Asset dynamics, liquidity, and inequality in decentralized markets

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Economic Inquiry

ASSET DYNAMICS, LIQUIDITY, AND INEQUALITY IN DECENTRALIZED MARKETS

MAURIZIO IACOPETTA and RAOUL MINETTI*

The Kiyotaki and Wright model has exerted a considerable influence on the monetary search literature. We argue that the model also delivers important insights into a broader range of macroeconomic and development issues. The analysis studies how market frictions and the liquidity of assets affect the distribution of income. Experiments illustrate how the economy adjusts to shocks to asset returns and to the matching technology. They also deal with long-run transition. An experiment interprets the reversal of fortune hypothesis as a situation in which an economy with a low-return asset takes over a similar economy with a high-return asset. (*JEL* C61, C63, E41, E27, D63)

I. INTRODUCTION

Most of the dynamic general equilibrium theory is based on the idea that individuals trade goods and services in centralized markets. The assumption that agents trade against a budget line can be a useful simplification when running macroeconomic experiments, but sometimes it washes away phenomena that emerge from the interaction of individuals that differ in some fundamental aspects. The Kiyotaki and Wright (1989) framework (hereafter KW) has been widely praised for its capacity to connect individuals' behavior with aggregate outcomes. The presence of genuinely heterogenous agents trading commodities in decentralized markets implies that aggregate relationships are not simply the magnification of a representative individual behavior. However, it also poses an important hurdle when obtaining dynamic equilibria, a necessary step for studying the adjustment of the economy toward a long-run equilibrium. Indeed, despite its considerable influence on the search literature (see Lagos, Rocheteau, and Wright 2017) KW has hardly been used to perform macroeconomic experiments. Building on a methodology discussed in Iacopetta (2018) and Bonetto and Iacopetta (2018), we show that the connections between microbehavior and aggregate variables offered by the KW framework can shed light on a wide range of facts that have been studied both by macro and development scholars.[1] In particular, the setup allows us to relate the frictions of market transactions and the dynamics of income inequality and productivity to the trading strategies of individuals. The experiments we propose emphasize mechanisms of this class of decentralized models that are usually absent both

*We wish to thank Federico Bonetto, Todd Keister, Ricardo Lagos, and seminar participants at the Poole School of Management, North Carolina State University, Michigan State University, and at the University of Rome, Tor Vergata, for their comments. All remaining errors are ours.

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1. An important feature of our approach that differentiates it from previous attempts in studying dynamic patterns in KW is that it does not require any ad hoc assumption on agents' ability to process or access information: agents are rational, forward-looking, with full knowledge of the distribution of assets and of the trading strategies of other individuals. Conversely, Matsuyama, Kiyotaki, and Matsui (1993), Wright (1995), Luo (1999), and Sethi (1999) search for equilibria in a similar environment using evolutionary dynamics. Marimon, McGrattan, and Sargent (1990) explore how artificially intelligent agents can learn to play speculative equilibrium.

ABBREVIATIONS

KW: Kiyotaki and Wright (1989)
NE: Nash Equilibrium
OECD: Organization for Economic Co-operation and Development

Economic Inquiry
(ISSN 0095-2583)
Vol. 57, No. 1, January 2019, 537–551

doi:10.1111/ecin.12721
Online Early publication September 21, 2018

in macroeconomic models with centralized trade and in search models with symmetric equilibria.

One application revisits the "reversal of fortune" hypothesis. This contends that a country with a large initial endowment may, in the long run, be undertaken by a country with a more modest initial endowment, because the latter is more prone to developing market-oriented activities (Acemoglu, Johnson, and Robinson 2002 and Engerman and Sokoloff 1997). In our experiment, an economy that has larger returns on a class of assets selects a long-run equilibrium that is less productive than that selected by an economy that exhibits more modest asset returns. The low-return economy takes over the high-return economy because in the former agents choose to trade and produce more intensively.

A second experiment uses trading frictions, a core feature of the model, to interpret the ramifications of market reforms. It reveals that if reforms ameliorate the matching technology, a more equitable distribution of income may follow, because assets become more liquid. There are two main reasons for inequality in our framework: (1) assets fetch different returns and every individual is allowed to carry only one type of asset at a time; (2) assets differ in their degree of liquidity. Although individuals have equal opportunities in accessing the decentralized market, the odds that a match leads to the maximum gain (which comes by acquiring the consumption goods) varies both across individuals and across time. The exercise will explain that liquidity can squeeze or magnify inequality. A general pattern that emerges is that when a shock induces some agents to play "speculative" strategies, income inequality shrinks because more frequent market interactions tend to correct inequality as a result of the variance of returns.

A third set of experiments focuses on equilibria selection. The recent financial crisis has revived the interest in multiple equilibria not only among scholars but also in the specialized press (Wolf 2018). It has been noted that financial crises not only lower liquidity and depress income (Kiyotaki and Moore 2012) but can also bring the level of inequality up (see Atkinson and Morelli 2011). Income inequality increased in Malaysia, Singapore, and South Korea in the aftermath of the 1997 East Asian crisis (Lee 2016). The relatively high level of inequality in Latin America has also been partly attributed to frequent episodes of crisis (Fallon and Lucas 2002; Galbraith and Lu 2001; Gasparini and Lustig 2011; Lustig 2000). In our environment, the real consequences on the average income and on income distribution caused by a shock to the rates of return on holdings are conditioned by equilibria selection.

The rest of the article unfolds as follows. The next section briefly describes the economic environment, illustrates the evolution of the distribution of holdings under a given profile of strategies, and defines the best response functions of three types of representative agents. Section III defines macroeconomic indicators. Section IV proposes three types of macroeconomic experiments: One illustrates a case of fortune reversal between two economies. A second one follows the responses to a shock that improves the matching rate. A third set of experiments studies the fluctuations in liquidity and production caused by a shock to one of the assets' rates of return. Section V concludes.

II. THE MODEL ECONOMY

There are three differences with respect to the decentralized economy described in KW. First, to facilitate the description of the dynamics, time is continuous rather than discrete. Second, we extend the model to consider "commodities" that generate positive returns (Lucas trees) rather than entailing costs of storage (a similar extension is also presented in Lagos, Rocheteau, and Wright 2017). We also allow the ranking of assets with respect to their returns to change, as this gives us freedom of running experiments in which the economy can switch across different equilibria. Third, as in Wright (1995), agents are not necessarily equally distributed across types—again an extension motivated to increase the type of equilibria that can emerge. However, we retain the assumption, which has been subject to legitimate criticisms that there is a limit on the individual's amount of holding. While relaxing this assumption might deliver a more realistic assessment of the magnitude of the responses of production and income to a shock, it would also make the dynamic analysis more complex.[2] As it will become clear soon, even under the storage capacity constraint, the investment decision plays a key role in the dynamics. In particular, in one version of the model, the emergence of a high-production equilibrium is induced by the decision

2. Examples of influential works with a similar asset-holding restriction are Diamond (1982), Rubinstein and Wolinsky (1987), Cavalcanti and Wallace (1999), and Duffie, Gârleanu, and Pedersen (2005).

of one group of individuals to give up a fraction of the current rents on holdings to increase the frequency of trade.

