Visibility Bias in the Transmission of Consumption Norms and Undersaving*

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Abstract

We study how bias in the social transmission process affects contagion of time preference norms. In the model, consumption is more salient than non-consumption. This visibility bias causes people to perceive that others are consuming heavily and to infer that others have favorable information about prospects for future consumption. The biased transmission of beliefs increases consumption and the equilibrium interest rate. Information asymmetry about the wealth of others dilutes the inference from high observed consumption that the future prospects are good. In consequence, in contrast with the Veblen wealth-signaling approach, information asymmetry about wealth *reduces* overconsumption. The visibility bias approach offers a novel explanation for the dramatic drop in the savings rate in the US and several other countries in the last thirty years. In contrast with other approaches, the visibility bias approach suggests that relatively simple policy interventions can ameliorate undersaving.

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1 Introduction

In acquiring attitudes about the world, people are heavily influenced by their cultural milieu, and by interactions with other individuals, especially when it is hard to come to a clear conclusion by introspection. Several authors have argued that people find it hard to decide how heavily to discount the future in making savings decisions (e.g., Akerlof and Shiller (2009)), owing either to lack of relevant information, or failure to process it effectively.

It is hard to be sure what stream of satisfaction will actually result from a consumption/savings rule chosen today.[1] It is hard to forecast remaining lifespan or health in old age; most people do not process the relevant public but technical information contained in mortality tables and medical research. Uncertainty about health also makes it hard to judge how much one will enjoy different levels of consumption expenditure at an older age. Finally, it is hard to predict risky future consumption realizations, and therefore, how much saving is needed today.

There is a great deal of evidence suggesting that people are indeed often 'grasping at straws' in their savings decisions. This is reflected in very basic mistakes and in relying on noisy cues in deciding how much to save (Samuelson and Zeckhauser (1988), Shefrin and Thaler (1988), Madrian and Shea (2001), Beshears et al. (2008), Benhassine et al. (2015)). There is also considerable evidence that social interactions affect several dimensions of consumption, saving, and investment choices.[2]

Empirically, the effects of social interactions differ from what would be expected based solely on rational information transmission, as they include contagion of behaviors about which there is ample public information, such as participating in the stock market; and there is transmission of unprofitable activities such as trading in individual stocks.[3] Surprisingly, however, there has been little formal modeling of how bias in social learning processes affect consumption choices over time.

In our model, social learning about others' beliefs about future prosperity is biased by the fact that engaging in a consumption activity is more salient to others than not doing so. For example, a boat parked in a driveway draws the attention of neighbors more than the absence of a boat. Similarly, it is more noticeable when a friend or acquaintance is encountered eating out or reports taking an expensive trip than when not, or acquires an enjoyable product as compared with not doing so. We call the greater availability and

[1] Allen and Carroll (2001) point out that "...the consumer cannot directly perceive the value function associated with a given consumption rule, but instead must evaluate the consumption rule by living with it for long enough to get a good idea of its performance. ... it takes a very large amount of experience ... to get an accurate sense of how good or bad that rule is."

[2] Duflo and Saez (2002, 2003)), Hong, Kubik, and Stein (2004), Brown et al. (2008), Charles, Hurst, and Roussanov (2009), Kaustia and Knüpfer (2012), Georgarakos, Haliassos, and Pasini (2014), Shemesh and Zapatero (2015), and the evidence reviewed in Hirshleifer and Teoh (2009).

[3] Individuals are not, on average, good at trading individual stocks (Barber and Odean 2000). In an experimental consumption/savings setting, social interaction caused subjects to deviate more from the optimal consumption path over time (Carbone and Duffy 2013).

salience of potential consumption events that do rather than do not occur *visibility bias*. We further assume that people do not adequately adjust for the selection bias in favor of attending to the consumption rather than nonconsumption events of others. This results in overestimation of others' consumption expenditures.

These key premises of our model—that consumption activities are more available and salient to others than nonconsumption; and that people do not adequately adjust for the selection bias in their attention toward consumption—are motivated by the psychology of attention, salience, and social communication (see Section 2). With regard to communication, transmission of information in conversation is greater for positive information and for more arousing information (Berger and Milkman 2012); we expect enjoyable consumption in general to be more positive and arousing than the passive choice not to consume.

Visibility bias in our model is not inherently an error; it is a source of bias in the *social transmission* of information. For example, noticing a neighbor's new car more than an old one need not signify any cognitive failure. There can be good reasons to allocate attention to occurrences (or more generally, to salient events). However, failing to adjust appropriately for this selection bias in attention/observation *is* a mistake that biases inferences.

Visibility bias makes consumption more available than non-consumption for later retrieval and cognitive processing. In consequence, people infer high consumption and low savings rates by others, and conclude that future consumption prospects are good and therefore that the low saving is appropriate. Observers in our model therefore increase their own actual consumption.

In the model, overestimation of the consumption of others is self-reinforcing, as each individual becomes an overconsuming model for others. So misperceptions of consumption norms can result in severe undersaving in society as a whole. In market equilibrium, the reluctance of individuals to save implies a higher interest rate. Furthermore, each individual views the beliefs of others about future prospects as more optimistic than his own. This comes from overestimation of others' consumption, and the fact that each individual, as a Bayesian, updates only partially from his prior, which reflects privately acquired information, based upon the information gleaned from others.

Such a mismatch between beliefs and social reality, wherein everyone individually rejects a norm (in this case, for a high impatience), yet believes that others embrace it, is called *pluralistic ignorance* (Katz and Allport 1931). For example, social psychology studies find that college students overestimate how much other students engage in and approve of heavy alcohol use (Prentice and Miller (1993), Schroeder and Prentice (1998)) and uncommitted or unprotected sexual practices (Lambert, Kahn, and Apple 2003). These studies argue that pluralistic ignorance encourages such behaviors. In our model it is overconsumption that is promoted by pluralistic ignorance.

