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Coordinating business cycles[☆,☆☆]

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ABSTRACT

We develop a quantitative theory of business cycles with coordination failures. Because of demand complementarities and increasing returns, firms seek to coordinate production and multiple equilibria arise. We use a global game approach to discipline equilibrium selection and show that the unique dynamic equilibrium exhibits multiple steady states. Coordination on high production may fail after a large transitory shock, pushing the economy in a quasi-permanent recession. Our calibrated model rationalizes various features of the 2007–2009 recession and its recovery. Government spending, while generally harmful, can increase welfare when the economy is transitioning between steady states. Other policy instruments are preferable to fix miscoordination.

1. Introduction

Over the post-war period, the United States economy has shown a remarkable tendency to revert back to its long-run trend after recessionary episodes. In contrast, its evolution in the aftermath of the 2007–2009 recession has been startling. After the trough of the recession was reached in the second quarter of 2009, most major economic aggregates started growing again but never caught up with their previous trends. As Fig. 1 shows below, real GDP seems to have settled on a parallel but lower growth path from which it has not moved since, despite the COVID-19 recession of 2020.[1]

We propose a quantitative theory of coordination failures that can account for this pattern. At the heart of the mechanism are demand complementarities and increasing returns that link firms' production decisions: the choice by one firm to scale up production generates additional income that raises the demand for other firms' products, thereby increasing their incentives to produce. The presence of this complementarity opens up the possibility of miscoordination and multiple equilibria. To discipline equilibrium selection and explore the model's quantitative and normative implications, we propose a global approach and show that such techniques can be applied in a dynamic general equilibrium context. Two main insights emerge from the theory. First, because of the coordination motives, strong self-reinforcing forces appear that can maintain the economy in a depressed state after a

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[1] Figure A.9 in the Appendix shows that the conclusion that the economy has been performing below trend since 2007Q4 is robust to various definitions of the trend.

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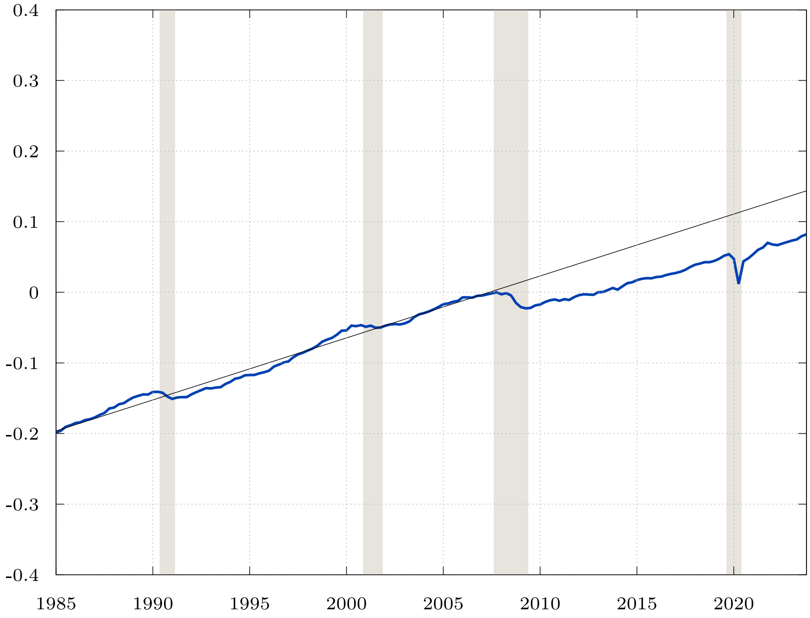

Fig. 1. Evolution of US real GDP per capita over 1985–2023.
Notes: Series shown in logs, undetrended, centered at 2007Q4. GDP is the BEA series in constant 2017 prices, seasonally adjusted. The linear trend is computed over the period 1985Q1–2007Q3. Shaded areas correspond to NBER recessions.

recession. More specifically, multiple steady states may arise: one with high output and high demand, the other one with low output and low demand. Sufficiently large transitory shocks can hinder coordination on high production and trigger a transition from the high to the low steady state: the economy then becomes stuck in a quasi-permanent recession in line with the recovery from the 2007–2009 recession. Second, as our explanation for the recession relies on coordination failures, our theory suggests a role for government intervention. We study various policies and find, in particular, that government spending, while generally detrimental to coordination, may sometimes raise welfare by successfully preventing the economy from falling to the low steady state.

The theory builds on the standard neoclassical growth model with monopolistic competition. In this environment, firms are subject to a complementarity as they take into account the level of aggregate demand when making individual production and pricing decisions. This complementarity provides firms with a motive to coordinate their actions and is, as such, the first key ingredient for coordination failures to arise. The second key ingredient is a form of increasing returns. For its tractability and ease of use with a global game approach, we consider a *discrete technological choice*: after incurring a fixed cost, firms can upgrade their technology and operate at higher productivity. This assumption aims to capture various margins of adjustment for firms: the adoption of a new technology, fixed investments, capacity utilization, entry/exit on some markets, and many others. It is also a common modeling device in the Big Push and growth literature (Murphy et al., 1989; De Ridder, 2024) and coordination literature (Cooper, 1994; Chamley, 1999). Importantly for our mechanism, the discreteness of the decision guarantees a strong response of production to changes in aggregate demand, which is key to sustain equilibrium multiplicity.

Together, the two main ingredients of the model — demand complementarities and increasing returns — generate multiple rational expectation equilibria. In each period, the economy may admit a high-output and a low-output equilibrium. In the high-output equilibrium, firms operate with the high technology, and aggregate employment and investment are high. On the opposite, in the low-output equilibrium, firms adopt the low technology, employment and investment are low, and the economy is depressed.

Models with multiple equilibria raise a host of methodological issues when taken to the data or when used for normative analysis. Solving those concerns usually requires to take a stand on which equilibrium is played. A large part of the business cycle literature with multiple equilibria deals with this issue using sunspots (Azariadis, 1981; Diamond and Fudenberg, 1989; Benhabib and Farmer, 1994). But underlying the use of sunspots is the implicit assumption that sunspot variables are perfectly observed and that agents have an implausibly strong ability to communicate and agree on which equilibrium to play. Policy analysis raises further concerns: since sunspots usually select equilibria in an exogenous way, they tend to ignore the impact of policies on equilibrium selection and are potentially subject to the Lucas critique.

In this paper, we explore instead the view proposed in the global game literature that equilibrium multiplicity in many coordination games is fragile and sensitive to the introduction of incomplete information and strategic uncertainty (Carlsson and Van Damme, 1993; Morris and Shin, 1998). Following this approach, we endow firms with private signals about the state of the world, and show that a unique recursive equilibrium exists in our economy when these signals are sufficiently informative or the fundamental sufficiently volatile. This result complements the literature by showing that uniqueness is obtained not only in the static one-shot game known to the global game literature, but also in a macroeconomic dynamic general equilibrium model.

This global game refinement turns our model from one with multiple equilibria into one with a unique equilibrium but, importantly, that unique equilibrium can feature multiple steady states in the dynamics of capital. Indeed, capital plays a central role in shaping how firms coordinate. Specifically, adoption of the high technology is positively associated with aggregate productivity and the capital stock. Intuitively, an abundance of cheap capital or a high productivity fuels the growth of firms and therefore facilitates coordination on high output. Inversely, if capital is scarce and expensive or productivity is low, firms are more likely to coordinate on low output. This positive relationship between an endogenous state variable like capital and coordination is the key source of *dynamic complementarities* in our framework and is critical to generate persistence and multiple steady states. In other words, coordination becomes self-reinforcing through capital accumulation: successful coordination on the high technology in the past raises output and investment, which in turn facilitates coordination in the future.

We show that the dynamics of the capital stock typically features two stable steady states. The high steady state exhibits high levels of output and aggregate demand, and a large mass of firms using the high technology, while the low steady state features the opposite. After a bad shock of sufficient size and duration, the economy runs the risk of falling into the low steady state, a situation that can be described as a *coordination trap*. It then enters a chronic state of depression as it sinks into a vicious cycle of declining capital stock and miscoordination. Only large positive shocks to productivity or strong policy interventions can bring the economy back to the high steady state. The theory therefore provides a foundation for long-lasting demand-deficient downturns.

We calibrate the model to the United States economy and show that it performs similarly to a real business cycle (RBC) model in terms of standard deviation of major aggregates and their correlation with output. It, however, outperforms the RBC model in explaining business cycles asymmetries as it generates a substantial amount of negative skewness as in the data. In addition, the simulated ergodic distributions of various aggregates are bimodal, a feature that is also roughly visible in the data. The multiplicity of steady states also generates strong non-linearities in how the economy responds to shocks. We find that for small shocks the economy reacts essentially as a standard RBC model: after a brief downturn, the economy grows back to its original state. For a medium shock, however, firms may fail to coordinate on high output, leading to a decline in investment that perpetuates the downturn, but the economy eventually recovers to its initial state. Shocks are therefore amplified and propagated through the coordination mechanism, even without a change in steady state. For a large shock, the coordination problem becomes sufficiently severe that the economy transitions to the low steady state, never returning to its original state.

To evaluate to what degree the theory can account for the events surrounding the Great Recession, we calibrate a sequence of productivity shocks to replicate the observed TFP series over 2007–2009 and then let productivity recover. We find that these shocks are sufficiently large to push the economy from the high to the low steady state. In addition, the time series generated by the model broadly replicate the behavior of their empirical counterparts in the aftermath of the recession, with consumption, employment, observed TFP, investment and output stabilizing to a lower steady state after a period of transition. Our coordination theory can therefore quantitatively explain some of the unusual features of this recession.

Coordination failures are often used to motivate government intervention, including government spending policies. In our model, the competitive equilibrium is inefficient because of monopolistic distortions and the associated aggregate demand externality, and government intervention is potentially useful. Our findings suggest that government spending, in the form of government consumption, is detrimental to welfare in most of the state space, as the coordination problem magnifies the dynamic welfare losses due to the crowding out of private investment. However, government spending may sometimes increase welfare. The intuition is as follows. When preferences allow for a wealth effect on the labor supply, an increase in government spending puts downward pressure on wages. As a result, the cost of production declines and firms can coordinate more easily on high output. Through this channel, government spending helps coordination. To illustrate this mechanism, we proceed to a series of numerical simulations and find that government spending can increase welfare, with output multipliers as high as 3, when the economy is on the verge of transitioning into the low steady state.

Even though government spending can be welfare improving, it is always suboptimal. We thus consider the problem of a social planner in this economy and find that simple subsidies are enough to implement the efficient allocation. First, an input subsidy corrects the inefficient firm size that results from the monopoly distortions. Second, a profit subsidy makes firms internalize the aggregate demand externality on their technology decisions.

Related literature

Our paper belongs to a long tradition in macroeconomics that views recessions as episodes of coordination failures.[2] A distinguishing feature of our work is the use of a global game approach to discipline the equilibrium selection. Our paper thus relates to the seminal articles by Carlsson and Van Damme (1993) and Morris and Shin (1998). It further relates to the dynamic global game literature as in Morris and Shin (1999) and Angeletos et al. (2007) and their applications such as Goldstein and Pauzner (2005) and others surveyed in Morris and Shin (2003). In comparison to these papers, we consider a macroeconomic application to business cycles in general equilibrium. Closer to our business cycle application, Chamley (1999) studies a stylized model of regime switches with complementarities in payoffs, and obtains equilibrium uniqueness through an imperfect information technique similar to a global game approach. Regime switches are infrequent because of slow learning about the fundamental. In contrast, our paper studies regime switches in an almost standard real business cycle model and obtains infrequent regime switches through the interaction of capital accumulation with coordination.

[2] Among others: Azariadis (1981), Diamond (1982), Cooper and John (1988), Kiyotaki (1988), Jones and Manuelli (1992), Benhabib and Farmer (1994), and Farmer and Guo (1994), Wen (1998) or more recently Kaplan and Menzio (2016), and Eeckhout and Lindenlaub (2019).