A brief description of the economy follows. There are three types of individuals, denoted by 1, 2, and 3. Each type consists of a large number of people, N_i, for $i = 1, 2$, and 3. The fraction of each type is $\mu_i = N_i/N$, where N is the overall size of the population $\left(N = \sum_i N_i\right)$. People live forever. An agent of type i derives utility exclusively from consuming good i and can produce only good $i + 1$ (modulo 3). Production takes place immediately after consumption. Type-i's[3] instantaneous utility from consumption and the disutility of producing good $i + 1$ are denoted by U_i and D_i, respectively, and their difference is $u_i = U_i - D_i$. There is a capacity constraint. At each instant of time, an individual can hold only one unit of some storable good i that offers an instantaneous return $r_i \leq 0$, measured in units of utility (the terms good, commodity, inventory, and asset will be used interchangeably). The return of good i is the same for all agents of any type. The discount rate is denoted by $\rho > 0$.

A pair of agents is randomly and uniformly chosen from the population to meet for a possible trade. The matching process is governed by a Poisson process of intensity α. A meeting does not necessarily mean that the two parties trade. A bilateral trade occurs if and only if it is mutually agreeable. If both agents want what the other has, they swap goods. Otherwise, they part company and keep the same good in the inventory as they wait for the next call. Agent i always accepts good i and consumes it immediately upon reception. Therefore, agent i enters the market either with one unit of good $i + 1$ or with one unit of good $i + 2$.

The proportion of type i agents that hold good j at time t is denoted by $p_{i,j}(t)$. Then, the vector $\tilde{\boldsymbol{p}}(t) = \left\{p_{i,j}(t)\right\}$ for $i = 1$, 2, and 3 and $j = 1$, 2, and 3 describes the state of the economy at time t (from now on, it is understood that i and j go from 1 to 3). However, because $p_{i,i}(t) = 0$,

$$(1) \qquad p_{i,i+1}(t) + p_{i,i+2}(t) = \mu_i,$$

for any $t > 0$, the state of the economy can be represented in a more parsimonious way by $\boldsymbol{p}(t) = \{p_{1,2}(t),\ p_{2,3}(t),\ p_{3,1}(t)\}$. An individual i has only to decide whether to exchange her production good for the other type of good. Type-i's choice at time t of giving up good $i + 1$ for $i + 2$ (indirect trade) is denoted with $\tau_i(t) = 1$; the opposite choice is indicated with $\tau_i(t) = 0$. Hence, the objective of agent i is to select a time path $\tau_i(t)$ that maximizes her expected stream of present and future net utility, given other agents' paths of strategies, $\boldsymbol{\theta}(t) = [\theta_1(t),\ \theta_2(t),\ \theta_3(t)]$, and the distribution of goods $\boldsymbol{p}(t)$, for any $t > 0$. Formally, let $\Delta_i(s) \equiv V_{i,i+1}(s) - V_{i,i+2}(s)$,[4] and let $\tilde{\tau}_i(s; \boldsymbol{\theta}(s), \boldsymbol{p}(s))$ denote the optimal (or best) response profile of strategies of representative agent i to other players' strategies $\boldsymbol{\theta}(s)$ along the pattern of inventories $\boldsymbol{p}(s)$ for $s > t$. Then, the optimal choice can be characterized as follows[5]:

$$(2) \qquad \tilde{\tau}_i(s; \boldsymbol{\theta}(s), \boldsymbol{p}(s)) = \begin{cases} 1 & \text{if } \Delta_i(s) < 0 \\ 0 & \text{otherwise,} \end{cases}$$

for any $s \geq t$. Finally, if all agents of the same type adopt the same set of strategies, so that $\tau_i(t) = \theta_i(t)$ for every i, for a given $\boldsymbol{\theta}(t)$ the distribution of assets evolves as follows (the time index is dropped):

(3)
$$\dot{p}_{1,2} = \alpha\left\{p_{1,3}\left[p_{2,1}\left(1 - \theta_2\right) + p_{3,1} + p_{3,2}\left(1 - \theta_1\right)\right] - p_{1,2}p_{2,3}\theta_1\right\},$$

(4)
$$\dot{p}_{2,3} = \alpha\left\{p_{2,1}\left[p_{3,2}\left(1 - \theta_3\right) + p_{1,2} + p_{1,3}\left(1 - \theta_2\right)\right] - p_{2,3}p_{3,1}\theta_2\right\},$$

(5)
$$\dot{p}_{3,1} = \alpha\left\{p_{3,2}\left[p_{1,3}\left(1 - \theta_1\right) + p_{2,3} + p_{2,1}\left(1 - \theta_3\right)\right] - p_{3,1}p_{1,2}\theta_3\right\}.$$

The terms inside the brackets before the minus sign in Equation (3) calculate the fraction of type 1 agents that is called for a match while holding good 3, and that ends up in the position of carrying good 2. Such an event materializes either because of barter or because the type 1 agents leave the meeting with good 1, consume it,

3. When no confusion arises, we will use the loose language of calling an agent of type i simply as agent or individual i, or for short type-i.

4. Appendix S1 contains the analytical expressions for $V_{i,i+1}$ and $V_{i,i+2}$.

5. Observe that the analysis focuses on pure strategy equilibria. Kehoe, Kiyotaki, and Wright (1993) show that allowing for mixed strategies gives rise to dynamic equilibria that include cycles, sunspots, and other non-Markovian equilibria. Renero (1998), however, argues that it is hard to find an initial condition from which an equilibrium pattern converges to a mixed strategy steady state equilibrium. More recently, Oberfield and Trachter (2012) have found that, in a symmetric environment, as the frequency of search increases, cycles and multiplicity in mixed strategy tend to disappear.

and then immediately produce good 2. The term after the minus sign accounts for events in which type 1 agents enter trades with good 2 and end up with good 3. A similar interpretation applies to Equations (3)–(5). The behavior of $p_{i,\,i+2}$ is derived through Equation (1).

As we focus on patterns that converge to a steady state, it is important to clarify when such a convergence occurs. Equations (3)–(5) suggest that convergence should depend on the set of strategies θ_i. As there are $2^3 = 8$ possible strategies, eight is also the number of steady state equilibria that can emerge. The following proposition states that seven out of the eight equilibria are locally stable.

PROPOSITION 1. *Under any time-constant profiles of strategies* $\boldsymbol{\theta}$, $\boldsymbol{p}(t)$, *with the possible exception of* $\boldsymbol{\theta} = (1, 1, 1)$, *the system of Equations (3)–(5) converges to a stationary distribution, from any initial position.*[6]

Proof. Appendix S1, Supporting information, contains the proof for seven cases and also explains that while sufficient conditions of convergence cannot be established for the remaining case (1,1,1), this strategy hardly supports a Nash equilibrium (NE). ■

We now turn to the definition of a NE.