This feature of our model can also help explain why parents, social observers, and religious leaders tend to preach in favor of thrift, and to criticize a 'now-focused' consumer culture. If society is subject to pluralistic ignorance, people believe that others are highly optimistic and see little reason to save. They therefore think others consume even more heavily than their own high actual level. Moral authorities may therefore believe that they can improve behavior by criticizing excessive current consumption.

Visibility bias effects help explain a well-known puzzle in savings rates. Personal saving rates in the U.S. have declined dramatically since the 1980s, from 10% in the early 1980s to a low of about 3% in 2007, while national debt has increased. This has raised concerns among many scholars and other observers about whether Americans will be able to sustain their standards of living in retirement.[4] A similar trend has occurred in many OECD countries, with ratios of household debt to disposable income often reaching well over 100% (OECD 2014). Economists have long struggled to explain this drop (Parker 1999; Guidolin and Jeunesse 2007). Parker (1999) concludes that "Each of the major current theories of the decline in the U.S. saving rate fails on its own to match significant aspects of the macroeconomic or household data." Guidolin and Jeunesse (2007) argue that factors such as greater capital mobility, new financial instruments, and aging populations do not suffice to explain the phenomenon, and conclude: "The recent decline of the U.S. private saving rate remains a puzzle."[5] The great savings decline presents a challenge to behavioral as well as rational models, since it is not obvious why psychological traits would shift over time toward impatience. But a plausible behavioral explanation is that agents with hyperbolic discounting have reduced saving in response to environmental shifts such as rising availability of credit cards and mortgage credit.

The visibility bias approach offers a novel explanation. The model is driven by observation of the consumption of others; greater observability of consumption intensifies the overconsumption effect. For example, the drop in costs of long-distance communication, the rise of cable television and VCR (video cassette recorders), and subsequently the rise of the internet, greatly increased the ability of individuals to observe others' consumption, as people are able to hear, view, or report via social networks about consumption experiences. The rise of an increased diversity of cable television offerings (including channels devoted to shopping, travel, home remodeling, and other costly leisure pursuits, as well as dramas that less directly highlight consumption activities) further increased visibility. It is very common for people, in communicating by phone or other electronic networks, to report on such activities as traveling, eating out, and recent product purchases. Such observation is the driving force behind overconsumption in our model. Of course, there are many other drivers of savings rates, but visibility offers a possible explanation for the large

[4]For example, over 50% of U.S. adults say that they could not easily come up with $400 to cover an emergency expense (?). More than half of households with bank cards carry debt from month to month, almost always at at high interest rates; a substantial fraction borrow at close to their credit limits (Gross and Souleles 2002). See also (Poterba 2014) and *Wall Street Journal* June 22, 2018, "A Generation of Americans Is Entering Old Age the Least Prepared in Decades," https://www.wsj.com/!/articles/a-generation-of-americans-is-entering-old-age-the-least-prepared-in-decades-1529676033.

[5]Existing explanations for the decline in savings rates include recent gains in household wealth coming from the stock market and real estate; upward revisions in individuals estimate of their permanent-income due to technological advances and higher productivity, growing income inequality, a stronger social safety net, increasing medical expenditure, an aging population, easier access to and improvements in the credit markets owing to financial innovations, and trends in the way companies pay out to shareholders (disappearing dividends and more stock repurchases).

and anomalous drop in saving.

There are also notable differences in savings rates across countries and ethnic groups which are not well-explained by traditional economic models (Bosworth 1993). An implication of the visibility bias approach is that relatively modest differences in beliefs or constraints can be amplified through social influence. This can help explain the diversity of savings rates across groups. It suggests, for example, that cultural differences can have surprisingly strong effects.[6] Our model also implies that degree of urbanization will be negatively related to savings rate, as urbanization is associated with a higher intensity of social interaction and observation of the consumption of others. This is consistent with the evidence of Loayza, Schmidt-Hebbel, and Serven (2000), and is not directly predicted by non-social theories of consumption.

A plausible alternative theory of overconsumption and undersaving is that people are present-biased (i.e., subject to hyperbolic discounting, Laibson (1997)). Present bias is a preference effect, whereas the visibility bias approach is based on belief updating. Also, present bias is an individual-level bias, whereas the visibility bias approach is based upon social observation and/or interaction. The visibility bias approach therefore has the distinctive implications that the intensity of social interactions and shifts in the technology for observing the consumption of others affect how heavily people consume. It also implies that population level characteristics such as wealth dispersion matter, in contrast with pure individual-level biases such as present bias.

Another appealing approach to overconsumption is based on Veblen effects (Cole, Mailath, and Postlewaite 1995; Bagwell and Bernheim 1996; Corneo and Jeanne 1997; Charles, Hurst, and Roussanov 2009), wherein people overconsume to signal high wealth to others. In wealth signaling models, beliefs are rational, whereas the visibility bias approach is based upon biased inferences. The visibility approach has distinct empirical implications as well. For example, if all wealths were equal, Veblen effects would be eliminated, but the effects in the visibility bias approach still apply. So a visibility bias approach implies overconsumption even within peer groups with low wealth inequality. More generally, as discussed in Section 5.3, wealth dispersion and asymmetric information about others' wealths is the source of Veblen effects, whereas the effects in the visibility bias approach, overconsumption is strongest when there is *low* wealth dispersion and information asymmetry about wealth.

A third approach is based on investors deriving utility as a function of the consumptions of other investors (Abel 1990; Galí 1994; Campbell and Cochrane 1999). Unlike our model, the preference interaction approach does not in general result in equilibrium overconsumption (Dupor and Liu 1993; **?**).[7] Preference interactions potentially result in multiple equilibria with early or late consumption (Stracca and Al-Nowaihi 2005), whereas

[6]Carroll, Rhee, and Rhee (1994) do not find an effect of culture on savings. They describe this as a tentative conclusion owing to data limitations. In contrast, using a similar methodology, Carroll, Rhee, and Rhee (1999) conclude that there *are* cultural effects.

[7]Concern for relative consumption as in 'keeping up with the Joneses' can induce a fear of falling behind which raises precautionary savings (Harbaugh 1996).

the visibility bias approach predicts a specific direction, overconsumption.[8] Also, the belief-based effects of our approach imply several distinctive implications.