Our paper contributes to the literature on dynamic global games, which includes significant works like Angeletos et al. (2007), and Chassang (2010) or Mathevet and Steiner (2013). A key novelty in our approach lies in the introduction of a payoff-relevant endogenous state variable (namely, capital). This state variable alters the coordination dynamics by creating intertemporal incentives and a two-way feedback loop. A crucial implication of this feedback is the potential for multiple steady states, as prior coordination on the high regime fuels capital accumulation, which in turn encourages coordination on the high regime in the future. Machado (2024) explores a similar idea in the context of financial crises, where banks' net worth plays a role akin to that of capital in our setup.

Related to the dynamic global game literature are the works of Burdzy et al. (2001) and Frankel and Pauzner (2000) who resolve the equilibrium indeterminacy in dynamic coordination games by introducing time-varying payoffs and a sufficient amount of frictions to prevent agents from taking action in every period. More closely related to our paper in this tradition is the work of Guimaraes and Machado (2018) who examine the impact of investment subsidies in an extension of the Frankel and Pauzner (2000) model to monopolistic competition and staggered technology choice. In their model, firms receive exogenous opportunities to change their technology according to a Calvo-type Poisson process. The persistence of regime changes in their model is governed by the slow arrival of these opportunities. In contrast, we rely on a global game approach to discipline equilibrium selection in a standard business cycle model with capital. The dynamics of regime switches in our model is driven by the interaction of capital accumulation and coordination.

While global games have been widely used as selection devices in a variety of applications, several studies question the robustness of the equilibrium uniqueness to alternative informational structures. Angeletos and Werning (2006) and Hellwig et al. (2006) show that multiplicity can prevail when the precision of the information contained in prices grows faster than that in private signals. Mitigating this concern to some extent, the literature on uncertainty-driven business cycles (Bloom, 2009; Fajgelbaum et al., 2017) documents that uncertainty and disagreement are substantial and countercyclical in the data, suggesting that public information remains limited in the context of business cycle applications. Beyond the role of public information, Gaballo (2018) shows that arbitrarily small private uncertainty can induce multiplicity into an otherwise unique-equilibrium model in which producers are only privately informed. These studies highlight the critical role of how information is aggregated through prices and emphasize the need to carefully specify and identify the information structure in applied work. Acknowledging this limitation of the global game approach, we propose a simple, tractable information structure that we identify using survey data from the Survey of Professional Forecasters. We leave to future research the more complex task of empirically identifying the broader process by which information is aggregated through prices.

Our approach also relates to the literature on sentiment-driven business cycles. Angeletos and La'O (2013) propose a unique-equilibrium model in which sentiment-driven fluctuations arise through correlated signals. Benhabib et al. (2015) model non-fundamental fluctuations by introducing incomplete information in a model that otherwise features a unique equilibrium. In contrast to our paper, the introduction of incomplete information leads to equilibrium multiplicity. In our paper, we start from a model with multiple equilibria and use a global game refinement to eliminate all equilibrium non-fundamentalness. As a result, while changes in fundamentals may lead to shifts in coordination, the model rules out fluctuations driven purely by sentiment or "animal spirits." Chahrour and Gaballo (2020) propose a macroeconomic model with a housing sector where small changes in fundamentals can induce large aggregate responses, interpretable as sentiments in the limit as shocks become vanishingly small. Our model shares the feature that small fundamental shocks can have outsized effects when they trigger regime changes and does so in a unique-equilibrium framework.

Finally, our paper touches upon various themes familiar to the poverty trap literature in growth theory. Murphy et al. (1989) propose a formal model of the Big Push idea that an economy can escape a no-industrialization trap if various sectors industrialize simultaneously. In terms of the dynamics generated by the model, our paper is more closely related to Azariadis and Drazen (1990) who introduce threshold externalities in the neoclassical growth model to allow for a multiplicity of locally stable steady states. Our paper relies on a demand-driven coordination problem to achieve similar transition stages in the dynamics of the economy and studies their implications for business cycles.

The paper is structured as follows. Section 2 introduces the environment and presents our baseline model under complete information. Section 3 describes the incomplete information version of the model and establishes our main uniqueness result. In Section 4, we calibrate the model and show that it replicates salient features of the recovery from the 2007–2009 recession. Section 5 analyzes the policy implications of the model and describes our findings on government spending. The full statements of propositions and the proofs can be found in the appendix.

2. Complete information

In this section, we introduce the physical environment of our model, which remains the same throughout the paper. We begin under the assumption of complete information as it allows us to build intuition about the source of equilibrium multiplicity and the role of coordination in this economy.

2.1. Environment

Time is discrete and goes on forever. A continuum of firms use capital and labor to produce differentiated intermediate inputs. A competitive sector then combine those inputs into a final good that is used for investment and for consumption by a representative household.

2.1.1. Households and preferences

The preferences of the representative household are given by

$$\mathbb{E}\sum_{t=0}^{\infty}\beta^t U\left(C_t, L_t\right), \tag{1}$$

where $0 < \beta < 1$ is the discount factor, $C_t \geqslant 0$ is consumption of the final good and $L_t \geqslant 0$ is labor. We adopt the period utility function of Greenwood et al. (1988) (GHH hereafter)[3]:

$$U\left(C_t, L_t\right) = \frac{1}{1-\gamma}\left(C_t - \frac{L_t^{1+\nu}}{1+\nu}\right)^{1-\gamma}, \gamma > 0, \nu > 0.$$

The representative household takes prices as given. It supplies capital K_t and labor L_t in perfectly competitive markets and owns the firms. It faces the sequence of budget constraints

$$P_t\left(C_t + K_{t+1} - (1-\delta)K_t\right) \leqslant W_t L_t + R_t K_t + \Pi_t, \tag{2}$$

where P_t is the price of the final good, W_t the wage rate, R_t the rental rate of capital and Π_t the profits it receives from firms. Capital depreciates at rate $0 < \delta < 1$.

2.1.2. Final good producers

The final good is produced by a perfectly competitive, representative firm that combines a continuum of differentiated intermediate goods, indexed by $j \in [0,1]$, using the CES production function

$$Y_t = \left(\int_0^1 Y_{jt}^{\frac{\sigma-1}{\sigma}} dj\right)^{\frac{\sigma}{\sigma-1}}, \tag{3}$$

where $\sigma > 1$ is the elasticity of substitution between varieties, Y_t is the total output of the final good and Y_{jt} denotes the input of intermediate good j. Profit maximization, taking the output price P_t and input prices P_{jt} as given, yields the usual demand curve and the price of the final good,

$$Y_{jt} = \left(\frac{P_{jt}}{P_t}\right)^{-\sigma} Y_t \text{ and } P_t = \left(\int_0^1 P_{jt}^{1-\sigma} dj\right)^{\frac{1}{1-\sigma}}. \tag{4}$$

2.1.3. Intermediate good producers

Intermediate good j is produced by a monopolist that uses a constant returns to scale production function with capital K_{jt} and labor L_{jt},

$$Y_{jt} = A_{jt} e^{\theta_t} K_{jt}^{\alpha} L_{jt}^{1-\alpha}, \tag{5}$$

where $0 < \alpha < 1$ is the capital intensity. The productivity term $A_{jt}e^{\theta_t}$ depends on a firm-level productivity level A_{jt} and an aggregate fundamental θ_t that follows an AR(1) process,

$$\theta_t = \rho\theta_{t-1} + \epsilon_t^{\theta}, \tag{6}$$

where $\epsilon_t^{\theta} \sim \text{iid } \mathcal{N}\left(0, \gamma_\theta^{-1}\right)$.

We introduce increasing returns in the model in the form of a simple binary technological choice.[4] Firms can either operate a low technology, $A_{jt} = A_l$, at no extra cost, or they can pay a fixed cost $f > 0$ to operate a high technology, $A_{jt} = A_h$ with $A_h > A_l$. In what follows, we use the notation $\omega = A_h/A_l$ and assume that the fixed cost f is expressed in terms of the final good.[5]

This technological choice can capture many margins that firms use to adjust production. Among others, it may capture the adoption of a technology, a fixed investment (equipment, R&D), discrete margins of capacity utilization (plant opening/shutdown, number of shifts or production lines), hierarchical changes, entry/exit in some markets, international trade, etc. We do not take a stance at this point on its exact origin. Importantly, the discreteness of the decision breaks the convexity of the firms' cost function. As a result, firms are able to expand their production swiftly in response to changes in aggregate conditions, which is crucial to sustain multiple equilibria in this economy.

Intermediate producers take the rental rate of capital R_t and the wage W_t as given. For each technological level A_i, $i \in \{h, l\}$, they solve the following static problem:

$$\Pi_{it} = \max_{Y_{it}, P_{it}, K_{it}, L_{it}} P_{it}Y_{it} - R_t K_{it} - W_t L_{it}, \tag{7}$$

[3] GHH preferences allow us to derive analytical expressions for many equilibrium quantities, but are not essential for our mechanism to operate. We relax this assumption in our policy exercises as the preference specification matters for the effect of fiscal policy.

[4] We restrict the technology to take only two values for simplicity and sharper intuitions. Global game techniques and the key steps of our uniqueness proof in the dynamic model can be extended to any finite number of levels.

[5] What units (labor, final goods, etc.) adoption costs are denominated in is important. Our results hold qualitatively as long as the adoption costs are less cyclical than aggregate demand. This condition is met, for instance, when the cost is fixed in terms of labor or the final good. In the limiting case where the cost is denominated in terms of the producer's own output, technology adoption becomes constant and independent of the business cycle.

subject to their demand curve (4) and production technology (5). Intermediate producer j then picks the technology A_{jt} that maximizes its profits

$$A_{jt} = \underset{A_i \in \{A_h, A_l\}}{\operatorname{argmax}} \left\{ \Pi_{ht} - P_t f, \Pi_{lt} \right\}.$$

2.2. Equilibrium definition

We are now ready to define an equilibrium for this economy. Denote the complete history of aggregate productivity shocks by $\theta^t = \left(\theta_t, \theta_{t-1}, \ldots\right)$.

Definition 1. An equilibrium is a sequence of household policies $\left\{C_t\left(\theta^t\right), K_{t+1}\left(\theta^t\right), L_t\left(\theta^t\right)\right\}_{t=0}^{\infty}$, policies for firms $\left\{Y_{it}\left(\theta^t\right), K_{it}\left(\theta^t\right), L_{it}\left(\theta^t\right)\right\}_{t=0}^{\infty}$, $i \in \{h, l\}$, a measure $m_t\left(\theta^t\right) \in [0,1]$ of firms operating the high technology and prices $\left\{P_t\left(\theta^t\right), R_t\left(\theta^t\right), W_t\left(\theta^t\right)\right\}_{t=0}^{\infty}$ such that (i) the household maximizes utility (1) subject to (2); (ii) intermediate producers solve their problem (7); (iii) prices clear all markets; and (iv) the measure of firms $m_t\left(\theta^t\right)$ satisfies

$$m_t\left(\theta^t\right) = \begin{cases} 1 & \text{if } \Pi_{ht} - P_t f > \Pi_{lt}, \\ \in (0,1) & \text{if } \Pi_{ht} - P_t f = \Pi_{lt}, \\ 0 & \text{if } \Pi_{ht} - P_t f < \Pi_{lt}. \end{cases} \tag{8}$$

Our equilibrium concept is standard. Notice that the definition introduces the equilibrium measure $m_t\left(\theta^t\right)$ of firms with high technology, which must be consistent with individual technology decisions (8).

2.3. Characterization

Two features of our environment simplify the characterization of the equilibria: (i) under GHH preferences, the amount of labor supplied by the household is independent of its consumption-saving decision, and (ii) the problems of the final and intermediate good producers are static. We can therefore characterize the equilibrium in two stages: we first solve for the *static* equilibrium in every period, which determines the production and the technological choice, and we then turn to the *dynamic* equilibrium, which uses the first stage as an input, to characterize the optimal consumption-saving decision and the dynamics of the economy.