A. Definition of a NE.

Given an initial distribution of inventories $\boldsymbol{p}(0) = \boldsymbol{p}_0$, a *NE* is a path of strategies $\boldsymbol{\theta}^*(t)$ together with a distribution of inventories $\boldsymbol{p}^*(t)$ such that for all $t > 0$:

i. $\boldsymbol{p}^*(t)$ and $\boldsymbol{\theta}^*(t)$ satisfy the dynamics Equations (3–5) with the initial condition $\boldsymbol{p}^*(0) = \boldsymbol{p}_0$, and subject to the constraint (1);

ii. For all $t > 0$, every agent maximizes his or her expected utility given the profile of strategies of the rest of the population;

iii. $\tilde{\tau}_i\left(t; \boldsymbol{\theta}^*(t), \boldsymbol{p}^*(t)\right) = \theta_i^*(t)$ for all $t > 0$.

Observe that the definition is not restricted to a stationary state. While it is in general not possible to derive analytically all the dynamic Nash equilibria, it is possible to characterize all the Nash steady state equilibria, for a given distribution of the population across the three types. An example is given by the following proposition.

6. For the profile of strategies (1,1,1), proving that $\boldsymbol{p}(t)$ converges to a fixed point is more challenging. But such profile of strategy happens not to be a steady state Nash equilibrium (see Proposition 2).

TABLE 1
Steady State Equilibria

Strategies	Assets Distribution	Strategies	Assets Distribution
(0,1,0)	$\frac{1}{3}\left[1, \frac{1}{2}, 1\right]$	(1,1,0)	$\frac{1}{3}[a, b, 1]$
(1,0,0)	$\frac{1}{3}\left[\frac{1}{2}, 1, , , 1\right]$	(1,0,1)	$\frac{1}{3}[b, 1, a]$
(0,0,1)	$\frac{1}{3}\left[1, , , 1, \frac{1}{2}\right]$	(0,1,1)	$\frac{1}{3}[1, a, b]$

Note: $a \equiv \frac{1}{2}\sqrt{2}$ and $b \equiv \sqrt{2} - 1$.

PROPOSITION 2. *When the population is equally split across the three types, the six steady state NE reported in Table 1 exist. In some cases, a pair of NE coexists.*

Proof. See Appendices S1 and S2. ■

Which of the equilibria reported in Table 1 emerges depends crucially on the specification of the returns on assets. For example, in Model A of KW, that in the current framework corresponds to the return configuration $r_3 < r_2 < r_1$, the only two possible (pure strategy) equilibria are

$$(6) \qquad \boldsymbol{\theta} = (0, 1, 0) \text{ and } \boldsymbol{p} = \frac{1}{3}(1, 1/2, 1),$$

that exists if

$$(7) \qquad \frac{r_2 - r_3}{u_1 \alpha} > p_{3,1} - p_{2,1} = 1/6$$

and

$$(8) \qquad \boldsymbol{\theta} = (1, 1, 0) \text{ and } \boldsymbol{p} = \frac{1}{3}\left(\frac{1}{2}\sqrt{2}, \sqrt{2} - 1, 1\right),$$

that exists if

$$(9) \qquad \frac{r_2 - r_3}{u_1 \alpha} < p_{3,1} - p_{2,1} = \frac{\sqrt{2}}{3}\left(\sqrt{2} - 1\right),$$

where the $p_{i,j}$ in the inequalities (7) and (9) are evaluated in the respective steady states. A joint reading of conditions (7) and (9) reveals that the two equilibria—usually referred to, respectively, as fundamental and speculative equilibrium, in reference to the trading strategy followed by type-1 agents—cannot coexist. The two equilibria are summarized in row R1 of Table 2. The specifications $r_2 < r_1 < r_3$ and $r_1 < r_3 < r_2$ would generate also unique steady state equilibria (see Table 2A).

Under any of the three configurations of return just reviewed, multiple equilibria can be obtained by changing the pattern of specialization. For instance, Model B in KW is obtained

TABLE 2
Steady State Equilibria, Strategies, and Money

	Returns	*F*	S	Assets (*F*)	Assets (*S*)	M (*F*)	M (*S*)
Panel A							
R1	$r_3 < r_2 < r_1$	(0,1,0)	(1,1,0)	$\frac{1}{3}\left[1, \frac{1}{2}, 1\right]$	$\frac{1}{3}[a, b, 1]$	1	1,3
R2	$r_2 < r_1 < r_3$	(1,0,0)	(1,0,1)	$\frac{1}{3}\left[\frac{1}{2}, 1, 1\right]$	$\frac{1}{3}[b, 1, a]$	3	2,3
R3	$r_1 < r_3 < r_2$	(0,0,1)	(0,1,1)	$\frac{1}{3}\left[1, 1\frac{1}{2}\right]$	$\frac{1}{3}[1, a, b]$	2	1,2
Panel B							
R4	$r_2 < r_3 < r_1$	(1,1,0)	(1,0,1)	$\frac{1}{3}[a, b, 1]$	$\frac{1}{3}[b, 1, a]$	1, 3	2, 3
R5	$r_3 < r_1 < r_2$	(0,1,1)	(1,1,0)	$\frac{1}{3}[1, a, b]$	$\frac{1}{3}[a, b, 1]$	1, 2	1, 3
R6	$r_1 < r_2 < r_3$	(1,0,1)	(0,1,1)	$\frac{1}{3}[b, 1, a]$	$\frac{1}{3}[1, a, b]$	3, 2	1, 2

Notes: $a \equiv \frac{1}{2}\sqrt{2}$ and $b \equiv \sqrt{2} - 1$. The *F* and *S* columns contain the triplet (θ_1, θ_2, θ_3) that describes the fundamental and the speculative steady state strategy, respectively. The following two columns are the assets' stationary distributions: [$p_{1,2}$, $p_{2,3}$, $p_{3,1}$]. The last two columns indicate which asset is traded indirectly—or acts as "money"—in the fundamental and speculative equilibrium, respectively. In rows R1 through R3, the equilibria are unique; only one type of agent plays speculative strategies in the S equilibrium. In the R4–R6 rows, the two equilibria may coexist; two types of agents play speculative strategies in the S equilibrium.

