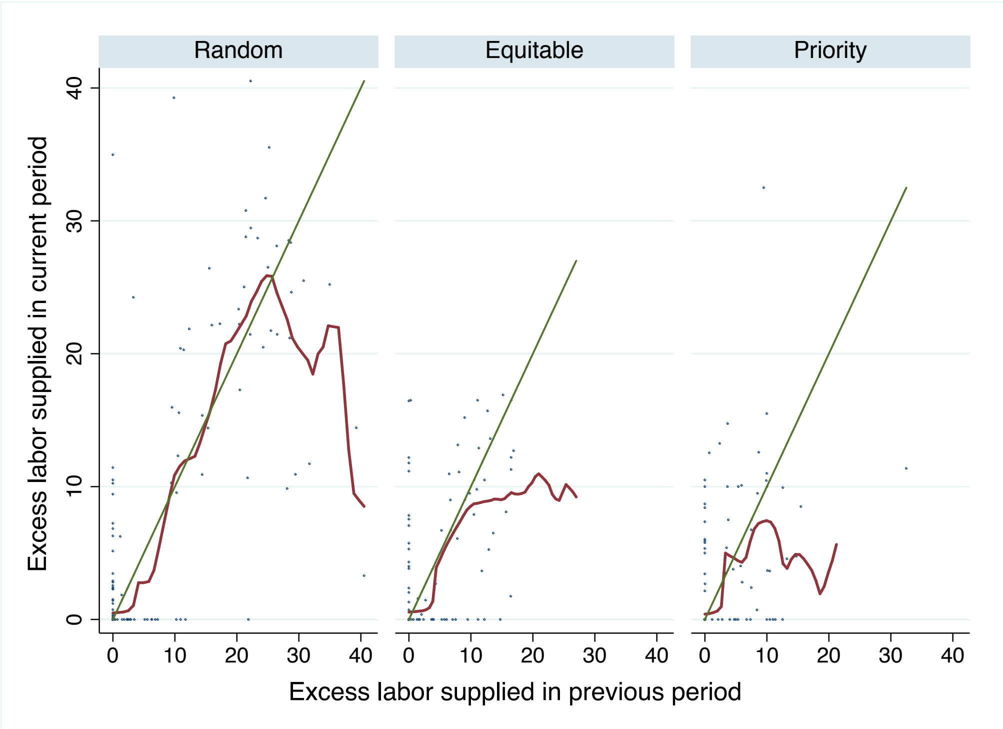
Note: These figures display data for each subject/period starting from period 1. We excluded observations for which subjects did not submit their decisions on time (when this was the case the decisions were recorded as zero units of labor requested and zero units of output requested).

Figure 4: Persistence of Rationing

(a)

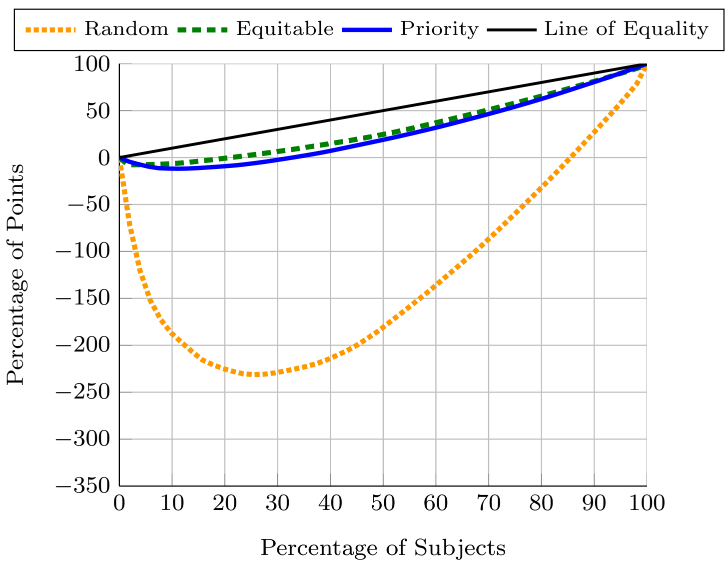


(b)



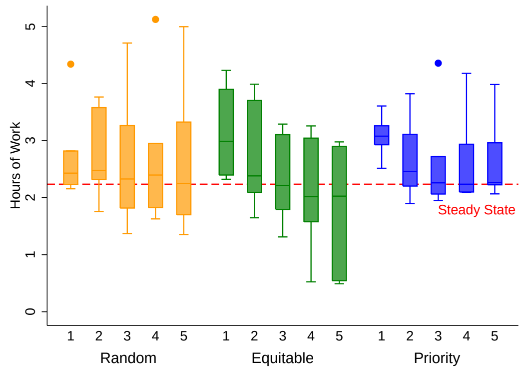
The green 45-degree line denotes observations in which the aggregate quantity of output or labor rationed remains constant across two periods. Observations above (below) the diagonal line denote instances of rationing increasing (decreasing) in the next period. The solid red line denotes a local polynomial smoothed line.