2.3.1. Partial equilibrium

We first characterize the decision of intermediate producers in partial equilibrium to highlight the role of aggregate demand and factor prices in their technology choice. Substituting the demand curve (4) in the expression for profits (7), the first-order conditions for capital and labor yield

$$R_t K_{it} = \alpha \frac{\sigma - 1}{\sigma} P_{it} Y_{it} \quad \text{and } W_t L_{it} = (1-\alpha) \frac{\sigma - 1}{\sigma} P_{it} Y_{it}. \tag{9}$$

Total factor expenses is therefore equal to a fraction $\frac{\sigma-1}{\sigma}$ of total sales, so that

$$\Pi_{it} = \frac{1}{\sigma} P_{it} Y_{it} = \frac{1}{\sigma} \left(\frac{P_t}{P_{it}}\right)^{\sigma-1} P_t Y_t,$$

where we have substituted the demand curve (4). In this monopolistic setup, production decisions are linked across firms as the total income generated by the private sector affects the level of demand faced by each individual producer. As a result, profits depend on the firm's *relative* price and on aggregate demand Y_t. In particular, when aggregate demand is high, firms have stronger incentives to expand. This demand linkage is the main source of strategic complementarity in our model.

We can now simplify the technology decision to

$$A_{it} = \underset{A_i \in \{A_h, A_l\}}{\operatorname{argmax}} \left\{ \frac{1}{\sigma} \left(\frac{P_t}{P_{ht}}\right)^{\sigma-1} Y_t - P_t f, \frac{1}{\sigma} \left(\frac{P_t}{P_{lt}}\right)^{\sigma-1} Y_t \right\}, \tag{10}$$

where the individual prices are optimally set at a constant markup over marginal cost, $P_{it} = \frac{\sigma}{\sigma-1} MC_{it}$ and $MC_{it} = \frac{1}{A_i e^{\theta_t}} \left(\frac{R_t}{\alpha}\right)^{\alpha} \left(\frac{W_t}{1-\alpha}\right)^{1-\alpha}$ for $i \in \{h, l\}$.[6]

Expression (10) highlights the key forces that determine the choice of technology in our environment. Firms with high technology enjoy lower marginal costs of production and therefore sell their products at lower prices. Eq. (10) tells us that, when choosing between the two technology levels, firms compare two affine functions of aggregate demand — the one associated with the high technology having a higher slope but a lower intercept than the one associated with the low technology. As a result, firms pick the high technology when aggregate demand is high. Intuitively, when demand is high, firms face high variable costs in capital and labor and have strong incentives to pay the fixed amount f in order to exploit economies of scale and save on these costs. On the other hand, firms have no reason to pay the fixed cost when demand is low and total variable costs are relatively small.

[6] See Appendix D.1 for the full derivation.

2.3.2. General equilibrium

Under GHH preferences, we can derive analytical expressions for aggregate quantities as a function of the measure m_t of firms with high technology.

Proposition 1. *For a given measure m_t of firms with high technology the equilibrium output of the final good is given by*

$$Y_t = \overline{A}\left(\theta_t, m_t\right) K_t^{\alpha} L_t^{1-\alpha}, \tag{11}$$

where $\overline{A}\left(\theta_t, m_t\right) = \left(m_t A_h^{\sigma-1} + \left(1-m_t\right) A_l^{\sigma-1}\right)^{\frac{1}{\sigma-1}} \exp\left(\theta_t\right)$ *and aggregate labor is*

$$L_t = \left[(1-\alpha)\frac{\sigma-1}{\sigma}\overline{A}\left(\theta_t, m_t\right) K_t^{\alpha}\right]^{\frac{1}{\alpha+\nu}}. \tag{12}$$

The corresponding production and profit levels of intermediate firms are, for $i \in \{h, l\}$,

$$Y_{it} = \left(\frac{A_i \exp\left(\theta_t\right)}{\overline{A}\left(\theta_t, m_t\right)}\right)^{\sigma} Y_t \quad \text{and} \quad \Pi_{it} = \frac{1}{\sigma}\left(\frac{A_i \exp\left(\theta_t\right)}{\overline{A}\left(\theta_t, m_t\right)}\right)^{\sigma-1} P_t Y_t. \tag{13}$$

Proposition 1 establishes a number of important results. We see from Eq. (11) that the economy aggregates into a Cobb–Douglas production function with TFP $\overline{A}\left(\theta_t, m_t\right)$. Importantly, this aggregate TFP is an endogenous object that corresponds to an average of intermediate firms' effective productivities. As a result, aggregate output increases with the measure of firms m_t, as high technology firms operate a more productive technology.

The complementarity between aggregate demand and technological choices is at the core of our framework: higher aggregate demand encourages firms to choose the high technology; more firms choosing the high technology, in turn, results in higher output and aggregate demand. Multiple equilibria arise in our environment when this two-way feedback between demand and production is sufficiently strong. The picture remains incomplete, however, if one ignores the role of general equilibrium effects behind technological choices. Firms' adoption choices depend on factor prices, which are affected by the measure of high technology firms m_t in equilibrium, since firms compete on factor markets. Importantly, firms face *congestion* on factor markets: when adopting the high technology, firms scale up their factor demand, putting upward pressure on the cost of capital and labor. This congestion effect leads to a form of substitutability between firms' adoption decisions. Whether there is overall strategic complementarity in technology decisions between firms in our setup ultimately depends on which of these two forces dominates: *complementarity* through aggregate demand linkages or *substitutability* through competition on factor markets.

2.3.3. Equilibrium multiplicity

Using our analytical results on equilibrium production and profits, we now characterize the static equilibrium technology decision for some given stock of capital K_t and productivity θ_t.

Proposition 2. *Consider the following condition on parameters:*

$$\frac{1+\nu}{\alpha+\nu} > \sigma - 1. \tag{14}$$

Under condition (14), there exist thresholds $B_H < B_L$ such that:
(i) if $A_l e^{\theta_t} K_t^{\alpha} < B_H$, the static equilibrium is unique and all firms choose the low technology, $m_t = 0$;
(ii) if $A_l e^{\theta_t} K_t^{\alpha} > B_L$, the static equilibrium is unique and all firms choose the high technology, $m_t = 1$;
(iii) if $B_H \leqslant A_l e^{\theta_t} K_t^{\alpha} \leqslant B_L$, there are three static equilibria: two in pure strategies, $m_t = 1$ and $m_t = 0$, and one in mixed strategies, $m_t \in (0, 1)$.

If condition (14) is not satisfied, the static equilibrium is always unique.

Multiple equilibria arise under condition (14).[7] In regions of the state space where capital is abundant and productivity θ_t is high, such that $A_l e^{\theta_t} K_t^{\alpha} \geqslant B_H$, a *high equilibrium* exists in which all firms choose the high technology, $m_t = 1$. In these regions, renting capital is inexpensive and technology is productive, so firms operate at a large scale. As a result, total output and aggregate demand are high, which further encourages firms to expand and adopt the high technology. On the opposite, in regions of the state space where capital is scarce and productivity low, such that $A_l e^{\theta_t} K_t^{\alpha} \leqslant B_L$, a *low equilibrium* exists with $m_t = 0$: firms operate at a small scale and do not find it worthwhile to pay the fixed cost f to expand their production. For the intermediate region $B_H \leqslant A_l e^{\theta_t} K_t^{\alpha} \leqslant B_L$, the two equilibria coexist in addition to a third mixed equilibrium. The economy is then subject to self-fulfilling prophecies: depending on firms' expectations, it may end up in either the high or the low equilibrium. Fig. 2 depicts the situation described in the proposition.

The condition for multiplicity (14) captures the conflict between the strategic substitutability from competition in the factor markets, on the left-hand side, and the demand-side complementarity, captured by σ. This condition is satisfied when the intermediate good varieties are strong complements, if σ is low, or when the left-hand side is large. The latter term, $\frac{1+\nu}{\alpha+\nu}$, is the

[7] The multiplicity condition can be weakened by allowing for decreasing returns. For aggregate returns to scale $0 < \eta < \frac{\sigma}{\sigma-1}$, the condition for multiplicity becomes $\frac{1}{\eta}\frac{1+\nu}{\alpha+\nu} > \sigma - 1$.

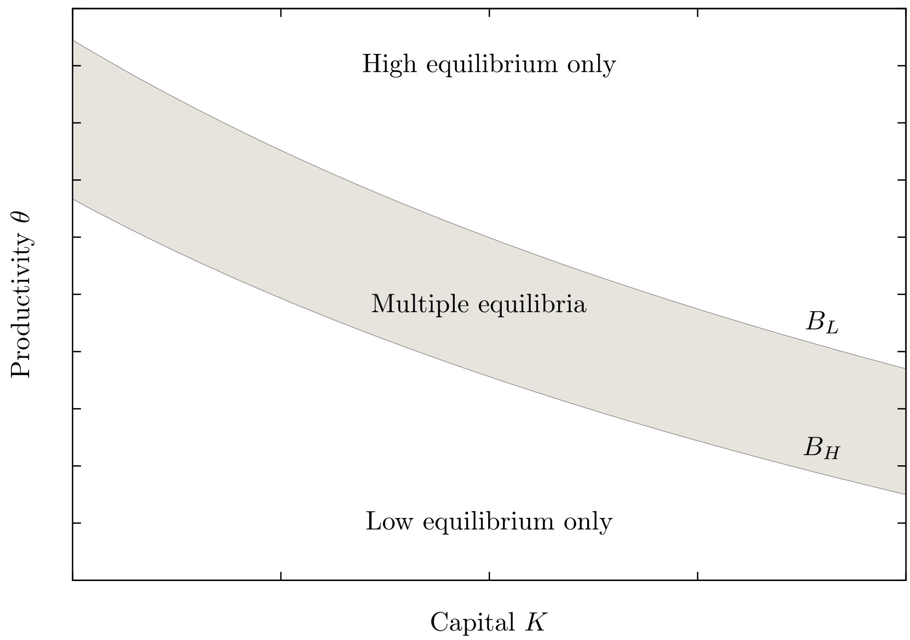

Fig. 2. Multiplicity in the static game as a function of the state space.

elasticity of aggregate production with respect to changes in TFP and it captures the scalability of the economy to changes in average productivity. Multiple equilibria are thus more likely to arise when scalability is high, which happens when the labor supply is elastic (ν small) and when production is intensive in the flexible factor, labor (α small). This scalability term captures, in particular, the idea that multiple equilibria can only be sustained if factor prices react moderately to changes in m_t. We assume that condition (14) is satisfied from now on.

2.3.4. *Efficiency*

At this stage, it is natural to wonder whether a planner should intervene to improve the outcome of the coordination game. We consider the following planning problem

$$\max_{K_{t+1},L_t,m_t} \mathbb{E}\sum_{t=0}^{\infty}\beta^t U\left(\left(m_t Y_{ht}^{\frac{\sigma-1}{\sigma}} + \left(1-m_t\right)Y_{lt}^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} + (1-\delta)K_t - m_t f - K_{t+1}, L_t\right),$$

subject to the production function (5) and the resource constraint. Proposition 3 describes the efficient allocation.

Proposition 3. *If $\frac{1+\nu}{\nu+\alpha} > \sigma - 1$, there exists a threshold B_{SP}, with $B_{SP} \leqslant B_L$, such that the planner makes all firms use the high technology, $m_t = 1$, if $A_l e^{\theta_t} K_t^{\alpha} \geqslant B_{SP}$ or the low technology, $m_t = 0$, if $A_l e^{\theta_t} K_t^{\alpha} \leqslant B_{SP}$. The threshold B_{SP} is lower than B_H for σ small.*

Underlying this result, is an equivalence between the condition for equilibrium multiplicity, given by (14), and the convexity of the planner's problem in m_t. When (14) is satisfied, the planner always chooses a corner solution, either $m_t = 0$ or 1. Since coordinating on the high technology is costly, the planning solution is non-trivial and there exists a threshold B_{SP} such that all firms adopt the high technology if and only if $A_l e^{\theta_t} K_t^{\alpha} \geqslant B_{SP}$. When the productivity level and the capital stock are low, using the high technology is too expensive and it is efficient to coordinate firms on the low equilibrium instead.