TABLE 3
Baseline Parameters

Population	Discount	Matching	Utility	Returns		
μ_i	δ	α	u_i	r_1	r_2	r_3
$\frac{1}{3}$	0.03	1	1	0.21	0.2 or 0.1	0

Notes: When $r_2 = 0.2$, the economy converges to the fundamental equilibrium (0,1,0), whereas when $r_2 = 0.1$ it converges to the speculative equilibrium (1,1,0). The steady state capital income share is 0.37 and 0.51, for the fundamental and speculative equilibrium, respectively.

as a variation of Model A by assuming that agent i produces $i + 2$ instead of good $i + 1$. As observed in Lagos, Rocheteau, and Wright (2017), an equivalent environment with multiple equilibria can also be created with the same production specialization of Model A (type-i agent produces good $i + 1$) by changing the ordering of returns. This is the approach we follow here. Table 2B reports the three returns ordering that create a Model B-type of the environment. For instance if $r_2 < r_3 < r_1$ (Table 2B, R4), a (1,1,0) NE always exists and a (1,0,1) equilibrium exists if

$$p_{3,2} > \frac{r_1 - r_3}{\alpha u_2} \tag{10}$$

$$p_{1,3} - p_{2,3} < \frac{r_2 - r_1}{\alpha u_3} \tag{11}$$

with $p_{3,2} = \left(1 - \frac{1}{2}\sqrt{2}\right)/3, p_{1,3} = \left(2 - \sqrt{2}\right)/3$, and $p_{2,3} = 1/3$. Hence, if conditions (10)–(11) hold, the economy exhibits multiple steady states.

III. MACROECONOMIC INDICES

The dynamics of the economy will be characterized through the behavior of liquidity, production, and inequality of income and welfare. A formal definition of these quantities follows.

A. Liquidity

The model delivers several liquidity indices that are comparable to those used in empirical macroeconomics. First, the stock of each of the three assets, x_i, can be interpreted as "market thickness"—a measure of how easy it is to find an asset on the market. A second measure of liquidity is the "frequency of trade," t_i, that measures the number of times good i is traded in a unit of time. The ratio t_i/x_i is sometimes called the velocity of circulation. KW proposes also the level of "acceptability" of an asset in a trade, $a_i = t_i/o_i$, as an index of liquidity, where o_i is the frequency with which good i is offered in a period of time. The variable a_i is, by construction, bounded between zero and one. It captures the probability that an asset is traded, given that someone offers it.[7]

B. Production

It is easier to first deal with the flow of consumption. Let $c_i ds$ be the fraction of agents of type i in the overall population that consumes goods between times s and $s + ds$. Then, the rate of consumption for type i individuals is

$$c_i = p_{i,i+1}\left(p_{i+1,i} + p_{i+2,i}\theta_{i+2}\right) + p_{i,i+2}\left[p_{i+1,i}\left(1 - \theta_{i+1}\right) + p_{i+2,i}\right].$$

As production immediately follows consumption, c_i also represents the rate of production of good $i + 1$. Aggregate production is $\sum_i \mu_i c_i$. In steady state, $c_i = c_{i+1}$. Clearly, the level of c_i is affected by the distribution of skills. If a good is produced by a small fraction of the population, the economy is trapped in a low-production equilibrium.

C. Income

Because prices are all set to one, the average flow of income generated by agents of type i holding good $i + 1$ and $i + 2$ is

$$g_{i,i+1} = \left(p_{i+1,i} + p_{i+2,i}\theta_{i+2}\right) + r_{i+1}$$

and

$$g_{i,i+2} = \left[p_{i+1,i}\left(1 - \theta_{i+1}\right) + p_{i+2,i}\right] + r_{i+2},$$

respectively. Interpreting r_{i+1} and r_{i+2} as capital income, and the rest as labor income, national income is $\sum_i \sum_j p_{i,j} g_{i,j}$.

D. Inequality

Income and welfare inequality are computed with a Gini coefficient that measures the area comprised between a 45° line and the Lorenz curve. The population is split into six income groups according to $g_{i,j}$, and into six welfare groups on the basis of the value functions $V_{i,j}$.

IV. EXPERIMENTS

This section proposes three types of simulations with economies of the type listed in Table 2A. While several steady state equilibria can emerge, for a given specification of preferences, and of production and matching technology, there is a unique steady state equilibrium. Therefore, in some of the simulations discussed in this section when, a result of a shock, a new steady state equilibrium emerges an old one vanishes. Scenarios with multiple steady states are discussed in Appendix S2.

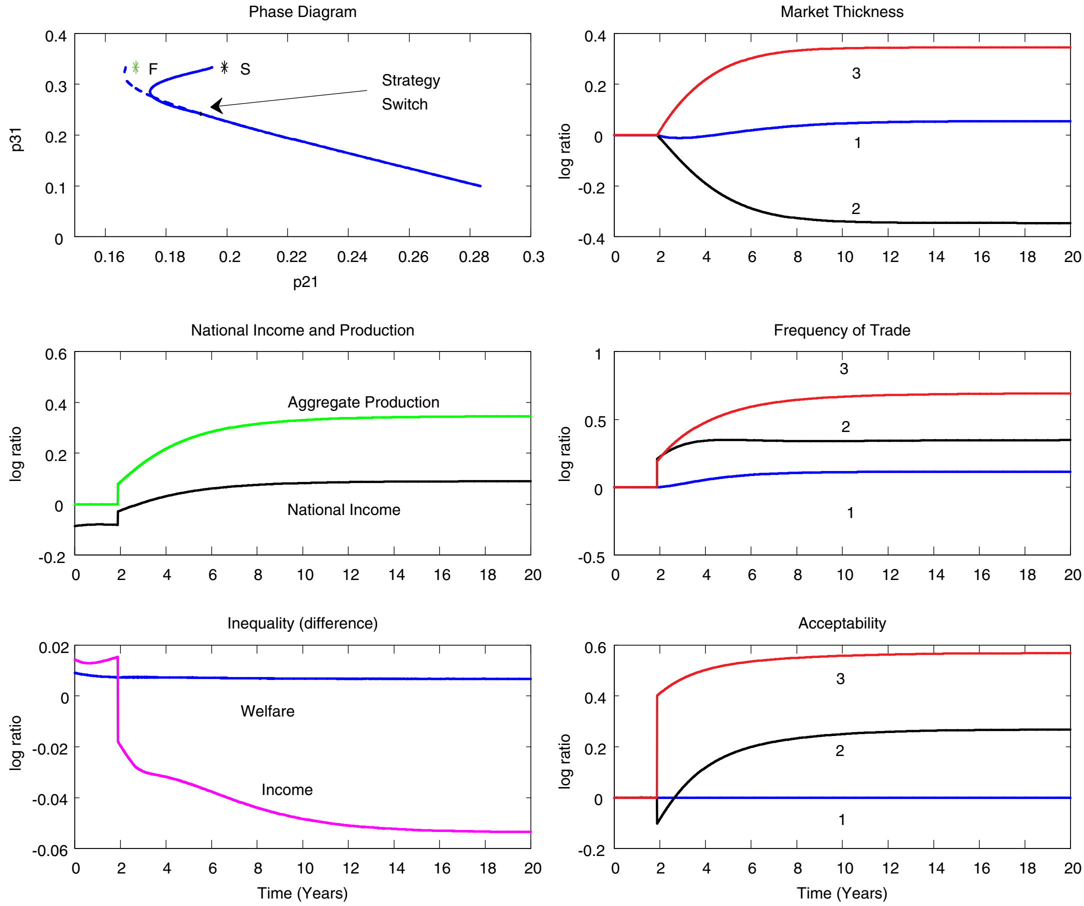
A. Reversal of Fortune over the Transition