A further distinctive empirical and policy implication of the visibility bias approach is that exposing pluralistic ignorance will reduce overconsumption. This can be done by disclosing and saliently emphasizing information about the actual consumption or consumption attitudes of others. That a relatively simple policy intervention can potentially ameliorate the undersavings problem is specific to the visibility bias approach. Overconsumption in this approach derives from mistaken beliefs about others that can potentially be corrected. In contrast, the present bias approach is not based on social observation, and the other two approaches are based upon rational beliefs.

Finally, another approach that can lead to overconsumption is based on speculative disagreement (Heyerdahl-Larsen and Walden 2016). When investors with heterogeneous beliefs bet against each other in an asset market, they may all expect to profit, at least some of them mistakenly. Depending on agents' elasticity of intertemporal substitution, this can result in overconsumption. Several of the implications discussed above also distinguish our approach from the speculative disagreement approach.

2 Psychology Background

The two key assumptions of our model are that consumption activities are more available and salient to others than nonconsumption; and that people do not adequately adjust for the selection bias in their attention toward consumption. We now briefly summarize evidence from the psychology of attention and salience that motivate and support our assumptions.

There is extensive evidence that occurrences are more salient and more fully processed than nonoccurrences (e.g., Neisser (1963), Healy (1981), the review of Hearst (1991), and Enke (2017)). Occurrences provide sensory or cognitive cues that trigger attention. In the absence of such triggers, an individual will only react if (as is usually not the case) the individual is actively monitoring for a possible absence. This is what makes notable the phrase "The dog that did not bark" in the Sherlock Holmes story; it takes a genius to detect and recognize the importance of an absence. An example of the low salience of non-occurrences is neglect of opportunity costs, i.e., non-occurrences of benefits that would be received under alternative courses of action. Economics instructors are well aware that the opportunity cost concept is something that students struggle with.[9] Neglect of absences is also reflected in the principle of WYSIATI, "What you see is all there is," which Daniel

[8]Even with conventional preferences, externalities can also induce 'keeping up with the Joneses'-like effects (DeMarzo, Kaniel, and Kremer (2004, 2008)), though models based on this approach do not focus on the issue of over- or under- consumption.

[9]Another example of underweighting nonoccurrences relative to occurrences is omission bias, the tendency of people to dislike and disapprove of actions that can result in adverse consequences, as compared with suffering adverse consequences from refraining from taking an action. A classic example is an irrational reluctance to vaccinate (Ritov and Baron 1990).

Kahneman argues is one of the key features of System 1 thinking (Kahneman 2011).

There is evidence from both psychology, experimental economics, and field studies of *selection neglect*, a failure of observers to adjust appropriately for data selection biases (Nisbett and Ross 1980; Brenner, Koehler, and Tversky 1996).[10] In general, neglect of selection bias is implied by the representativeness heuristic of Kahneman and Tversky (1972). Owing to limited cognitive resources, doing so requires time, attention, and effort. Selection bias is especially hard for people to correct for because adjustment requires attending to the *non-occurrences* that shape a sample. A model of how neglect of selection bias affects economic decisions is provided in Hirshleifer and Teoh (2003).

The combination of visibility bias and selection neglect in our model can explain the *availability heuristic* of Kahneman and Tversky (1973), so overestimation of consumption in the model can be viewed as a consequence of the availability heuristic. According to the availability heuristic, people overestimate the frequency of events that come to mind more easily, such as events that are highly memorable and salient. For example, people overestimate the frequency of shark attacks because such attacks are vivid and heavily reported in the media relative to other causes of death such as car accident. The availability heuristic is a failure to adjust for the selection bias in information brought to conscious attention—this being the subset of information that was stored into memory and is easy to retrieve from it. In our model, this is disproportionately information about the consumption activities that were engaged in rather than not engaged in.

Experiments in the field confirm that engaging in a consumption activity is more salient to others than not engaging in the activity. As Frederick (2012) concludes, "purchasing and consumption are more conspicuous than forbearance and thrift." Consistent with our model's implication that this results in overestimation of others' consumption, in Frederick's experiment this salience results in overestimation by observers of how much other individuals value certain consumer products. He explains the difference in salience between consumption and non-consumption vividly: "Customers in the queue at Starbucks are more visible than those hidden away in their offices unwilling to spend $4 on coffee. We are repeatedly exposed to commercials of people enthusiastically gulping soda and gyrating to their iPods, but the large segment of nonusers is not so memorably depicted." Also consistent with visibility bias, people are influenced in car purchase decisions by observation of the purchases of others (Grinblatt, Keloharju, and Ikäheimo (2008), **?**)), and such effects are stronger in areas where commuting patterns make the cars driven by others more visible (McShane, Bradlow, and Berger 2012).

Consumption activities of others may also be more cognitively available than non-consumption because someone who is consuming chooses to talk about it more than someone who is not consuming. Generally it is more interesting to hear about an action than

[10] People often naively accept sample data at face value (Fiedler 2008). Mutual fund families advertise their better-performing funds; in the experimental laboratory both novice investors and financial professionals misinterpret reported fund performance owing to selection neglect (Koehler and Mercer 2009). Auction bidders in economic experiments tend to suffer from the winner's curse (neglect of the selection bias inherent in winning), and hence tend to lose money on average (Parlour, Prasnikar, and Rajan 2007).

inaction. Berger and Milkman (2012) provide evidence that online content is more likely to go viral when it is positive than negative, and more rather than less arousing. For various consumer products, positive word-of-mouth discussion of user experiences tends to predominate over negative discussion (see the review of East, Hammond, and Wright (2007)). A plausible reason is that users would like others to persuade others of their expertise at product choice (Wojnicki and Godes 2008). This evidence suggests that people are more prone to sharing news about enjoyable consumption activities than the news that they stoically refrained from doing so.

3 The Basic Model

We first consider the effects of visibility bias in learning about the consumption of others on individual decisions when all investors have the same initial wealth and age. We start by focusing on individual optimization with interest rate given.