Because of the demand externality, the efficient allocation differs in important ways from the competitive outcome. Fig. 3 shows the social planner's (SP) threshold, B_{SP}, together with the thresholds of the competitive economy (CE), B_L and B_H. Proposition 3 shows that B_{SP} always lies below B_L, which indicates that the planner is more prone to pick the high technology. This result is a direct consequence of the demand externality: firms do not internalize that by choosing the high technology, they would generate more income to be spent on other firms' products, while the planner does. The competitive equilibrium therefore suffers from *coordination failures*: in the area surrounded by the dashed curves, between B_L and B_{SP}, the planner always picks the high technology while firms in the competitive economy may coordinate differently.

Fig. 3 depicts a situation in which B_{SP} lies below B_H, which happens when the degree of complementarity is strong (σ low). When σ is large, the planner's threshold B_{SP} lies between B_H and B_L and, in part of the state space, the planner may sometimes prefer the low technology when the competitive economy coordinates on the high equilibrium.

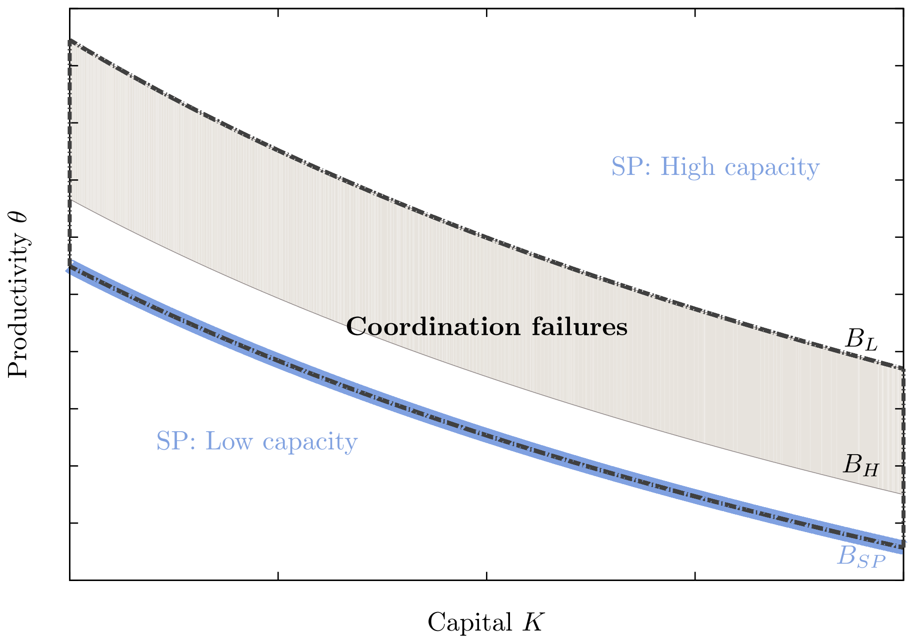

Fig. 3. Planner's decision versus the outcome in the competitive economy.

3. Incomplete information

The forces that lead to multiplicity in the model with complete information may have interesting dynamic implications, but the presence of multiple equilibria raises important methodological issues for policy and quantitative analysis. This multiplicity is also fragile and hinges on the assumption of common knowledge. In this section, we adopt a global game approach. By introducing incomplete information in the model, we show that uniqueness of the full dynamic general equilibrium obtains for a small departure from common knowledge.

3.1. Environment

To cast the model into a global game framework, we slightly modify the timing of events and the information available to firms when they choose their level of technology utilization. The physical structure of the environment remains the same as in the previous section.

3.1.1. Information and timing

Each period t is now split into two stages: (i) intermediate producers first choose their technology under incomplete information about current productivity θ_t, and (ii) the true state of θ_t is then revealed, production decisions take place and all markets clear.

In the first stage, all agents know the past realizations of θ, which are included in their information set $\mathcal{I}_t = (\theta_{t-1}, \theta_{t-2}, \dots)$. At the beginning of the period, nature draws the new productivity level θ_t from the stochastic process (6) but it remains unobserved by agents. The ex-ante beliefs of agents about current productivity are therefore $\theta_t \mid \mathcal{I}_t \sim \mathcal{N}\left(\rho\theta_{t-1}, \gamma_\theta^{-1}\right)$. In contrast to the model with complete information in which agents observed the fundamental θ_t perfectly, we assume that each intermediate producer j only receives a noisy signal $v_{jt} = \theta_t + \varepsilon^v_{jt}$, where the noise $\varepsilon^v_{jt} \sim \mathcal{N}\left(0, \gamma_v^{-1}\right)$ is iid across agents and time. After observing their private signal, firms use Bayes' rule to update their beliefs to

$$\theta_t | \mathcal{I}_t, v_{jt} \sim \mathcal{N}\left(\frac{\gamma_\theta \rho \theta_{t-1} + \gamma_v v_{jt}}{\gamma_\theta + \gamma_v}, \frac{1}{\gamma_\theta + \gamma_v}\right). \tag{15}$$

Intermediate producers then use their individual beliefs to make their technology decisions in the first stage of the period.

In the second stage, consumption-saving decisions are made, production takes place and all markets clear. The observation of production and aggregate prices reveals the aggregate productivity θ_t, which becomes common knowledge. Since the input choices and production take place simultaneously, these decisions are made under complete information. As a result, the equilibrium expressions derived in Proposition 1 are still valid, with the exception that m_t is now the solution to the coordination game under incomplete information that we describe below. After observing the true value of θ_t, the private signals are no longer useful and are discarded. Firms therefore share the same information at the beginning of every period.

3.1.2. Technology decision

Under the new information structure, the surplus from using the high instead of the low technology is the difference between the expected profits from using both technologies:

$$\Delta\Pi\left(K_t,\theta_{t-1},m_t,v_{jt}\right)\equiv\mathbb{E}_\theta\left[U_c\left(C_t,L_t\right)\left(\Pi_h\left(K_t,\theta_t,m_t\right)-f-\Pi_l\left(K_t,\theta_t,m_t\right)\right)\mid\theta_{t-1},v_{jt}\right]. \tag{16}$$

An agent with private signal v_j chooses the high technology if and only if $\Delta\Pi\left(K_t,\theta_{t-1},m_t,v_{jt}\right)\geqslant 0$. Three important features of expression (16) are worth emphasizing. First, in contrast to the complete information case, agents compute the expectation of profits under their own individual beliefs, given by (15). Second, in addition to the uncertainty about the fundamental θ_t, there is strategic uncertainty in this environment: since other agents base their decisions on their own noisy private signals, the measure of firms using the high technology is itself uncertain and m_t is a random variable. Third, because of the uncertainty within the period, between stage 1 and 2, intermediate producers take into account the fact that the household does not value consumption equally in all states of the world. As a result, firms use the representative household's stochastic discount factor $U_c(C,L)$ to evaluate profits.

3.1.3. Equilibrium definition

Because the global game selects equilibria as a function of $\left(K_t,\theta_{t-1}\right)$, the economy has a Markovian structure. We thus define a recursive equilibrium for this economy. We use θ_{-1} to denote the productivity of the previous period and normalize the price index to $P_t=1$ in each period.

Definition 2. A recursive equilibrium consists of (i) a value function for the household $V(k;K,\theta,m)$ and decision rules $\{c(k;K,\theta,m),$ $l(k;K,\theta,m),k'(k;K,\theta,m)\}$; (ii) decision rules for individual intermediate producers $\left\{Y_i(K,\theta,m),K_i(K,\theta,m),L_i(K,\theta,m),\Pi_i(K,\theta,m)\right\}$ for $i\in\{h,l\}$; (iii) aggregates $\{Y(K,\theta,m),L(K,\theta,m),\Pi(K,\theta,m)\}$; (iv) price schedules $\{R(K,\theta,m),W(K,\theta,m)\}$; (v) a law of motion for aggregate capital $H(K,\theta,m)$; and (vi) a measure $m\left(K,\theta_{-1},\theta\right)$ of firms with high technology *such that:*

1. *The household solves the problem*

$$V(k;K,\theta,m)=\max_{c,l,k'}U(c,l)+\beta\mathbb{E}\left[V\left(k';H(K,\theta,m),\theta',m'\right)|\theta\right]$$

subject to $c+k'-(1-\delta)k\leqslant R(K,\theta,m)k+W(K,\theta,m)l+\Pi(K,\theta,m)$;

2. *Intermediate producers of type* $i\in\{h,l\}$ *solve the problem*

$$\Pi_i(K,\theta,m)=\max_{P_i,Y_i,K_i,L_i}P_iY_i-R(K,\theta,m)K_i-W(K,\theta,m)L_i,$$

subject to $Y_i=P_i^{-\sigma}Y(K,\theta,m)$ *and* $Y_i=A_i(\theta)K_i^\alpha L_i^{1-\alpha}$;

3. *Aggregate output and profits are given by*

$$Y(K,\theta,m)=\left(mY_h(K,\theta,m)^{\frac{\sigma-1}{\sigma}}+(1-m)Y_l(K,\theta,m)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}},$$
$$\Pi(K,\theta,m)=m\left(\Pi_h(K,\theta,m)-f\right)+(1-m)\Pi_l(K,\theta,m);$$

4. *Capital and labor markets clear*

$$K=mK_h(K,\theta,m)+(1-m)K_l(K,\theta,m),$$
$$l(K;K,\theta,m)=mL_h(K,\theta,m)+(1-m)L_l(K,\theta,m);$$

5. *Consistency of individual and aggregate capital decisions:* $H(K,\theta,m)=k'(K;K,\theta,m)$;
6. *The aggregate resource constraint is satisfied*

$$c(K;K,\theta,m)+H(K,\theta,m)=Y(K,\theta,m)+(1-\delta)K-mf;$$

7. *For all* K, θ_{-1} *and* θ, *the measure of firms with high* technology $m\left(K,\theta_{-1},\theta\right)$ *solves the fixed point problem*

$$m\left(K,\theta_{-1},\theta\right)=\int\mathbb{1}\left[\Delta\Pi\left(K,\theta,m,v_j\right)\geqslant 0\right]\sqrt{\gamma_v}\phi\left(\sqrt{\gamma_v}\left(v_j-\theta\right)\right)dv_j, \tag{17}$$

where ϕ *is the probability density function of a standard normal and* $\Delta\Pi$ *is defined by* (16).

Our definition of a recursive equilibrium is standard except for condition (17) which corresponds to the equilibrium of the global game played by the firms: the measure m is the aggregation of the technology decisions when individual firms have the correct beliefs about its equilibrium distribution.

3.2. Existence and uniqueness

When choosing their level of technology, firms play a global game as in Carlsson and Van Damme (1993) and Morris and Shin (1998). A key insight from this literature is that the existence of multiple equilibria depends on the information structure. In particular, full knowledge about the strategy of the other players allows agents to coordinate in a way that leads to multiplicity.

The introduction of a small amount of strategic uncertainty, however, can eliminate this multiplicity. We extend these results to our dynamic general equilibrium environment.[8]

Another contribution of this paper is to show how uniqueness of the static technology decision game extends to the rest of the dynamic environment. This result is not a straightforward application of global game techniques for several reasons. First, there is a complex two-way feedback between the game and the dynamic consumption-saving choice. Second, firms' technology decisions aggregate into a non-concave production function with endogenous TFP, opening the possibility of multiple solutions to the consumption-saving problem. Third, our economy is subject to distortions due to monopolistic competition. All these factors require specific techniques to prove the uniqueness of the equilibrium.

We now state our main result.