The first application of the dynamics of the model economy addresses the conjecture that, since the work of Acemoglu, Johnson, and Robinson (2002), has been known as "reversal of fortune" theory. Europeans in areas of relative affluence such as Mesoamerica and Andes privileged, according to the theory, the short-run goal of extracting resources and neglected the development of institutions that encourage investment and growth. In one of the first formulations of this hypothesis, Engerman and Sokoloff (1997) argued that initial inequality in wealth and human capital conditioned subsequent patterns of development in Latin American countries. Engerman and Sokoloff (1997) observe that although British and Latin American colonies in the New World began with similar legal and cultural background, and attracted immigrants from similar places and economic classes, they evolved quite distinct societies and sets of economic institutions. The Spanish practices of awarding claims and land, native labor, and rich mineral resources to members of the elite generated a large wealth disparity in the Spanish colonies of Mexico and Peru. In contrast, in the northern colonies of North America the regime of mixed farming centered on grains and livestock meant a more equal distribution of wealth: "[T]he circumstances on these latter regions [northern colonies of North America] encouraged the evolution of more equal distribution of wealth, more democratic political institutions, more extensive domestic markets and the pursuit of more growth-oriented policies than did those in the former [Spanish colonies of Mexico and Peru]" (p. 263).

While the reversal of fortune hypothesis has been widely debated from an empirical standpoint (see Acemoglu and Robinson 2012, for an overview and Fukuyama 2014, ch. 16 and ch. 21 for a more critical assessment), formal analysis is lacking. We interpret the divergence patterns of development between the Spanish and North American colonies as an equilibrium selection

7. Appendix S1 illustrates the formal derivation of t_i, x_i, and o_i.

FIGURE 1
Reversal of Fortune



Notes: For parameters see Table 3. The top-left plot is a partial view of the evolution of the assets' distribution of two similar economies that share the same initial condition. The economy with $r_2 = 0{:}1$ converges to the speculative NE (1,1,0) and the economy with $r_2 = 0{:}2$ converges to the fundamental equilibrium (0,1,0). The curves of the remaining plots are ratios or differences of the speculative economy's time series relative to the ones of the fundamental economy. The numbers inside the three right plots identify the type of asset traded.

driven by different levels of initial inequality. The mechanism that we illustrate starts from the premises, as emphasized in the empirical literature just discussed, that initially the more unequal country is also wealthier. Specifically, in the economy that we identify with Latin America, the return on assets produced by type 1 agents is higher than in the other economy, that is the northern colonies of North America. This difference captures the basic idea that in Latin America the set of institutions created the conditions to extract more rents relative to North America. In our setting, the country with more equal wealth distribution converges to the speculative equilibrium, while the country with the skewed distribution converges to the fundamental equilibrium. In our interpretation of equilibrium selection, the country with the lower discrepancy in the return of the three assets is the one featuring institutions of "higher quality." The analysis implies, in accordance with what was observed by Engerman and Sokoloff, that the economy with lower inequality and a relatively more modest initial rent on assets, develops a more extensive market and generates a greater volume of production. By contrast, the country with the highest return on assets in the long run exhibits a poorer performance, because agents have no incentive to trade and market liquidity remains low.

In the language of the model, consider two economies that are similar in all respects except that in one (S-economy) the return on good 2 is lower than in the other (the F-economy). The returns satisfy $r_3 < r_2 < r_1$ in both economies. With the initial distribution of inventories, only good 1 is used in indirect trading in either economy. Over the transition, as the difference between $p_{3,1}$ and $p_{2,1}$ increases (top-left plot of Figure 1), good 3 becomes relatively more marketable than good 2. In the S-economy, where the good 2 commands a smaller return than in the F-economy, good 3 emerges as an asset exchanged in indirect trading,[8] whereas in the F-economy it does not. Said differently, in the F-economy agents 1 choose to obtain a higher fraction of their income from hoarding capital. Conversely, in the S-economy agents are willing to give up some capital income and to be more active in production.[9]

Except for inequality, the two economies exhibit similar macroeconomic and financial indicators until type 1 agents of the S-economy change their strategies. From then on, the S-economy performs better. Aggregate production is larger, mostly thanks to an expansion in the production of good 3 (the production of good 1 is relatively smaller for a while in the S-economy because of a sudden drop in its marketability).

The middle-left graph of Figure 1 contains the key insight of the exercise: The F-economy has an initial advantage in terms of income because of the higher returns in asset 2. Nevertheless, this initial advantage induces F-economy's type 1 agents to play fundamental strategies, whereas their counterparts in the S-economy engage in indirect trading. The reversal emerges gradually as the market thickness and the frequency of trade of good 3 become significantly large to compensate type 1 agents for the loss of their rental income.

The crossing between the two economies occurs also with respect to income inequality (bottom-left graph of Figure 1). In the F-economy, the group of type 2 individuals holding good 3 converges to a zero income. These individuals do not earn any capital rent, and do not have any immediate prospect of trading their holding against a consumption good. Conversely, because in the S-economy good 3 is accepted by type 1 agents, the average income at the lower end is about half of that of the richest group (see Table 4).

TABLE 4
Reversal of Fortune

	Bottom/Top	Gini	Capital Share
Panel A: Fundamental Equilibrium			
Initial position	0.1840	0.1091	0.3685
Steady state	0	0.1131	0.5074
Panel B: Speculative Equilibrium			
Initial position	0.1840	0.1235	0.3110
Steady state	0.5283	0.0595	0.3633

Notes: The first column of panel A shows the ratio between the bottom and the top income level at the initial point of the transition and when the economy reaches the fundamental steady state (see Figure 1). For parameters' specification, see Table 3. The second and third columns report the initial and final values of the Gini index, and of the average capital income share, respectively. In steady state, the bottom income group consists of type 2 individuals holding good 3. Their income is zero because they have no immediate prospect of obtaining a consumption good and have no capital income ($r_3 = 0$). Panel B shows similar data for the economy that converges to the speculative steady state with $r_2 = 0.1$. (In the initial phase of the transition agents 1 also play fundamental strategies.)

B. Market Frictions

The second experiment is inspired by episodes of structural reforms, such as those enacted by South Korea and other East Asian countries in the late 1990s, in the aftermath of the 1997 crisis, aimed at increasing the flexibility of markets and reducing allocative frictions. In South Korea, the reforms reduced the obstacles to the reallocation process in financial markets by deterring the continuous rollover of credit relationships that had characterized the precrisis period. The reforms, for instance, facilitated banks' screening of applicants and thus raised banks' ability to create matches with firms and to reallocate loans (Chamley and Rochon 2011). Although the model lacks some of the institutional details, such as banks, it allows us to study the consequences of a more fluid market by studying agents' responses to an increase in the matching rate α.