3.1 Optimal Consumption

Each individual maximizes a quadratic expected utility function with zero subjective rate of discount over two dates,

$$U = c_0 - \frac{\alpha}{2}c_0^2 + E\left[c_1 - \frac{\alpha}{2}c_1^2\right]. \tag{1}$$

At date 0, each individual chooses how much to consume and how much to borrow or lend at the riskfree interest rate $r = 0$, so the budget constraint is

$$c_1 = W - c_0 - \epsilon, \tag{2}$$

where, c_0 and c_1 are consumptions at dates 0 and 1, W is date 0 wealth, and ϵ is a potential consumption shock at time 1. We assume that

$$\epsilon = \begin{cases} 0 & \text{with probability } \ p \\ W & \text{with probability } \ 1-p, \end{cases} \tag{3}$$

so with probability $0 < p < 1$, the agent's date-1 wealth is high, and with probability $1-p$ it is low. We permit negative consumption, $c_1 < 0$, so the agent may choose positive consumption at time 0 despite the risk. We assume that $\alpha W < 1$, to ensure that utility is increasing in consumption.

The negative wealth shock, which we view as being rare $(1 - p \ll 1)$, can represent a systematic event, such as a major depression, or an underfunded pension system; or an idiosyncratic event that all agents are symmetrically exposed to, such as the possibility of a financially costly illness or disability, or a drop in demand for the agent's human capital (e.g., job loss). The key is that agents draw inferences about the probability of such events (even if their occurrence is independent across agents) from their observations of the consumption of others.[11]

The agent's estimated probability that date-1 wealth will be high ($\epsilon = 0$) is $\hat{p}$. Based on this estimate, the agent chooses date-0 consumption to maximize expected utility, implying the first order condition

$$1 - \alpha c_0 = \hat{p}[1 - \alpha(W - c_0)] + (1 - \hat{p})[1 - \alpha(-c_0)]. \tag{4}$$

So optimal consumption is

$$c_0 = \hat{p}\left(\frac{W}{2}\right), \tag{5}$$

meaning that date 0 consumption is proportional to the estimated probability that future consumption will be high. So if people were sure of a high outcome, they consume half their wealth; if $\hat{p} < 1$ they consume less than half and save more than half. In this stylized model, the first and second periods are of equal length, leading to the half/half split of consumption. In a more realistic model the time periods could be viewed as unequal, leading to other divisions of consumption.

Empirically, there is evidence that fear of adverse wealth shocks strongly affects consumption/savings decisions (Malmendier and Shen 2018). There is also evidence of that people learn from others about risk of financial disaster, and that learning of a neighbor's financial disaster causes people to cut back on current indebtedness **??**.

3.2 Visibility Bias and Learning About Others' Consumption

There are $N \gg 1$ identical agents, all facing identically distributed ϵ risks. Total date 0 consumption of an agent is divided into K different activities which we call "bins" (K large), where each bin represents potential consumption of $W/(2K)$. There are thus in total NK agent-consumption bins. An agent who chose to consume $W/2$ at date 0 (consistent with belief $\hat{p} = 1$, i.e., no risk of a negative shock) would then consume in every bin, whereas an agent who chooses to consume 0 (consistent with belief $\hat{p} = 0$, i.e., certainty of the adverse outcome) would not consume in any bin.

We refer to the agent's prior as the agent's perceived distribution of p based only on private signals, not social observation. The prior reflects private information, which makes it useful for agents to update based upon the observation of others. Specifically, each agent has a Beta-distributed prior for p, which is based on observation of Q private signals about the state. So $p \sim Beta(Q_n, Q - Q_n) = Beta(Qq_n, Q(1 - q_n))$, where Q is a common natural

[11] An alternative modeling approach that would yield similar results would be to assume that agents are learning from others about the probability of dying young, which would also affect the benefits from saving. Yet another approach would assume that owing to visibility bias, people overestimate the subjective discount rates of others; and that owing to conformism, people update their own discount rates accordingly.

number for all agents, $Q \in \mathbb{N}$, $0 \leq Q_n \leq Q$, and $q_n \stackrel{\text{def}}{=} Q_n/Q$.[12] Based on his signals, the agent's prior estimate of the probability for a high outcome is then $E[p] = q_n$. We call q_n agent n's *prior type*.

We may think of the prior type distribution as arising when each agent, starting with an improper $Beta(0, 0)$ "prior prior distribution" independently observes Q consumption bins, each of which contains consumption with unbiased probability p, and conditions on these observations to update to a prior $Beta(Q_n, Q - Q_n)$ distribution, based on Q_n bins with observed consumption. Viewing Q_n as ex ante stochastic, it has a binomial distribution for each agent. It follows that since N is very large, the fractions of agents of different prior types is deterministic and follows a binomial distribution across agents, as follows by the Glivenko-Cantelli theorem.

Specifically, each agents prior type is ℓ/Q, where $\ell \sim Binom(Q; p)$. By the law of large numbers, it follows that the deterministic fraction f_ℓ, of agents associated with prior type ℓ/Q is

$$f_\ell = \binom{Q}{\ell}(1-p)^{Q-\ell}p^\ell, \qquad \ell = 0, 1, \ldots, Q.$$

By a standard properties of binomial distributions over count variables (in this case, ℓ), it follows that the average prior type is

$$\sum_{k=0}^{Q} \left(\frac{k}{Q}\right) f_{k/Q} = p. \tag{6}$$

So on average, agents' prior estimates are correct.

We refer to a bin as *full* if it contains consumption and *empty* otherwise. Each agent observes $M \gg 1$ bins of the other agents' $B = (N-1)K$ bins, believes the M bins to be an unbiased sample. In other words, he thinks that the probability of observing a full bin is equal to the overall fraction of bins that are full. In the *base model* we now develop, the observations are assumed to be independently selected from the rest of the population. Subsequently we will change the assumption, when introducing a *network model* in which observations depend upon an agent's position in a social network.