Proposition 4. *For γ_v large and ω sufficiently close to 1, such that, in particular,*

$$\frac{\sqrt{\gamma_v}}{\gamma_\theta} > \frac{1}{\sqrt{2\pi}} \frac{\omega^{\sigma-1}-1}{\sigma-1}, \tag{18}$$

and additional assumptions stated in the Appendix, there exists a unique dynamic equilibrium. The equilibrium technology decision takes the form of a continuous cutoff $\hat{v}\left(K,\theta_{-1}\right)$ such that firm j adopts the high technology if and only if $v_j \geqslant \hat{v}\left(K,\theta_{-1}\right)$. Furthermore, the cutoff is a decreasing function of its arguments.

The proof of Proposition 4 is structured according to the natural separation that arises in our model between the static technology decision stage and the dynamic consumption-saving stage. In the first part of the proof, we focus on the global game, taking some stochastic discount factor as given, and provide sufficient conditions for the uniqueness of the static equilibrium of the game. However, uniqueness of the static coordination game is not sufficient to guarantee uniqueness of a *dynamic* equilibrium because of complementarities across periods. In the second part of the proof, we show that the economy under the endogenous TFP that arises from the global game admits a unique dynamic equilibrium.

Part 1 proceeds in two steps. First, we show that when private signals are sufficiently precise, i.e., γ_v large, consumption risk vanishes and we can ignore the stochastic discount factor in expression (16). This step is particularly useful as it allows us to approximate arbitrarily well the solution to the global game by solving a simplified game independently from the consumption-saving decision of the household.

As is common in the global game literature, this game is solved by iterated deletion of dominated strategies as in Morris and Shin (1998). Strategic uncertainty is essential for this procedure. In particular, higher strategic uncertainty leads to more substantial deletion of strategies at each iteration, which promotes uniqueness. Condition (18) is sufficient to guarantee that the deletion process converges to a unique equilibrium, which takes the form of a cutoff strategy. It states in particular that the fundamental θ must be sufficiently uncertain (γ_θ small) and, perhaps surprisingly, that private signals must be sufficiently precise (γ_v large). This last condition is required to generate enough strategic uncertainty: since firms put more weight on their heterogeneous signals when they are precise, γ_v must be sufficiently large to generate enough dispersion in beliefs and, therefore, in strategies.

Part 2 of the proof deals with the consumption-saving problem of the household. Once the technology decisions have been made, the model reduces to a neoclassical growth model with monopoly distortions and endogenous TFP. Because of these two features, specific techniques are required to show existence and uniqueness of the equilibrium. We build on the work of Coleman and John (2000) and Datta et al. (2002), who use a version of Tarski's fixed-point theorem on lattices, which states that monotone operators on lattices have a non-empty set of fixed points. Our proof extends this earlier work to environments with monopoly distortions and endogenous TFP.

The main challenge in the second part of the proof arises from the possibility of multiple solutions to the Euler equation because of the endogenous response of TFP $\overline{A}(\theta, m)$. We show that multiplicity does not happen as long as θ is sufficiently volatile (i.e., γ_θ is low, so that the transition between technologies is smooth in expectation) and ω is not too large (i.e., TFP cannot jump too fast). Under those conditions, the Euler equation is a monotone pseudo-concave operator that admits a unique positive fixed point.

According to Proposition 4, the optimal technology decision takes the form of a cutoff $\hat{v}\left(K,\theta_{-1}\right)$ such that only firms with private signals $v_j \geqslant \hat{v}\left(K,\theta_{-1}\right)$ adopt the high technology. Hence, the measure of firms operating the high technology is $m\left(K,\theta_{-1},\theta\right) = 1-\Phi\left(\sqrt{\gamma_v}(\hat{v}-\theta)\right)$, where Φ is the cumulative distribution of a standard normal. Since the cutoff is decreasing in K, the equilibrium measure of firms with high technology increases with K.

Fig. 4 compares the equilibrium aggregate output $Y(K,\theta,m)$ under incomplete information to the three possible equilibria of the complete information model: the high-technology equilibrium ($m=1$), the low-technology equilibrium ($m=0$) and the mixed-strategy equilibrium. As shown in the figure, the equilibria under complete and incomplete information essentially coincide in the regions without multiplicity. In the intermediate shaded region—where multiple equilibria exist under complete information—the global game's outcome differs markedly from the complete information case and yields a gradual transition between the two extremes.

The global game's monotonic relationship between capital and the adoption rate plays a fundamental role in generating intertemporal complementarities and persistence, as we elaborate in the next section. This monotonicity is not guaranteed under

[8] Applications of global games to market economies are sometimes problematic as prices may reveal enough information to restore common knowledge and multiplicity (Atkeson, 2000). In our setup, prices do reveal the true value of the fundamental, but since they are only determined at the production stage, after the technology decisions are taken, we retain the uniqueness result.

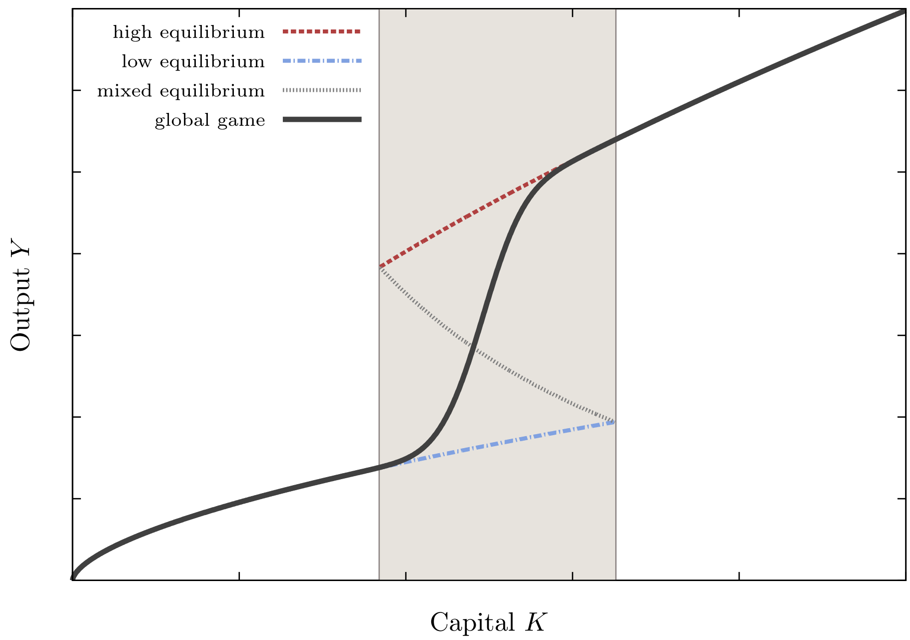

Fig. 4. Aggregate output as a function of K for some given (θ_{-1}, θ).

complete information. This point is particularly well illustrated by the mixed equilibrium in Fig. 4. When condition (14) for multiplicity is satisfied, the mixed equilibrium exhibits a negative relationship between capital and the adoption rate. This occurs because firms must remain indifferent between the two technologies. When capital is scarce and costly, firms have reduced incentives to scale up and adopt the high technology. This must be offset by higher aggregate demand and higher adoption among other firms to maintain indifference. Under incomplete information, firms cannot coordinate on such strategies. Instead, firms rely on the knowledge that a higher stock of capital marginally favors the high technology to eliminate lower rates of adoption in their iterated deletion of dominated strategies. As a result, the adoption of the high technology rises progressively with capital. This positive relationship with an endogenous state variable, such as capital K, lies at the heart of the persistence mechanism and steady-state multiplicity that we present in the next section.

As the figure illustrates, under the global game, the economy effectively aggregates into a neoclassical growth model with an endogenous TFP that introduces a nonconvexity in the production set. Because of this non-convexity, aggregate output Y is an S-shaped function of capital K. Intuitively, when capital is scarce firms prefer to operate at a low scale and, therefore, to produce with the low technology. As capital becomes more abundant and the rental rate declines, the incentive to use the high technology strengthens—further magnified by the demand externalities. The steep part of the S-shaped curve corresponds to the transition between the two technologies. Figure A.8 in Appendix A shows how increasing the adoption cost f affects the various equilibria and the multiplicity region. With a higher adoption cost, the multiplicity region widens and shifts to higher levels of capital, as firms need to operate at a larger scale to justify incurring the cost. In other words, the adoption cost f controls the location of the nonconvexity in aggregate production but does not determine whether uniqueness or multiplicity arise in some region of the state space.

3.3. Dynamics

We now explore the dynamic properties of the economy under incomplete information. Following our conclusions about the global game in the previous section, the S-shape observed in aggregate production carries over to key macroeconomic variables such as consumption, employment and, most critically for the dynamics, investment. This feature is central to generating persistence in coordination. In our economy, capital is the only endogenous state variable that connects the technology adoption games across periods and is, as such, the sole source of *dynamic complementarities*: past successful coordination on the high technology leads to higher output and capital accumulation, which in turn favors coordination in later periods.

Panel aof Fig. 5 illustrates this mechanism by displaying the laws of motion of capital for various values of productivity θ. As the figure shows, for a high θ, the law of motion of K intersects the 45°-line once at a high capital level to the right of the transition region. Similarly, when productivity is low, the only intersection occurs at a low level of capital to the left of the transition region. However, for intermediate values of productivity, the law of motion can feature three intersections: a high and a low stationary point, both stable, and an unstable one in the middle region. We denote by $\overline{K}_h(\theta)$ the set of stationary points at the right of the transition region, where most firms operate the high technology and production is high, and refer to their basin of attraction as the

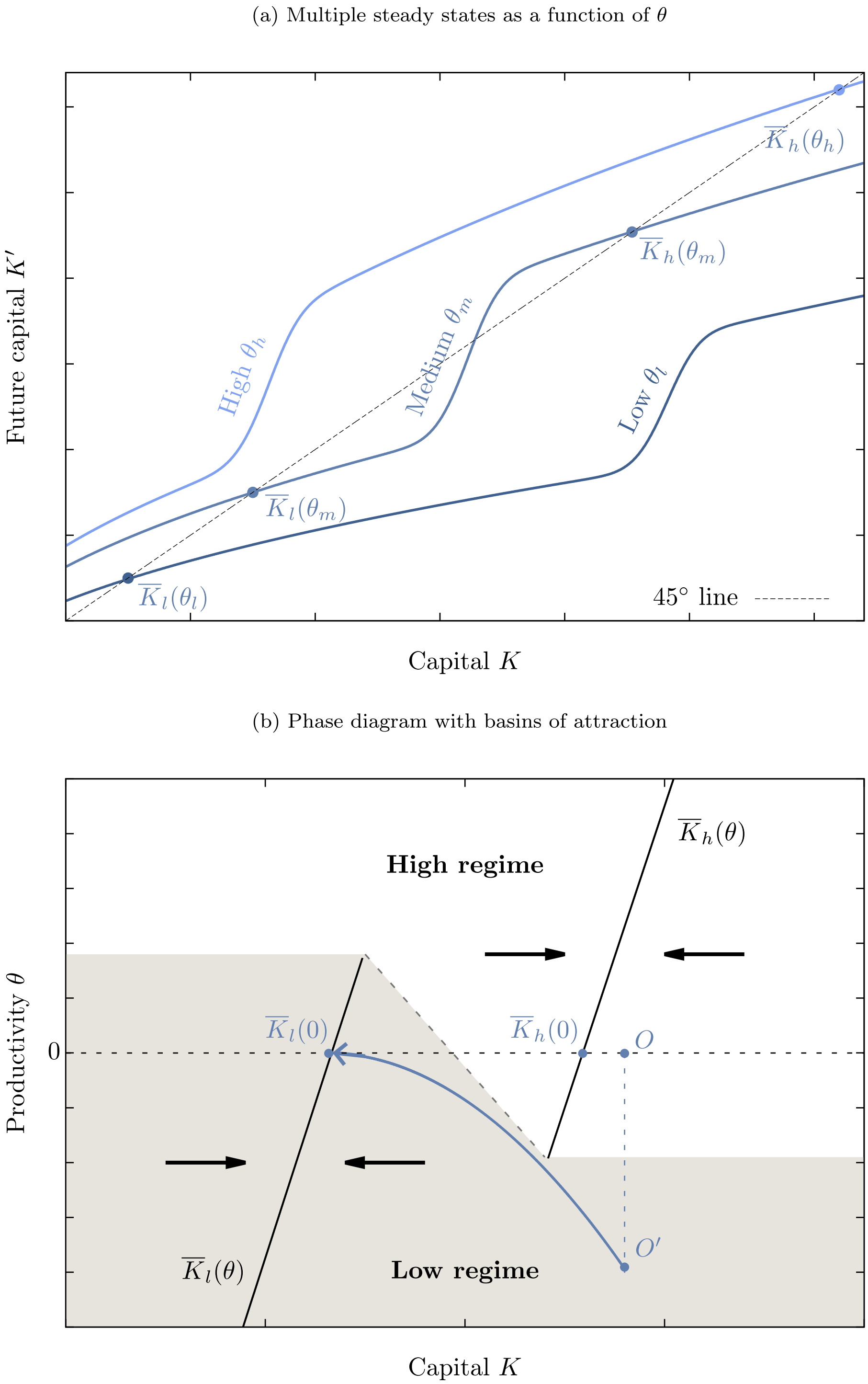

Fig. 5. Model dynamics.

high regime. Similarly, $\overline{K}_l(\theta)$ designates the set of stationary points at the left of the transition region, where firms mostly produce the low technology and production is low, and refer to their basin of attraction as the *low regime*. As we will see, this multiplicity of stationary points generates non-linear dynamics.