The immediate effect of the shock that lifts up α is a boost in production and national income, reflecting the more frequent trading activity. In

8. The literature sometimes refers to this phenomenon as the emergence of commodity money.

9. Specifically, the S-economy converges to the speculative equilibrium $\boldsymbol{\theta} = (1, 1, 0)$, $\boldsymbol{p} = \frac{1}{3}\left[\frac{1}{2}\sqrt{2}, \sqrt{2} - 1, 1\right]$, and the F-economy to the *fundamental* equilibrium $\boldsymbol{\theta} = (0, 1, 0)$, $\boldsymbol{p} = \frac{1}{3}\left[1, \frac{1}{2}, 1\right]$. Appendix S1 states the conditions for the existence of these equilibria.

TABLE 5
Market Frictions

Steady State	Bottom/Top	Gini	Capital Share
F (preshock)	0	0.1131	0.5074
S (postshock)	0.6274	0.0467	0.2757

Notes: The matching technology improves by 50%. The initial set of parameters is depicted in Table 3, with $r_2 = 0.2$. The economy transits from the fundamental to the speculative steady state, where trading is more frequent (Figure 2).

the experiment depicted in Figure 2, initially the economy is on a fundamental steady state (0,1,0) when it is hit by a shock that rises the matching parameter α by 50%. The frequency of trade in assets 2 and 3 doubles immediately after the shock; the acceptability indices of these two assets also increase substantially. Interestingly, the shock also affects the distribution of assets, as it causes the economy to transit from a fundamental to a speculative steady state equilibrium. As a result, income inequality declines, because the holders of assets 2 and 3 earn a more meager capital income, relative to asset 1 holders. The top-right plot indicates that the volume of asset 2 shrinks, because this is partially replaced by asset 3. As a larger stock of the wealth is invested in a low-return asset, the fraction of the national income generated by capital return goes down significantly, the bottom to top income ratio rises, and the level of inequality is significantly reduced (Table 5).

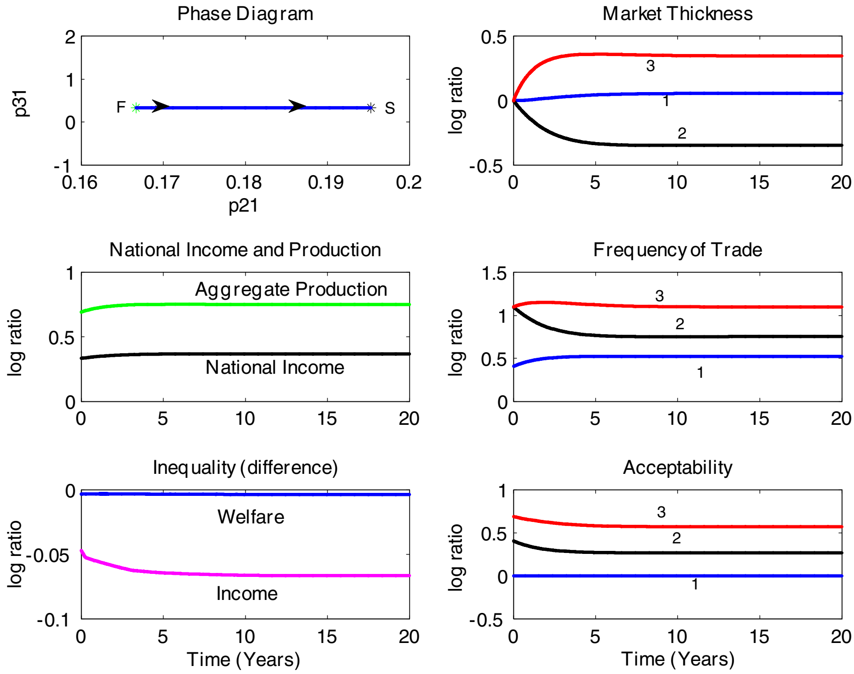
In sum, a reduction of market frictions not only boosts average income, but it also helps reduce income disparity. An interesting comparison can be drawn with the conclusion of the literature that studies the interaction between technological change and skills (see surveys of Acemoglu 2002; Aghion 2002; Hornstein, Krusell, and Violante 2005). The mechanism of inequality dynamics here is derived by interacting market transactions with the initial disparity in endowments: each type of agent has specific skills to generate a commodity whose return can be higher or lower than that of commodities produced by other types of agents. The improvement in the matching technology, by increasing the participation in the market, diminishes the relative importance of premia on returns, because a greater fraction of income is generated through market exchange. Goldin and Katz (2008) argue that in the first decades of the twentieth century technological change smoothed out income disparity in the United States, but it may have had the opposite effect of increasing inequality in more recent decades. However, Piketty (2014) claims that the more recent rise in inequality is rather because of a reinforcement of the rents position of privileged groups and organizations (next experiment explores this hypothesis).

The experiment also speaks to studies on the effect of market reforms on inequality (see Koo 2007, and Campos and Nugent 2015). The evidence on this effect is ambiguous, as also pointed out in recent, comprehensive reviews (see Astarita and D'Adamo 2017). Our experiment underscores the need to disentangle the impact on the asset market liquidity when evaluating the consequences of market reforms for inequality.

C. Shock to Asset Returns

The first experiment on the reversal of fortune illustrated that the gap between r_2 and r_3 can condition the path of development of the economy. Following the same intuition, we propose an experiment in which the shock increases r_2 and it is large enough to take away the economy from a speculative equilibrium and push it toward a fundamental long-run equilibrium, but not so large to alter the ranking of the rates of return, that is, even after the shock $r_3 < r_2 < r_1$ (next section deals with a case in which the shock reshuffles the order of returns). The consequences of a positive shock are that the economy's average income goes down because of the change of strategies of type 1 individuals, who, after the shock, are happy to keep their production good, which now generates a higher return, and trade it only against their consumption good. Type 1's strategy switch causes a decline in the frequency of trade. More precisely, the shock induces type 1 agents to give up indirect trading and to obtain a larger fraction of their income from hoarding capital. Figure 3 shows that the frequency of trade and the acceptability of assets decline. The liquidity drop is associated with a reduction of both national income and aggregate production. Welfare inequality declines slightly, but there is a substantial rise in income inequality. By renouncing to indirect trade, type 1 agents hoard asset 2 (see the top-right plot) for longer periods. As asset 2 yields a better return than asset 3, a larger fraction of agents 1's income is now derived from rents. Therefore, the gap between income and production is larger after the shock (see the left-middle graph of Figure 3). Because agents 2 face worse odds in trading away their holdings and they are also the ones that hold mostly the asset

FIGURE 2
Market Frictions



Notes: The preshock parameter values are in Table 3 with $r_2 = 0{:}1$ (fundamental equilibrium). The shock raises the matching parameter by 50%. The plots of ratios and differences are calculated with respect to the preshock state. The income capital share and inequality measures are reported in Table 5.

with the lowest return, there is a dramatic drop of the bottom/top income ratio. In fact, Table 6 indicates that income inequality doubles at the end of the adjustment process and that the capital income ratio goes up from 36% to 51%. The correlation is in line with Piketty's (2014) argument that a higher interest rate leads to greater capital income and to more inequality. Notice that here the expansion in inequality is induced mostly by the decline in liquidity (i.e., by rent-seeking behavior). Despite the decline in national income and liquidity, the middle-left plot of Figure 3 shows that the average income of type 1 agents goes substantially up, because it benefits from the higher returns of asset 2—a second major factor contributing to the increased income inequality.