The agent's belief that he is observing a random sample may actually be incorrect. Crucially, we assume that observation is tilted toward those activities in which consumption did occur. This derives from what we call *visibility bias*, the tendency to notice and recall occurrences rather than non-occurrences. We view the event of engaging in a consumption

[12]In the cases $Q_n = 0$ or $Q_n = Q$, the prior is improper. The Beta distribution, which has support is $[0, 1]$, is commonly used to described the distribution of unknown probabilities of a Bernoulli random variable (in this case, the occurrence of the good state). Intuitively, the agent's prior is obtained by observing signals that are equivalent to observing Q independent drawings of the Bernoulli variable, where q_n is the fraction of successes (so that Qq_n is the number of successes). So Q is a proxy for the agent's prior precision, and q_n for the agent's optimism.

activity as generally more salient to others than the event of not doing so.[13]

One reason that consumption activities are highly visible is that many are social, such as eating at restaurants, wearing stylish clothing to work or parties, and traveling. Furthermore, physical shopping is itself a social activity. Both physical and electronic shopping and product evaluation are also engaging topics of conversation, either in person or online. In contrast, saving is often a private activity and investing are often undertaken privately through banks, brokers, or retirement account software. Many television dramas display glamorous consumption activities, travel, entertaining, and dining, and some media channels explicitly focus on shopping and other costly leisure activities. There are of course exceptions to these generalizations, such as investment clubs, but overall, consumption tends to be more observable and salient to others than is saving.[14]

Specifically, if B^C of the B bins contains consumption and B^N do not, then we assume that the chance that an observed bin contains consumption is

$$\frac{k^C B^C}{k^C B^C + k^N B^N} = \frac{\frac{B^C}{B}}{\frac{B^C}{B} + \frac{k^N}{k^C}\left(1 - \frac{B^C}{B}\right)} = \frac{s}{s + \frac{1-s}{\tau}} \stackrel{\text{def}}{=} S_\tau(s), \tag{7}$$

where k^C is the probability that a bin is observed conditional upon it being full, k^N is the probability that a bin is observed conditional upon it being empty, $\tau = k^C/k^N \geq 1$, and $s = B^C/B$ is the consumption ratio. The parameter τ measures the overrepresentation of full bins in the observer's sample, i.e., *visibility bias.* When $\tau = 1$, the random observations match the actual distribution of consumption bins. When $\tau > 1$, there is overrepresentation of draws of consumption bins over non-consumption bins.[15] We call the failure of the agent to adjust for the overrepresentation *visibility bias.* The number of bins with consumption observed by agent n is Z_n, $0 \leq Z_n \leq M$. We define $z_n = Z_n/M$ as the fraction of

[13]The occurrence versus non-occurrence distinction that we focus upon is not the only source of differences in the salience of different consumption behaviors. Extreme outcomes also tend to be more salient. Other things equal, we might expect this to cause observers to notice especially when others have either unusually low or unusually high total consumption, with no clear overall bias toward either over- nor under- estimation of others' consumption. Such effects (which we do not model) would basically be orthogonal to those we focus on. Our focus is on an attentional bias—neglect of nonoccurrences—that has a clearcut directional implication.

[14]Two other comparisons are of interest. First, retirement savings have very low visibility to others, so our approach suggests that people will underestimate such saving. Second, buying a house is highly visible. This is another example of the higher visibility of engaging in a consumption activity than not doing so. The purchase of a house is usually a shift to a higher flow of current consumption of housing services financed by a major increase in indebtedness (and with the mortgage down payment usually much smaller than the size of the loan), i.e., higher current consumption at the expense of future consumption. Indeed, Lusardi, Mitchell, and Oggero (2018) report that in recent years, older Americans close to retirement hold more debt than earlier generations, primarily owing to the purchase of more expensive homes with smaller down payments.

[15]We refer to the observer as observing a biased sample of target activities. However, the algebra of the updating process in the model can equally be interpreted as reflecting a setting in which observers draw unbiased random samples of observations, but where there is a bias in the ability to *retrieve* different observations for cognitive processing and the formation of beliefs.

bins observed with consumption, and $z = \frac{1}{N}\sum_n z_n$. Neglect of visibility bias is the only deviation from rationality in the model. It is straightforward to show that the function $S_\tau(s)$ is strictly increasing in τ and $s \in (0,1)$, is concave in s, and satisfies $S_\tau(0) = 0$, $S_\tau(1) = 1$, and $S_0(s) \equiv s$.

An agent uses Bayesian updating to estimate p, based on his bin observations. The agent understands that more full bins indicate high consumption, and that high p promotes high consumption. Defining $\xi = M/Q$, it follows that the agent's posterior belief is

$$\hat{p}_n = \frac{Qq_n + Mz_n}{Q+M} = \frac{q_n + \xi z_n}{1+\xi}. \tag{8}$$

The variable ξ represents how much weight the agent puts on the new observations compared with his prior. This can be viewed as a proxy for the intensity of an agent's social interaction or social observation. An agent who observes others more updates more based on social observation.

Owing to visibility bias, agents overestimate others' consumption levels. The variables z_n and q_n for agent n are ex ante stochastic, but in the limit with many agents, the average estimate across agents $\bar{p} = \frac{1}{N}\sum_n \hat{p}_n$, given the consumptions of all agents and the distribution of priors, is, by the law of large numbers,

$$\bar{p} = \lim_{N\to\infty} \frac{1}{N}\sum_n \frac{q_n + \xi z_n}{1+\xi} = \frac{p + \xi E[z]}{1+\xi}. \tag{9}$$

Since each agent consumes in proportion to his estimates (as shown in (5)), and the average agent estimate is $\bar{p}$, it follows that the expected fraction of full bins observed under visibility bias is just $S_\tau(\bar{p})$, i.e.,

$$E[z] = S_\tau(\bar{p}). \tag{10}$$

Specifically, each agent observes M bins, each with probability $S_\tau(\bar{p})$ containing consumption, leading to an expected observed consumption fraction of $E[z] = E[z_n] = S_\tau(\bar{p})$.