The phase diagram in Panel b of Fig. 5 summarizes the dynamics of the economy over the whole state space.[9] The two black lines represent the high and low stationary points in the dynamics of capital: $\overline{K}_h(\theta)$ and $\overline{K}_l(\theta)$. The basin of attraction of the high stationary points in the upper right region — the high regime — is indicated by the white area, while that corresponding to the low stationary points in the lower left region — the low regime — is represented by the shaded area. Notice that the low regime does not exist for high values of θ while the high regime disappears for low values of θ.

In the absence of productivity shocks, the economy converges towards the steady state which corresponds to the basin of attraction it belongs to. Exogenous shocks to productivity θ can however push the economy from one regime to the other. When this happens, the economy starts converging towards its new steady state and the measured TFP adjusts accordingly.

Consider, for instance, an economy that starts at point O in Panel b of Fig. 5. Without shocks to θ, this economy would simply reach the high-regime stationary locus at $\overline{K}_h(0)$ and remain there. Small temporary shocks to θ can move the economy up or down on the diagram but, as long as it does not leave the high regime, the system eventually converges back to the same stationary point. A large negative shock to θ, such as the one illustrated by the dashed line from point O to O', could however move the economy to the low regime. When this happens, the low productivity level pushes firms to adopt the low technology, leading to a low level of output. As a result, the household invests less and the capital stock declines. Coordination on the high technology is further impeded as capital falls: firms continue to operate the low technology, perpetuating the decline in capital. As capital declines and productivity recovers, the economy follows the curved arrow in Figure Panel b of Fig. 5 from point O' to the low regime stationary locus $\overline{K}_l(0)$ where it remains trapped, even after productivity has returned to normal. As we can see, the response of the economy as a function of the size of the shock is highly non-linear.

While we focus on productivity shocks for simplicity, the mechanism that we propose is by no means restricted to these shocks, but can accommodate and provide propagation to other types of shocks considered in the literature, such as financial shocks. Consider, for instance, capital quality shocks, as in Gertler and Karadi (2011) and Gourio (2012). In Panel b of Fig. 5, we see that such a shock could move an economy from point O to the basin of attraction of the low regime, leading to a permanently depressed economy. In contrast, in an RBC model, the high marginal product of capital that would result from this shock would lead to an increase in investment and bring the economy back to its unique steady-state. The type of coordination problem that we analyze should be considered as a general propagation mechanism, which could interact in interesting ways with other types of shocks and frictions.

4. Calibration

To evaluate the quantitative importance of coordination for business cycle fluctuations we calibrate the model to the United States economy. After analyzing the model's predictions along various business cycle moments, we run a counterfactual experiment in which we study whether the model can account for the behavior of the economy after the 2007–2009 recession.

4.1. Parametrization

Because of changes in the trend growth rate before 1985, we target moments from the 1985–2015 period.[10] Our calibration strategy relies on the interpretation that the US economy was in the high regime over the period 1985Q1–2007Q3 and fell to the low regime after the 2007Q4–2009Q2 recession.[11] Our final quantitative exercise will provide support for this interpretation.

We calibrate the model at a quarterly frequency. The capital share α, the discount rate β and the depreciation rate δ are set to standard values. For the preferences of the household, we use log utility, so that $\gamma = 1$, and follow Jaimovich and Rebelo (2009) in setting $\nu = 0.4$, implying a Frisch elasticity of 2.5 in line with macro-level estimates. The fundamental productivity process θ is parametrized to replicate a persistence and a long-run standard deviation of log output of 0.995 and 6%, as observed over 1985–2015. We are left to calibrate four parameters: σ, γ_v, ω and f.

To discipline the technological choice, we use micro data from Compustat. We estimate firm-level TFP and markups following De Loecker et al. (2020).[12] To calibrate the elasticity of substitution σ, we target the average sales-weighted markup in our sample of 52% over the period 1985–2015. This gives us a value of $\sigma = 2.92$. This parameter value implies strong demand complementarities and puts our model in the region in which multiple steady states exist in the incomplete information environment. Such an elasticity is not uncommon in plant-level studies. Hsieh and Klenow (2014) uses a value of 3 to study the life cycle of plants in India and Mexico. An elasticity of 3 also corresponds to the median estimates of Broda and Weinstein (2006) at various levels of aggregation. Using trade data, Bernard et al. (2003) estimate a value of $\sigma = 3.79$ in a model of plant-level export behavior.

To calibrate the productivity gain ω from using the high technology, we run the following regression for firm i in sector j at date t:

$$\log\left(TFP_{ijt}\right) = \beta_j + \underset{(1.09e-4)}{0.00237^{***}}t - \underset{(1.85e-3)}{0.0167}^{***}\mathbf{1}\{t > 2007\} + \varepsilon_{ijt},$$

[9] The full state space is (K, θ_{-1}, θ). For simplicity, we however omit θ_{-1} in our phase diagram as it becomes irrelevant in the case of interest when γ_v is large.

[10] Figure A.9 in the Appendix shows how the trend varies over different periods for GDP and TFP. Data sources are detailed in Appendix B.

[11] Following this interpretation, we detrend the log time series using a linear trend computed over 1985Q1–2007Q3.

[12] See Appendix B for details.

Table 1
Parameters.

Parameter	Value	Source/Target
Time period	One quarter	
Total factor productivity	$A = 1$	Normalization
Capital share	$\alpha = 0.3$	Labor share 0.7
Discount factor	$\beta = 0.95^{1/4}$	0.95 annual
Depreciation rate	$\delta = 1 - 0.9^{1/4}$	10% annual
Risk aversion	$\gamma = 1$	log utility
Elasticity of labor supply	$\nu = 0.4$	Jaimovich and Rebelo (2009)
Persistence θ process	$\rho_\theta = 0.94$	Autocorrelation of log output
Long-run standard deviation of θ	$\sigma_\theta = 0.009$	Standard deviation of log output
Elasticity of substitution	$\sigma = 2.92$	Average markup
Precision of private signal	$\gamma_v = 1,154,750$	See text
TFP gain from high technology	$\omega = 1.017$	See text
Fixed cost	$f = 0.019$	See text

where β_j is a 4-digit NAICS sectorial fixed effect and where we allow for a linear time trend and a dummy for the post-2007 period. This regression suggests that firm-level TFP in the economy fell by an average of 1.67% in the aftermath of the recession. With the interpretation that the economy was in the high steady state until 2007 ($m_t \simeq 1$) and fell to the low steady state afterwards, we set $\omega = 1.017$.

In our model, the fixed cost f governs the frequency at which regime transitions occur. In particular, under our interpretation that the US economy stays mostly in the high regime, f determines the probability that the economy can fall in the low regime, which corresponds to a large, persistent fall in GDP. With only thirty years of data, time series averages are only mildly informative about the frequency of these transitions. We propose instead to rely on probabilistic forecasts. More precisely, the SPF provides mean probability forecasts of GDP growth over various bins. According to the survey, the probability that real GDP growth falls below −2%, its lowest category, is on average 0.63%.[13] Adjusting for an average trend growth rate of 2.9% in the SPF data, we pick f so that the average probability that output growth in our model will be lower than −4.9% over the next year is consistent with the survey. The calibrated value of f is such that if all firms were to produce with the high technology the fixed costs would amount to about 1.1% of average output. To verify that this number is not implausible, we compare it to the item "*Selling, General and Administration*" (XSGA) in Compustat, an often used proxy for overhead production costs in the data. We run the firm-level regression

$$fc_{ijt} = \gamma_j - \underset{(6.46e-4)}{0.0125}^{***}\mathbf{1}\{t > 2007\} + e_{ijt},$$

where γ_j is a 4-digit sectorial fixed effect and $fc_{ijt} = XSGA_{ijt}/SALE_{ijt}$ is the share of fixed costs over total sales. Our estimate supports the view that the share of fixed costs in production declined by about 1.25 percentage points, a number broadly in line with our calibration.

Finally, to calibrate the precision of the private signals γ_v, which governs the dispersion of beliefs, we rely on forecasting data from the Survey of Professional Forecasters (SPF). We target the interquartile range of forecasts about current quarter log GDP which averages to 0.24% over 1985–2015.[14]

The parameters are jointly estimated by a method of simulated moments that minimizes the distance between the empirical and simulated moments, computed over long-run simulations. Table 1 lists the parameters. As it turns out, our resulting parameters are such that condition (18), which guarantees the uniqueness of the global game equilibrium, is satisfied.

4.2. Quantitative evaluation

The calibrated parameters are such that, because of the coordination problem, the economy has two stable steady-states for intermediate values of θ, but only one steady-state for high or low values of θ.[15]

[13] We use the mean probability forecast about next year real GDP growth from the SPF. Because the SPF variable definitions change over time, we restrict our sample to 1992Q1–2009Q1, which corresponds to the largest available sample with a consistent definition included in our period of interest.

[14] In either the high or the low regime, m is nearly constant close to 1 or 0. Since regime transitions are rare in the US experience, the contribution of m to average output volatility is thus negligible. Using the expression $Y_t = \left((1-\alpha)\frac{\sigma-1}{\sigma}\right)^{\frac{1-\alpha}{\alpha+\nu}}\left(Ae^{\theta_t}\Omega(m_t)K_t^\alpha\right)^{\frac{1+\nu}{\alpha+\nu}}$ with $\Omega(m) = \left(m\left(\omega^{\sigma-1}-1\right)+1\right)^{\frac{1}{\sigma-1}}$, and ignoring the contribution of m, the variance of beliefs about current log output is $\mathrm{Var}\left(\log\left(Y_t\right)|\theta_{t-1}, v_t\right) = \left(\frac{1+\nu}{\alpha+\nu}\right)^2\frac{1}{\gamma_\theta+\gamma_v}$ yielding an interquartile range of $\mathrm{IQR} = 2\Phi^{-1}(0.75)\sqrt{\left(\frac{1+\nu}{\alpha+\nu}\right)^2\frac{1}{\gamma_\theta+\gamma_v}}$, where Φ is the CDF of a standard normal. Using the parameters of the calibration together with the SPF data over the period 1985–2015 yields the value of γ_v.

[15] Figure A.11 in the Appendix shows the dynamics of K for various values of θ.

Table 2
Dynamic properties of the data, the full model and the RBC model.