Figure 5: Lorenz Curve

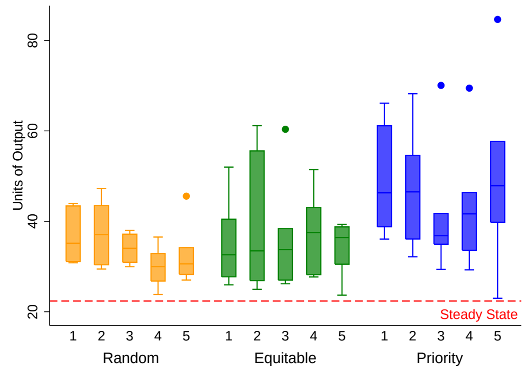


These are cumulative frequency curves showing the distribution of subjects against their average points (not including the bank account).

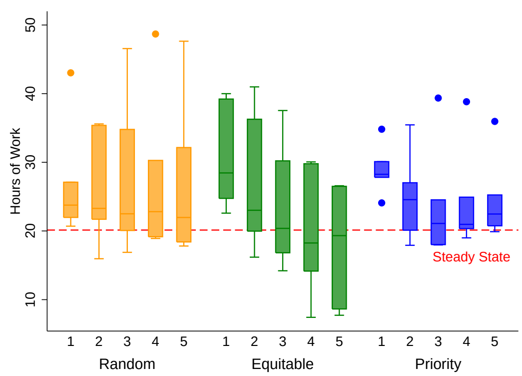
Figure 6: Labor Supply and Output Demand



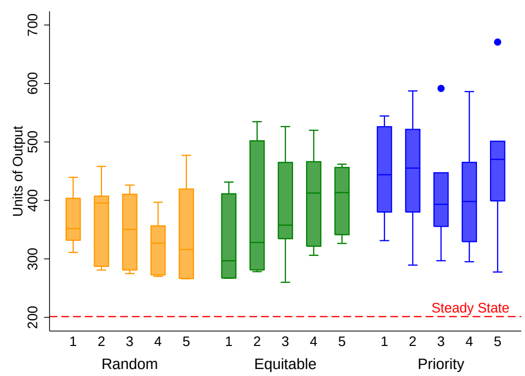
(a) Average of Median Labor Supply



(b) Average of Median Output Demand



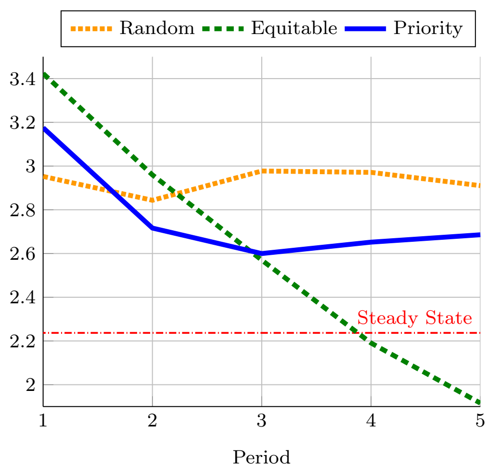
(c) Aggregate Labor Supply (Per-Period Average)



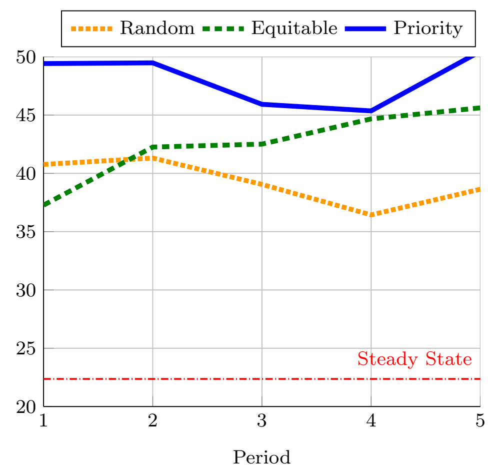
(d) Aggregate Output Demand (Per-Period Average)

Notes: The x-axis displays $i \in \{1, ..., 5\}$; $i = 1$ represents the range from the first period 1 to $TotalPeriod \times 0.20$ of each session, similarly $i = 2$ represents the range from the first period $TotalPeriod \times 0.20 + 1$ to $TotalPeriod \times 0.40$. The bottom and top of the box are the first and third quartiles; the band inside the box is the second quartile (the median). The upper (lower) limit of the whisker is the highest (lowest) value within the 1.5 interquartile range of the upper (lower) quartile. The red dashed line is the steady state value predicted by the theoretical model. The dots are the outliers. To be consistent with the sessions in which there were fewer than nine participants, we adjusted the aggregate labor supply (output demand): $Adj.AggregateLabor = AggregateLaborSupply \times 9/N (Adj.OutputDemand = AggregateOutputDemand \times 9/N)$.

Figure 7: Average Labor Supply and Output Demand Over Time



(a) Average Labor Supply



(b) Average Output Demand

Notes: The x-axis displays $i \in \{1, .., 5\}$; $i = 1$ represents the range from the first period 1 to $TotalPeriod \times 0.20$ of each session, and $i = 2$ represents the range from the first period $TotalPeriod \times 0.20 + 1$ to $TotalPeriod \times 0.40$.