We define the mapping T from observation of consumption fraction $S_\tau(x)$ to the posterior belief as

$$T(x) \stackrel{\text{def}}{=} \frac{p + \xi S_\tau(x)}{1+\xi}.$$

An equilibrium is defined as a solution $\bar{p}$ to (9,10), i.e., a fixed point $\bar{p} = T(\bar{p})$.[16] It is easy to verify that the unique equilibrium $\bar{p}$ when $\tau > 1$ is

$$\bar{p} = \frac{(\tau-1)(p+\xi) - 1 + \sqrt{V}}{2(1+\xi)(\tau-1)}, \qquad \text{where} \tag{11}$$

$$V = [(\tau-1)(p+\xi) - 1]^2 + 4p(1+\xi)(\tau-1). \tag{12}$$

[16]All agents determine their consumption simultaneously. In a variation of the model, agents choose consumption sequentially based on (biased) observations of previous agents' consumption. The large sample equilibrium with sequential observations is identical to the equilibrium with simultaneous observations that we study.

When $\tau = 1$, equilibrium is simply $\bar{p} = p$. We write

$$\bar{p} = B(\tau, p, \xi) \tag{13}$$

for the function defined by (11,12) for $\tau > 1$, and by $B(1, p, \xi) = p$. More generally, we define the function

$$\begin{aligned} B_g(\tau, p, \xi, g) &= \frac{(\tau-1)(p+\xi) - g + \sqrt{V}}{2(1+\xi)(\tau-1)}, \qquad \text{where} & (14) \\ V &= [(\tau-1)(p+\xi) - g]^2 + 4p(1+\xi)(\tau-1)g. & (15) \end{aligned}$$

and then have $B(\tau, p, \xi) = B_g(\tau, p, \xi, 1)$. The function B_g will be useful in our subsequent analysis.

In equilibrium, different agents have different $\hat{p}_n$'s because of randomness in the number of prior successes z_n, but the aggregate estimate $\bar{p}$ and corresponding per capita consumption, $\bar{c}_0$ are nonrandom by the law of large numbers. We call $\bar{p}$ the *equilibrium probability estimate*. It is proportional to aggregate (per-capita) consumption, $\bar{c}_0 = \bar{p}\left(\frac{W}{2}\right)$. The *over-consumption factor*, the ratio of consumption to optimal consumption (which is $p\left(\frac{W}{2}\right)$), is therefore $\bar{p}/p \geq 1$.

It is easy to verify that when $\tau > 1$,

$$\bar{p} > \frac{p + \xi S_\tau(p)}{1+\xi}.$$

In equilibrium an agent has higher consumption owing to visibility bias, thereby inducing higher consumption by other agents. This in turn encourages even higher consumption by the original agent. As we shall see, this feedback effect can be powerful.It is also possible to verify the following properties of the equilibrium.

Proposition 1 *In equilibrium:*

1. *The equilibrium probability estimate, $\bar{p}$, and aggregate consumption are increasing in visibility bias, τ, i.e., $\partial\bar{p}/\partial\tau > 0$, with $\bar{p} = p$ when $\tau = 1$.*

2. *As $\tau \to \infty$, $\bar{p} \to (p+\xi)/(1+\xi)$, so that $0 < \bar{p}_\infty < 1$;*

3. *If $\tau > 1$, the average estimated probability of high consumption, $\bar{p}$, and aggregate consumption are increasing in the fraction of observations, ξ, i.e., $\partial\bar{p}/\partial\xi > 0$;*

4. *If $\tau > 1$, as the number of observations of others' consumption bins, and thereby ξ, tends to infinity, $\bar{p} \to 1$, so that people ignore the risk of a bad outcome in determining their current consumption.*

Intuitively, Part 1 says that owing to visibility bias in consumption observations, and neglect of sample selection bias (or equivalently, use of the availability heuristic) in assessing frequencies, people overestimate others' consumption. In consequence observers overestimate how favorable the information of a target of observation is about that agent's state. This causes people to overconsume, where the effect is larger the greater the visibility bias.

Part 2 indicates that when visibility bias becomes maximally strong, beliefs become maximally overoptimistic, but that agents' prior beliefs have a moderating effect, so that the equilibrium beliefs do not "spiral" upward toward $\bar{p} = 1$. Agents put some weight on their priors, so even if 100% of observed bins are full, observers only update their beliefs to $(p + \xi)/(1 + \xi) < 1$. The prior beliefs thus put an upper bound on the severity of overconsumption.

Part 3 says that owing to visibility bias, greater observation of others as reflected in ξ implies more optimistic beliefs and greater aggregate consumption. As biased observation of others becomes very large relative to the prior precision, so that ξ approaches infinity, Part 4 says there may be drastic overconsumption (consuming as if they were sure there were no risk of a bad outcome). New biased observations dominate prior information, so that people become certain of a high outcome, even if visibility bias is small (τ close to one) and the probability for a high outcome, p, is low. This is because when the agent put a lot of trust into the information provided via social transmission, the feedback effect becomes very strong. Since $\bar{p} = p$ when $\tau = 1$, this also means that equilibrium consumption is very sensitive to changes in τ for some parameter values (i.e., for large ξ). Together, Parts 2 and 3 suggest that the feedback effect inherent in social transmission may be more important in generating severe overconsumption than visibility bias itself.

As a basic plausibility check, we also verify that the average estimated probability of high consumption, $\bar{p}$, and aggregate consumption are increasing in the true probability of the high state, p.

As discussed in the introduction, personal saving rates have plunged in the U.S. and several other OECD countries over the last 30 years, and existing rational theories do not seem to fully explain this phenomenon. Parts 1 and 3 of Proposition 1 provide a possible explanation.

Over the last several decades, improvements in electronic communications by such means as phone (the drop in cost of long-distance telephone service), the rise of cell phones and emails in the early 1990s, the rise of internet in the late 1990s, and blogging and social networking (such as Facebook) over the last decade have dramatically reduced the cost of conveying information about personal consumption activities. This is reflected in our model as an increase in both τ and ξ, as in Parts 1 and 3 of Proposition 1. Greater observation and communication in general about the behavior of others is reflected by higher ξ in the model. Greater opportunity to observe others intensifies the effects of visibility bias by increasing the weight on social observation relative to the prior, and implies a reduction in the savings rate.