	Output	Investment	Hours	Consumption
	Correlation with output			
Data	1.00	0.90	0.91	0.98
Full model	1.00	0.90	1.00	0.99
RBC model	1.00	0.95	1.00	0.99
	Standard deviation relative to output			
Data	1.00	3.09	1.03	0.94
Full model	1.00	1.44	0.71	0.88
RBC model	1.00	1.30	0.71	0.95
	Skewness			
Data	−1.24	−0.92	−0.62	−1.31
Full model	−0.46	−0.36	−0.45	−0.41
RBC model	0.00	−0.03	0.00	0.00

4.2.1. *Ergodic distributions*

To illustrate the unusual dynamic properties that result from the steady-state multiplicity, we simulate the model for one million periods and plot the ergodic distributions of measured TFP, output, investment, consumption, employment and the productivity process θ in logs in Figure A.12 in Appendix A. While productivity θ is normally distributed, the other aggregates are negatively skewed and have bimodal ergodic distributions, a sign that the economy spends a substantial amount of time in the low regime. For consistence with our detrending method, each simulated distribution is centered around the upper mode corresponding to the high regime. For comparison with the data, Figure A.13 in Appendix A reproduces the empirical distributions of these variables in log deviation from trend. As the data shows, bimodality is roughly observed for most variables, and our model offers a reasonable fit to the empirical distributions, except for investment which appears more dispersed in the data.

Business cycles moments

To further evaluate the fit of the model, we compute various business cycle moments from simulated time series and compare them to their empirical counterparts. The results are shown in Table 2 together with moments generated from a standard real business cycle model.[16] The differences between the full model and the RBC model highlight the influence of the coordination mechanism on the dynamics of the economy. In terms of standard deviations, and correlations with output, both models perform similarly. Our full model, however, clearly outperforms the RBC model in terms of skewness. This result stems from the presence of the two steady states, which implies that the economy spends a substantial amount of time in the depressed state.[17]

4.2.2. *Impulse response functions*

To illustrate the non-linear properties of the model, we now look at the response of various aggregates to productivity shocks. Starting in the high steady state, we hit the economy with three sequences of θ shocks of different sizes and durations, represented in panel (a) of Fig. 6. These specific shocks were chosen to illustrate the types of dynamics that the model can generate.

After the small shock (green dotted line), firms reduce their scale of operation only slightly. They keep coordinating on the high technology throughout the duration of the shock and, as a result, the economy recovers fairly quickly to the high steady state once the shock has disappeared. The response of the economy is essentially the same as what we would observe in a standard RBC model. The situation is different when the economy is hit by the shock of intermediate size, represented by the dashed lines in Fig. 6. In this case, firms reduce their production more drastically by adopting the low technology and cutting down on inputs, partly because of lower productivity and partly because of lower aggregate demand. Because of this failure of firms to coordinate on high production, the economy takes substantially more time to recover to the high regime. Finally, after the large shock, the measure of firms operating the high technology drops massively and stays low for a long time. With less resources, the household saves less and the capital stock declines, making coordination on the high technology even more difficult. The economy converges to the low steady state and remains trapped there even after productivity θ has fully recovered. Once in the low regime, only a sufficiently large positive shock can move the economy back into the basin of attraction of the high steady state.[18]

[16] Without our coordination mechanism to provide amplification and propagation, the aggregate productivity process in the RBC model must be recalibrated in order to fit the autocorrelation and standard deviation of log output. The long-run standard deviation of θ is recalibrated to $\sigma_\theta = 1.6\%$ and its persistence to $\rho_\theta = 0.97$. Preferences and technology parameters are otherwise the same as in our benchmark calibration.

[17] The negative skewness of these variables is a property of the data robust to changes in the time range. For instance, the skewness of log output over 1967–2015 is −0.47.

[18] Figure A.14 in the Appendix plots the response of the return on capital $R - \delta$ and the wage W to these shocks. Both of them drop on impact. When the economy settles in the low steady state, wages remain depressed, while the return on capital recovers to its initial long-run value. Note that R corresponds to the real rental rate of productive capital and is therefore the return on a risky asset. The behavior of R in our model is consistent with the detrended yield on AAA and BAA Corporate Bonds corrected for inflation expectations, which had recovered by 2014.

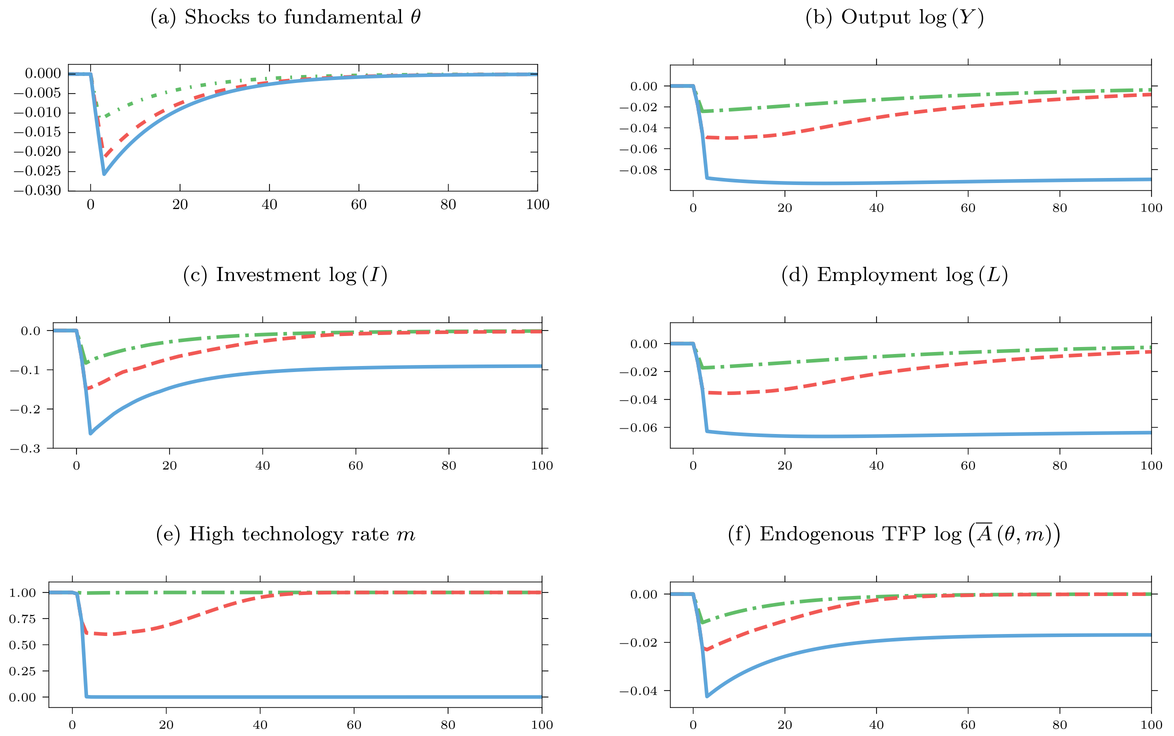

Fig. 6. Impulse response functions.
Notes: For the small shock (green dotted line), the innovations in θ are set to -2 standard deviations for 2 quarters. For the medium shock (dashed red line), the innovations are set to -2 standard deviations for 3 quarters. For the large shock (solid blue line), the innovations are set to -3 standard deviations for 3 quarters.

4.2.3. The aftermath of the 2007–2009 recession

We now turn our attention to the Great Recession. Panel (a) of Fig. 7 shows the behavior of output, employment, investment, consumption and TFP[19] from 2005 to 2015. All series are normalized to 0 at the beginning of the recession in 2007Q4. After the initial hit, consumption, output and employment slowly declined and stabilized at about 10% below their pre-recession levels. Similarly, investment initially dropped by about 45% before recovering to 25% below its pre-recession level.

To evaluate whether our model can replicate the US experience during this recession, we reverse-engineer a series of productivity shocks θ so that the endogenous TFP in our model matches the measured TFP series between the NBER recession dates of 2007Q4 and 2009Q2. The economy starts from the high steady state corresponding to $\theta = 0$. We set the innovations to productivity to zero after 2009Q3 and let the economy recover afterwards. As it turns out, such a series of shocks is enough to trigger a shift to the low regime.[20] The response of various aggregates is shown in panel (b) of Fig. 7. As we can see, our model offers a reasonable description for the evolution of consumption, employment and output. Notice also that our model provides an endogenous explanation for the protracted decline in measured TFP. The reaction of investment, on the other hand, is more muted in our model compared to the data as it falls by 32% on impact and then stabilizes at about 15% below its initial trend.[21] In the simulation, the initial drop in endogenous TFP is due to the direct impact of the productivity shock together with the transition from the high to the low technology by firms. Its long-run behavior, however, is solely driven by the endogenous technology choice, as exogenous productivity θ has completely recovered by then.

5. Policy

The prospect of coordination failures is often used in policy debates to justify large government interventions, including in particular expansionary fiscal policies. In this section, we study the appropriate policy response in our model when the economy

[19] We use the raw TFP measure from Fernald (2014) adjusted for labor quality. It is constructed as a Solow residual and is the empirical counterpart to the endogenous TFP $\overline{A}(\theta, m)$ from the model. See Figure A.10 in the Appendix for a comparison with other TFP measures.

[20] Our counterfactual experiment relies on aggregate productivity shocks only as our objective is not to provide a complete story for the 2007–2009 episode but for the recovery period that followed. As we mentioned earlier, our coordination mechanism may provide equally strong propagation to other theories of the recession based on financial shocks, policy changes, uncertainty or others.

[21] In the data, a substantial fraction of the drop in investment is due to a decline in residential investment, which the model does not address.

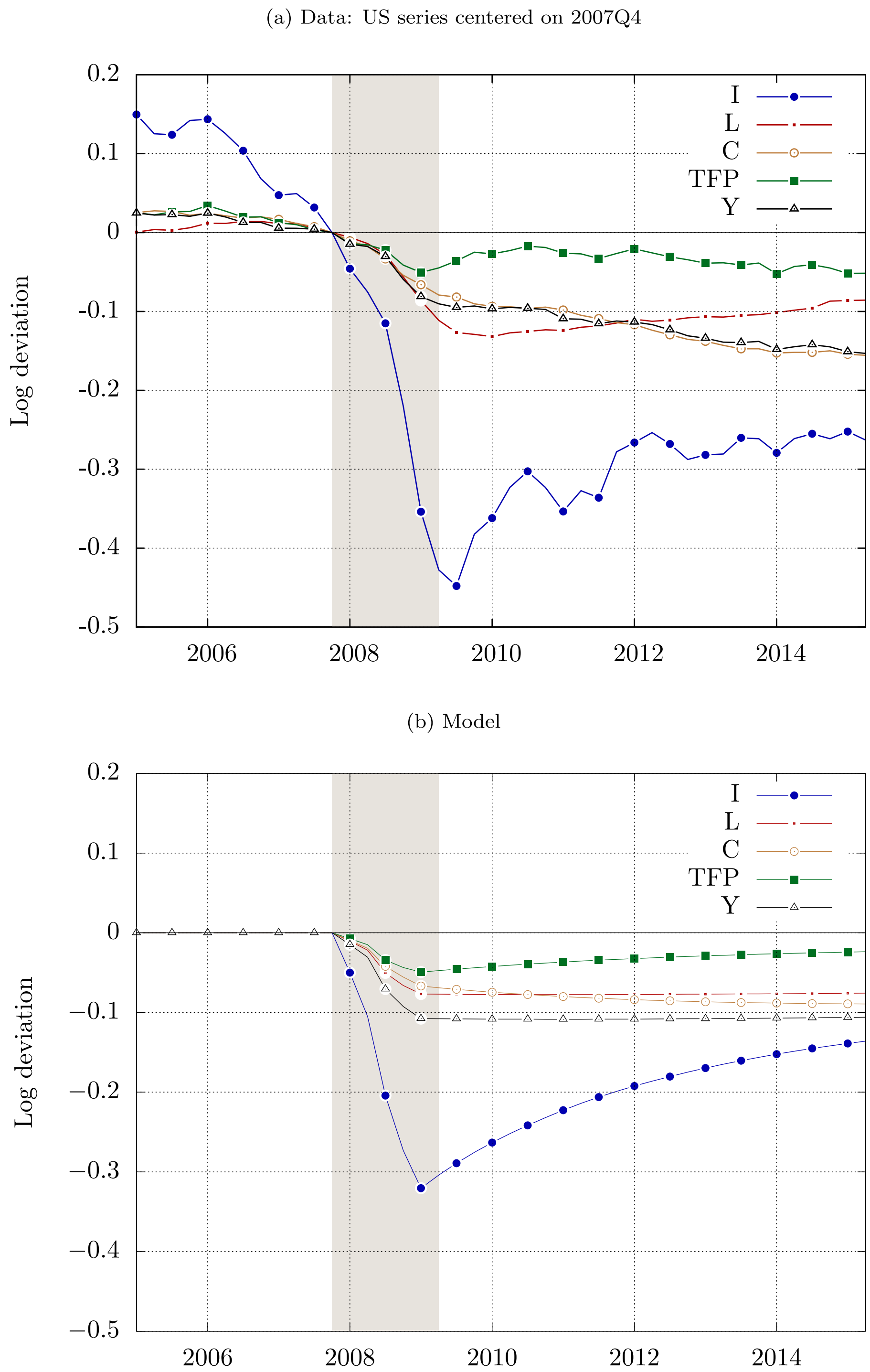

Fig. 7. The 2007–2009 recession and its aftermath.

is hindered by a coordination problem and discuss to what extent policies such as government spending may be beneficial, if at all desirable. We first solve for the efficient allocation and describe how it can be implemented using various subsidies. We then consider whether an increase in government spending can be welfare improving when the efficient subsidies are not available.