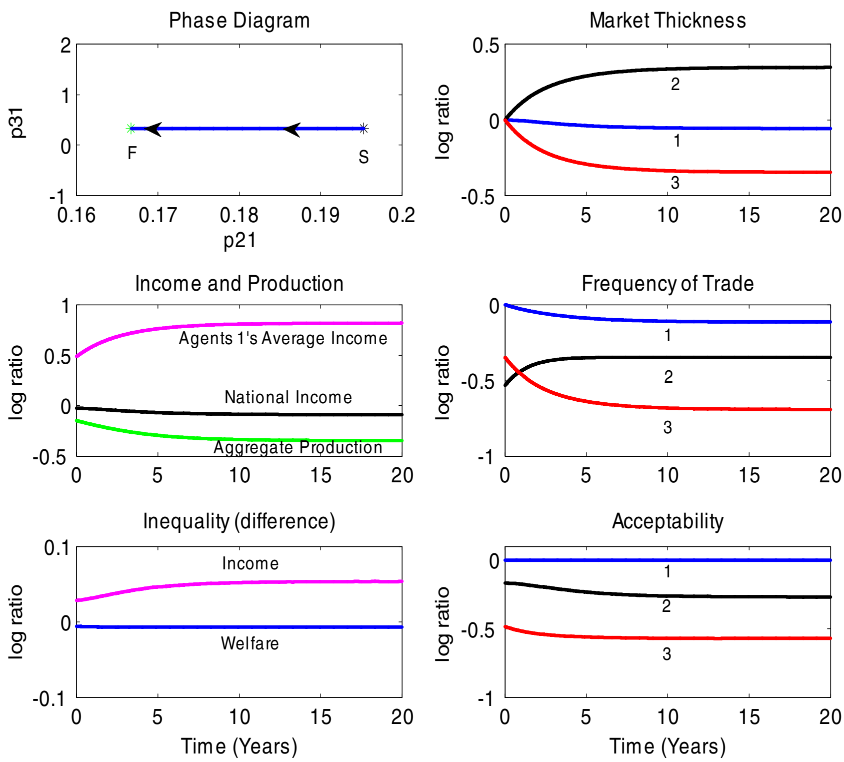
Discussion. The experiment generated a contemporaneous drop in liquidity and in national income, as well as a rise in income inequality as a result of a *positive* shock to r_2. It should be clear, however, that a similar scenario could be obtained, perhaps even more intuitively, through a *negative* shock to r_3, as what matters for the emergence of a long-run equilibrium is the difference $r_2 - r_3$ (see R1, Table 2). With this observation in mind, the model can be used to interpret the drop of liquidity and national income that has been observed in episodes of long crisis. These include the "lost decade" of Japan of the 1990s, which mostly originated from the accumulation of bad-performing loans in the banking sector following an asset price drop, or also, more recently, the slow recovery of some Southern European

TABLE 6
Higher Return of Asset 2

Steady State	Bottom/Top	Gini	Capital Share
S (preshock)	0.5288	0.0594	0.3634
F (postshock)	0	0.1131	0.5074

Notes: Inequality and capital share variations as a result of an increase in r_2 from 0.1 to 0.2. For remaining parameters, see Table 3. The economy transits from the speculative to the fundamental equilibrium (Figure 3).

FIGURE 3
Higher Return of Asset 2



Notes: The preshock set of parameters is displayed in Table 3, with $r_2 = 0{:}1$ (speculative equilibrium). The shock doubles the rate of return on asset 2. The ratios and differences are calculated with respect to an economy in its speculative Nash steady state.

countries from the global crisis of 2008–2010. These prolonged stagnations can affect inequality. For example, in Japan, in 1993 the Gini coefficient was more than 2 percentage points higher than in 1987 and by 2000 it exceeded the average of Organization for Economic Co-operation and Development (OECD) countries (Bank of Japan Survey of Business Conditions). Chiavacci and Hommerich (2017) argue that, as a result of the stagnation, Japan has transited from a growing economy regarded as an example of social equality, to a "gap society" (kakusa shakai) where inequality is deepening. A further example is provided by Italy, where the Gini index of income inequality has been rising in the aftermath of the global crisis, as pointed out by OECD (2011) and Ballarino et al. (2012).[10]

Ajello (2012), Shi (2012), and Del Negro et al. (2016) also study the correlation between liquidity and national income through adaptations of Kiyotaki and Moore (2012). These studies, however, do not consider the dynamics of inequality. A growing empirical literature finds that indeed crises affect inequality (see Atkinson and Morelli 2011). Evidence of an increase in inequality has been found, for example, for Malaysia and Singapore following the 1997 crisis. For South Korea, Lee (2016) uncovers an increase of inequality over the course of the East Asian crisis. Studies on the crises of Latin America also suggest that these crises have often raised inequality (Fallon and Lucas 2002; Galbraith and Lu 2001; Gasparini and Lustig 2011; Lustig 2000). Furthermore, Atkinson and Morelli (2011)

10. There are also episodes in which it is the increase in the return of one asset that leads the market for another asset to stall. In recent years in European countries banks have increasingly held substantial amounts of government bonds of core euro-area countries (especially Germany), perceived to be an appealing investment. This has allegedly led banks to reduce their involvement in the loan market.

provide evidence of an increase in inequality after the Nordic crises of the 1990s, while various studies point to higher income inequality following the 2008–2010 global crisis (see Piketty and Saez 2013).

Interestingly, in the studies mentioned above the description of the nexus between crises and inequality generally focuses on the direct effects of the crises through changes in the returns of assets and on the resulting change in the returns to agents' asset holdings. This includes the direct impact of falling asset prices and returns, which can especially affect the wealthy, or the effects of the following declines in incomes on the lower tail of the income distribution (see Atkinson and Morelli 2011, and references therein). In our experiment, we instead disentangle the link between crises and inequality through changes in asset market liquidity.