These technological changes also strongly suggest an increase in bias in favor of observing consumption over nonconsumption, i.e., visibility bias τ. The activities that are noteworthy to report on very often involve expensive purchases, as with eating out or traveling. Indeed, numerous television dramas and reality shows have long had a focus, implicit or explicit, on such consumption activities. The explicit side includes travel and shopping channel. For example, the first national shopping network began in 1985 as the Home Shopping Network. The implicit side includes dramas, not limited to those centered upon the antics of the wealthy ("Who shot JR?"). The shift to reality television also induced greater observation of the consumption activities of others.

In more recent years, social networking and review sites have been organized around consumption activities, such as Yelp and TripAdvisor. The universe of YouTube video postings includes travel and other consumption activities. On Facebook, a posting about a consumption event would trigger a notification to friends; a non-posting about not engaging in a consumption event does not trigger a notification.

On special interest online discussion sites (e.g., focused on high tech or classical music), participants often post about associated product purchases. Such posting are more interesting, and therefore more likely to occur, than a posting to announce the news that the individual did not buy anything today.

So whereas electronic reports tend to select especially strongly for consumption activities, in-person unmediated observation of nearby individuals or close friends are likely to often include even nonconsumption activities. So the rise in modern communications results in an increase in visibility bias (i.e., larger τ) and lead to higher overconsumption.[17,18]

The social influence parameter ξ is identical across individuals. With diverse ξ's, we expect that individuals who engage in greater social observation will overconsume more than those with lower ξ. Such individuals update their beliefs more optimistically. A similar point holds for individuals who are more subject to visibility bias, i.e., greater τ. It is evident that these predictions hold for the case in which ξ or τ is identical for almost everyone.

Proposition 2 *Consider a society with common social observation parameter ξ and visibility bias parameter τ, with the exception of a deviant individual who has a social observation parameter value of ξ', or alternatively a visibility bias parameter value τ'. Then the consumption of the ξ-deviant is increasing with ξ', and the consumption of the τ-deviant $\tau' \neq \tau$ is increasing with τ'. An ξ-deviant on average consumes more than the others if and only if $\xi' > \xi$. A $\tau -$ deviant on average consumes more than the others if and only if $\tau' > \tau$.*

The result follows from (8), since $E[\hat{p}] = \frac{p+\xi' S_{\tau'}(\bar{p})}{1+\xi'}$, which is increasing in ξ' and τ'. Proposition 2 suggests that people who engage in greater social observation or are more subject

[17]Increased Internet usage—especially through online social networking platforms—is associated with a larger number of weak ties in ones' social network, and such weak ties are especially useful in providing information and ideas, see (Donath and Boyd 2004; de Zúñiga and Valenzuela 2011) Also, a social networking platform that relies on advertising for its revenues may have an incentive to disproportionately convey notifications that relate to consumption activities.

[18]Hirsh (2015) provides evidence that the drop in savings rates was accompanied by increasing population-level extraversion in many countries. Hirsh's shifting extraversion explanation is compatible with our approach, since greater sociability causes greater observation of others' consumption. However, even in the absence of shifts in population-level psychological traits, our model can explain the drop in the savings rates by improvements in communication technologies.

to visibility bias will overconsume more. These implications are empirically testable.

A possible objection to the conclusion of overconsumption is that houses are an investment, and are highly visible to others. However, as discussed in footnote 14, the purchase of a house tends to be associated with an increase in the consumption of housing services, financed heavily by debt—i.e., an increase in current consumption at the expense of future consumption. Of course, buyers of expensive houses sometimes reduce non-housing consumption expenditures, but this need not imply an overall reduction in current consumption. Indeed, real estate equity is often accessed to finance non-housing consumption expenditures as well Chen, Michaux, and Roussanov (2013). A related objection is that in a multiperiod setting, the purchase of a house could be an indicator that an individual had saved heavily to accumulate enough for a substantial down-payment. However, it is not obvious that such an inference would follow in a setting in which people observe others repeatedly over time. We extend the model to allow for observation of the old by the young in Section 5.1. Even though we allow for a possible inference from observing high consumption by the old that they saved a lot, overall the inference of observers is that others consume heavily, so the result of equilibrium overconsumption still obtains.

4 Observation of Others in a Social Network

We can define an agent's location in a social network by whose consumption an agent can potentially observe. So network location affects perceptions of the consumption of others. So far, our results have focused on aggregate behavior rather than that of individual agents in a random network (i.e., random observations from the population). We now extend the model to allow for an arbitrary social network, to derive empirical implications for how individual social linkages and overall network connectedness affect beliefs and consumption.

Agents are connected in an undirected social network represented by the graph $\mathcal{G} = (\mathcal{N}, \mathcal{E})$, where $\mathcal{N}$ is the set of investors and $\mathcal{E}$ is the set of edges connecting them. The set of agents $\mathcal{N} = \{1, \ldots, N\}$, and $(m, n) \in \mathcal{E} \subset \mathcal{N} \times \mathcal{N}$ if investors m and n are connected through a direct social tie. By convention, the network is undirected, i.e., $(m, n) \in \mathcal{E} \Leftrightarrow (n, m) \in \mathcal{E}$, and investors are not connected to themselves ($(n, n) \notin \mathcal{E}$). The set of agents that n is socially linked to is $\mathcal{D}_n = \{m : (n, m) \in \mathcal{E}\} \subset \mathcal{N} \backslash \{n\}$, and n's connectedness is $d_n = |\mathcal{D}_n|$. The maximal degree in the network is $D = \max_n d_n$.[19]

Associated with the network is the symmetric *adjacency matrix* $\mathbf{E} \in \mathbb{R}^{N \times N}$, with $\mathbf{E}_{mn} = 1$ if $(m, n) \in \mathcal{E}$, and $\mathbf{E}_{mn} = 0$ otherwise. We focus on a connected network (meaning that there is a path between any two agents). Each agent therefore has at least one neighbor.