5.1. Efficient allocation

Our model economy suffers from two related inefficiencies. The first inefficiency arises as firms use their monopoly power to price their products at a markup over their marginal cost. As a result, firms produce and sell too little. The second inefficiency is due to the effect of the aggregate demand externality on technological choice. Firms do not internalize that using the high technology positively impacts the demand that other producers face and therefore fail to coordinate on the efficient technology level.

To shed light on these inefficiencies, we solve the problem of a constrained social planner that does not receive any signals and cannot aggregate the information available to private agents as in Angeletos and Pavan (2007). The planner can, however, instruct each firm to use the high technology with some probability $z(v) \in [0,1]$ as a function of its private signal v. With this policy instrument, the planner's problem is

$$V_{SP}(K,\theta_{-1}) = \max_{0\leqslant z(\cdot)\leqslant 1} \mathbb{E}\left[\max_{K',L} U\left(\bar{A}(\theta,m)\,K^{\alpha}L^{1-\alpha} - m(\theta,z)\,f - K' + (1-\delta)K, L\right) + \beta V_{SP}(K',\theta)\middle|\theta_{-1}\right]$$

where $m(\theta,z) = \int \sqrt{\gamma_v}\phi\left(\sqrt{\gamma_v}(v-\theta)\right) z(v)\,dv$, and ϕ is the probability density function of a standard normal. Notice that we already use the result, shown in the proof in Appendix E.5, that the economy admits aggregation and directly write the planner's problem using the aggregate production function.

We characterize the constrained efficient allocation and its implementation in the following proposition.

Proposition 5. *The competitive equilibrium with incomplete information is inefficient, but the constrained efficient allocation can be implemented with a lump-sum tax on the household, an input subsidy s_{kl} and a profit subsidy s_π to intermediate goods producers such that $1 - s_{kl} = \frac{\sigma-1}{\sigma}$ and $1 + s_\pi = \frac{\sigma}{\sigma-1}$.*

Proposition 5 shows that the constrained efficient allocation can be implemented in the competitive economy using simple instruments that correct the two distorted margins directly. To offset the distortions induced by the monopoly power, the planner uses an input subsidy s_{kl}, standard in the New-Keynesian literature, to encourage firms to expand to the optimal scale of operation. Despite this input subsidy, firms still operate at a suboptimal level because of the aggregate demand externality and the planner needs an additional instrument to induce the right technology choice. Perhaps surprisingly, a simple linear profit subsidy s_π is enough to correct this margin in the global game. By increasing profits, this subsidy makes firms internalize the impact of their technology choice on aggregate demand and incentivizes the adoption of the high technology. As a result, one should expect firms to coordinate more easily on the high technology under the optimal policy, and the basin of attraction for the high regime should consequently expand. In other words, the economy would visit the low regime less frequently, and the incidence and persistence of deep recessions would be reduced. Finally, to complete the implementation, we use a non-distortionary lump-sum tax on the household to ensure that the government budget constraint balances every period.[22]

5.2. Government spending

The optimal implementation result involves the use of input and profit subsidies. In the event that such instruments are unavailable to policymakers, for instance due to political economy reasons, we consider the impact of government spending on the economy. Since firms operate at an inefficiently low technological level in equilibrium, an increase in aggregate demand caused by government spending may, in principle, have a positive impact on welfare by raising the incentives to adopt the high technology. We investigate this claim in the context of our model.

We find that, in general, government spending is detrimental to welfare because the crowding out of private investment hurts coordination in subsequent periods. Government spending thus creates dynamic welfare losses. However, we also find that government spending can be welfare improving in a small region of the state space if the preferences of the household allow for a wealth effect on the labor supply, even in the absence of nominal rigidities or other frictions that tend to favor such policy interventions.

We now describe how these two channels operate. To do so, we assume that government spending is pure government consumption not valued by the household and financed through a lump-sum tax on the household.[23]

[22] This implementation is not unique and we show, in Appendix E.5, that another implementation based on a single sales subsidy can correct both margins at the same time because of the specific structure implied by the Dixit–Stiglitz model of monopolistic competition.

[23] As Ricardian equivalence holds in our environment the timing of taxes is irrelevant.

5.2.1. Crowding out of private spending

As in the neoclassical growth model, an increase in government spending leads to a reduction in the wealth of households which, as a result, save less in physical capital. Consequently, the amount of capital available in the following periods is reduced, which hurts coordination and reduces the measure of firms adopting the high technology, in contrast to what efficiency requires. In this sense, perhaps in contradiction with the common intuition, the coordination problem magnifies the crowding out effect of government spending in our model.

We can precisely establish this point in our benchmark framework. With GHH preferences, the crowding out effect associated with government spending unambiguously leads to welfare losses.

Proposition 6. *Under GHH preferences, for γ_v large, an unforeseen one-time increase in government spending financed by lump-sum taxes reduces welfare.*

The intuition behind this result is as follows. Under GHH preferences, the equilibrium output and employment only depend on current capital K, productivity θ and the measure of firms with high technology m. When γ_v is large, risk at the time of the technology choice is negligible and the stochastic discount factor is irrelevant in the surplus expression (16). As a result, in the limit as $\gamma_v \to \infty$, government spending has no impact on the outcome of the current coordination game. The measure m remains unaffected and only the crowding out effect remains. Government spending is thus a pure waste of resources.

5.2.2. Wealth effect on the labor supply

When the assumption of GHH preferences is relaxed, the labor supply curve of the household is affected by government spending.[24] As the household gets poorer, labor supply goes up, thereby putting downward pressure on wages. With cheaper inputs, firms expand and are more tempted to use the high technology, which alleviates the coordination problem and may result in welfare gains.

Figure A.15 in Appendix A illustrates the mechanism. The upper (red) and the lower (blue) curves represent the high and the low equilibria of the model with complete information. The black curves represent the unique equilibrium of the model with incomplete information, with and without government spending G. As government spending increases, firms are more tempted to use the high technology and the zone with multiple equilibria shifts to the left, from the dotted to the shaded region. As a result, the low equilibrium ceases to exist for the range of K to the right of the shaded region: the wage would be so low in that equilibrium that operating at a large scale with the high technology would always be preferable. In the environment with incomplete information, the equilibrium of the global game lies between the two equilibria of the complete information setup. The curve that indicates the unique equilibrium selected by the global game therefore also shifts to the left, from the dashed curve to the solid one. Notice that for values of K in the transition region, the resulting increase in the mass of firms using the high technology increases the endogenous TFP $\bar{A}$ which increases output, and, potentially, consumption, investment and welfare. Additionally, government spending can also helps coordination in subsequent periods. If it succeeds in raising investment, government spending can move the economy from the bad regime to the good one, therefore generating potentially large dynamic welfare gains.

5.2.3. Numerical simulations

To illustrate the overall impact of government spending on the economy, we proceed to a series of simulations. To allow for a wealth effect on the labor supply, we relax the assumption of GHH preferences and use instead standard separable preferences $U(C, L) = \log C - (1+\nu)^{-1} L^{1+\nu}$. The parameters and the details of the exercise are included in Appendix C. We consider an economy in which government spending G_t is high $G_t = G > 0$ with probability 1/2 and low $G_t = 0$ with probability 1/2. The draws are independent across time. We set G to equal 0.5% of the steady-state level of output and we assume that the value of G is revealed to all agents at the beginning of the period.

Figure A.16 in Appendix A shows the outcome of these simulations. In the top panel, we see that an increase in government spending G helps firms coordinate on the high technology in some region of the state space. Interestingly, this effect is only present for values of K in which the economy is close to the transition in m between the low and the high regime. Elsewhere, G has little to no impact on coordination. On Panel (b), we see that the interaction of coordination and government spending can give rise to large contemporaneous multipliers for output. When the gains from coordination are large enough to offset the crowding out effect, government spending may improve welfare, as expressed in consumption equivalent terms on panel (c). Notice, however, that government spending is generally detrimental to welfare, as the dynamic welfare losses coming from the crowding out effect dominate in most of the state space. Only in the region where the economy is close to a transition from the low to the high regime does government spending help coordination sufficiently to improve welfare. This result highlight the importance of the timing of government intervention.[25]

[24] We can no longer derive all our theoretical results under these new preferences, but the model can be solved numerically. We make sure, in particular, that uniqueness still obtains for the global game in our numerical simulations.

[25] Auerbach and Gorodnichenko (2012) find that the fiscal multiplier for total government spending in the United States is in general small but exceeds 1 during recessions. This evidence is potentially consistent with the model if the small recessions during that period coincide with episodes during which the economy slightly enters the transition zone before recovering.

6. Conclusion

We develop a dynamic stochastic general equilibrium model of business cycles with coordination failures. The model provides an alternative foundation for Keynesian-type demand-deficient downturns as the economy may fall into long-lasting recessions due to the failure of firms to coordinate on a higher output. The calibrated model outperforms the RBC benchmark in terms of business cycles asymmetries. It also replicated salient features of the slow recovery from the Great Recession. Government spending policies are generally detrimental to welfare, but may sometimes be welfare improving, without relying on nominal rigidities, when the economy is about to transition between regimes.

In this paper, we have limited the scope of our policy analysis to simple subsidies and a basic government spending policy, but other types of interventions may help alleviate the coordination problem. For instance, in the presence of nominal rigidities, monetary policy may encourage coordination in the future by affecting interest rates and the rate of accumulation of capital. Investment subsidies and other types of government spending may also lead to different conclusions.

Increasing returns in the firm's problem are an essential part of our mechanism. In this paper, we have focused on a simple binary technological choice, but we believe that the central mechanism of the paper applies to a larger class of models with increasing returns and other forms of non-convexities. For instance, it would be interesting to extend the model to include fixed costs of adjusting capital or labor, which have been widely documented in the empirical literature.

More broadly, we believe that the interaction of demand linkages and increasing returns can generate interesting mechanisms in other contexts. For instance, in Schaal and Taschereau-Dumouchel (2016) we study how introducing a demand externality into an otherwise standard search and matching model can make unemployment more volatile and persistent. The possibility of falling in the low regime may also have interesting asset pricing implications, as we can interpret our model as providing a theory of endogenous rare disasters. Another likely important factor influencing coordination is social learning. In Schaal and Taschereau-Dumouchel (2023), we consider an environment in which people learn from the actions of others in an investment game. The interaction of complementaries and social learning give rise to exuberant periods of economic activity followed by brutal crashes.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.jmoneco.2025.103829.

Data availability

Data will be made available on request.

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