D. Shock to Asset Returns: Multiple Switches

The previous experiment assumed, for simplicity, that the shock would not change the order of returns across the three assets. When it does, however, there are broader effects on the agents' strategies because new long-run equilibria emerge and existing equilibria vanish. In the previous experiment, the transition from a (1,1,0) equilibrium to a (0,1,0) equilibrium was caused by positive shock to r_2. We observed also that similar results can be obtained through a negative shock to r_3. Conversely, a positive shock to r_3 that is large enough to go over r_1 triggers a more articulated response of the economy as it may induce two groups of agents to abandon their current strategies. Figure 4 accounts for such a scenario. As with the previous experiment, initially the economy is on a (1,1,0) equilibrium and $r_3 < r_2 < r_1$. Letting r_3' be the return observed after the shock, we have that $r_2 < r_1 < r_3'$. The long-run consequences of this occurrence are easily grasped by comparing the equilibria of the R1 and R2 economies reported in Table 2. The initial state of the economy corresponds to the R1 speculative steady state. As a result of the shock, the new equilibrium (1,0,1) emerges (see R2 of Table 2). In the new steady state, type 3 rather than type 1 agents play speculative strategies (although type 1 agents do not change their trading behavior, indirect trade in the R2 economy actually comes through fundamental strategies). Inequality has a nonmonotonic adjustment. First, it goes up, reflecting the greater capital income disparity across groups, and then declines, as the patterns of trade partially level the playing field. In particular, the shock and the responses that it triggers make type 1 and type 2 agents better off, whereas type 3 agents are worse off. Type 2 agents benefit as the return on the good they produce goes up. Type 1 agents gain from the fact that their production good is now more "liquid," for it is accepted in indirect trading. Conversely, type 3 agents lose from the shock because their production good is no longer accepted in indirect trading. Overall, Table 7 shows that the shock rebalances substantially the income levels of the poorest and richest individuals and slashes the Gini index by half. Contrary to previous examples, however, this time there is a negative long-run correlation between inequality and capital share, because the capital windfall goes to type 2 agents that used to face the least favorable trading odds. Furthermore, the liquidity of asset 1 and asset 3 move in opposite directions, a phenomenon that also contributes to the contraction of inequality.

TABLE 7
Higher Return of Asset 3

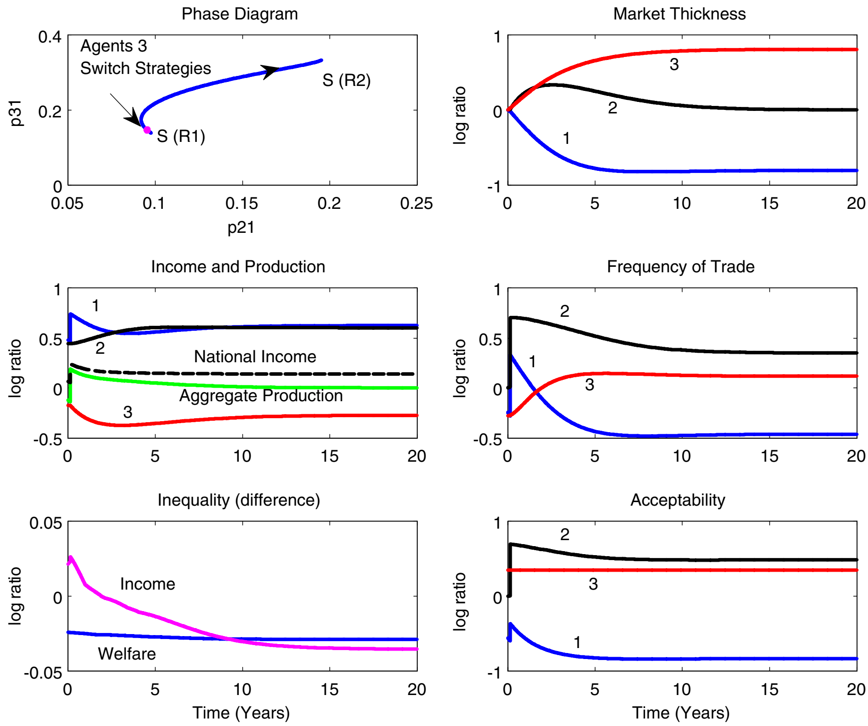
Steady State	Bottom/Top	Gini	Capital Share
S of R1 (preshock)	0.5288	0.0594	0.3634
S of R2 (postshock)	0.7358	0.0241	0.4453

Notes: The rate of return of asset 3, r_3, increases from 0 to 0.22. The remaining parameters are reported in Table 3, with $r_2 = 0.2$. The economy transits from the R1 speculative equilibrium to the R2 speculative equilibrium (Figure 4).

V. CONCLUSION

This article used a KW framework to examine the relationship between liquidity, productivity, and the distribution of income. A novel methodology allowed us to study the dynamics of the KW economy not only around a stationary state, but also when the initial position of the economy is far from it. Macroeconomic and development experiments hinted at the breadth of possible applications. One experiment interpreted the effects of the quality of institutions on development (Acemoglu and Robinson 2012) as an issue of equilibrium selection driven by an initial difference in the distribution of rents across assets. The relatively more unequal economy chooses an equilibrium characterized by a lower level of production and a lower frequency of transactions—a result that we also related to the explanation of Engerman and Sokoloff

FIGURE 4
Higher Return of Asset 3



Notes: The initial position is the speculative equilibrium, under R1 configuration. The shock raises the rate of return of asset 3 above that of the other two assets (r_3 goes from 0 to 0.22).

(1997) about the development delay of Latin America.

One macroexperiment showed that a reduction of market frictions can boost average income and help reduce income disparity. Another macroexperiment considered the effects of an alteration of the asset returns on liquidity, on the level of production, and on income distribution. We observed that the simulated economies exhibited a relatively low level of inequality: their income Gini index was between a quarter and a half of the one reported for the most egalitarian countries because the only sources of inequality considered are the marketability and the returns of assets. The model suggests that inequality originated from capital income is compressed substantially when assets become more liquid, because agents find it more profitable to earn income from production rather than from hoarding capital.

Finally, one may wonder how these results are conditioned by the limited-storage capacity assumption—agents can hold only one unit of an indivisible asset at a time. Relaxing the assumption, which, as noted in Section II, is mostly motived by analytical convenience, would, arguably, generate some convergence in the average return of portfolio of the three types of agents; consequently, some of the equilibria reviewed in Table 2 might not survive. Nevertheless, as long as trading frictions remain a significant part of the environment, such a convergence would be limited, because market transactions cannot level the playing field completely: individuals who produce assets with a high return would still maintain, on average, a return advantage. We note, however, that if allowing for asset accumulation may cause some equilibria to disappear, a similar result could be obtained with an acceleration of the frequency of trade. For instance, in model A with a larger α only "speculative" or mixed strategy steady state equilibria would survive and the remaining frictions (difference in asset returns, indivisibility, limit to accumulation, and differences in tastes) would matter little. While such an operation is useful to test the limits of the model, it also runs against the intuition that frictions are part of the ordinary working of the economy.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Appendix S1. Proofs and derivations

Appendix S2. Extensions