[19] To ensure that there is a large enough number of agents so that the law of large numbers can be used, as in the previous section, we make the technical assumption that there are actually a large number of agents representing each node position in the network. Each agent randomly observes the consumption bins of agents in its neighboring node positions. The approach is similar to the replica network approach in Walden (2017). Each node in the network thus represents a whole equivalence class of identical agents, and there is a sufficient large number of agents in the economy so that expectations rather than realizations can be used in the subsequent equilibrium fixed point definition, as in the base model of Section 3.2.

Agent n, with prior type q_n, randomly observes $d_n M$ consumption bins of his neighbors' $d_n K$ bins. Here, we assume that K is sufficiently large that all agents treat these observations as effectively independent, i.e., as if the agent were sampling with replacement. An agent with more neighbors will thus have more observations, and therefore update his consumption behavior more aggressively than an agent with few neighbors. This is captured by the variation of d_n, as contrasted with the base model in which all agents have the same number of observations, M, corresponding to $d_n = 1$ for all n. Given their observations of their neighbors, each agent forms posterior beliefs $\hat{p}_n$, that govern their own consumption. Specifically, z_n is the fraction of agent n's observations of n's neighbors's bins that are full. It follows that when there is visibility bias, $\tau > 1$,

$$E[z_n] = S_\tau \left(\frac{1}{d_n} \sum_{m \in \mathcal{D}_n} \hat{p}_m \right). \tag{16}$$

Definition 1 *A network consumption equilibrium is a vector,* $\bar{\mathbf{p}} = (\bar{p}_1, \bar{p}_2, \ldots, \bar{p}_N)' \in [0,1]^N$*, such that*

$$\bar{p}_n = \frac{p + d_n \xi S_\tau \left(\frac{1}{d_n} \sum_{m \in \mathcal{D}_n} \bar{p}_m \right)}{1 + d_n \xi}, \qquad n = 1, \ldots, N. \tag{17}$$

This is the natural generalization of the equilibrium concept used in the preceding section.

The aggregate (per capita) equilibrium probability estimate is

$$\bar{p} = \frac{1}{N} \sum_n \bar{p}_n,$$

and the aggregate consumption is $\bar{c}_0 = \bar{p}\,(W/2)$. The network economy is characterized by the tuple $\mathcal{T} = (\mathbf{E}, \xi, \tau, p)$, where $\mathbf{E}$ is the adjacency matrix of the connected network, $\xi > 0$, $\tau > 1$, and $0 < p < 1$. Owing to neglect of visibility bias, each agent behaves as if the economy is actually $\mathcal{T}' = (\mathbf{E}, \xi, 1, p)$.

The following proposition characterizes the equilibrium:

Proposition 3 *Consider an economy represented by* $\mathcal{T} = (\mathbf{E}, \xi, \tau, p)$.

1. *There exists a network equilibrium vector,* $\bar{\mathbf{p}} \in [p,1]^N$*, with correct consumption, i.e.,* $\bar{p} = (p, p, \ldots, p)'$ *if and only if* $\tau = 1$.

2. *The equilibrium vector is unique if*

$$\left(1 + \frac{1}{\xi D}\right) [(\tau - 1)p + 1]^2 > \tau. \tag{18}$$

Alternative sufficient conditions for uniqueness are that:

(i) The prior probability for high consumption is sufficiently high, $p > \frac{1}{2}$, or

(ii) *Visibility bias is sufficiently low, i.e., τ is sufficiently close to one, so that* $\tau < 1 + \frac{1}{\xi D}$, or

(iii) *Visibility bias is sufficiently high, i.e., τ is sufficiently large, so that* $1 < p(\tau - 1)$.

3. *As $\tau \to \infty$, the equilibrium vector converges to*

$$\bar{\mathbf{p}} = \left(\frac{p + d_1\xi}{1 + d_1\xi}, \frac{p + d_2\xi}{1 + d_2\xi}, \ldots, \frac{p + d_N\xi}{1 + d_N\xi} \right)'.$$

From here on, we focus on the case when $p > 1/2$, justified by our assumption that the negative wealth shock (which occurs with probability $1 - p$) is quite rare. This implies that the equilibrium vector is unique.

For reasons of tractability, network models often focus on symmetric networks. In this context we define a network as symmetric if all agents having the same connectivity, d.[20] For symmetric networks, we also have:

Proposition 4 *When the social network is symmetric, equilibrium satisfies $\bar{p}_n = B(\tau, p, d\xi)$, $n = 1, \ldots, N$, so that all agents have the same beliefs and consumption.*

Specifically, in a symmetric network, all agents consume $(\frac{W}{2})B(\tau, p, d\xi)$. It follows that all the results in Proposition 1 generalize to symmetric networks. Moreover, the following results hold with respect to connectivity, d:

Corollary 1 *When the social network is symmetric:*

- *Equilibrium consumption $\bar{c}_0$ is increasing in connectivity, d.*
- *As connectivity, $d \to \infty$, equilibrium consumption approaches $W/2$, corresponding to $\bar{p}_n = 1$ for all n.*

So, overconsumption is more pronounced in more well-connected societies.

4.1 Individual consumption and centrality

The network equilibrium relation (17) suggests that an agent's equilibrium consumption increases in his connectedness, d_n, because the more connections he has, the more weight he puts on his observations and the less weight on his (lower) prior. An agent's consumption is also higher the higher the consumption of the agents he is connected to. The consumption of these neighbors, in turn, tends to be increasing in their connectedness. So an agent's consumption depends upon a potentially unlimited iteration of dependencies, where each stage tends to be increasing with the relevant agents' connectedness.

[20] Most of the many ways of defining network symmetry impose stronger conditions than we do (e.g., that the number of nodes at distance t is the same for any two nodes and any $t \geq 1$).

Measures of *centrality* from network theory are sometimes designed to take into account how many connections the focal agent has, how many connections his neighbors' have, and so forth indefinitely. This suggests that an agent's equilibrium consumption may be increasing with some appropriate concept of network centrality. Well-connected (central) agents should overconsume more.

This idea that better-connected agents will consume more can only be evaluated in a network where agents differ in their connectivity. To examine such effects, we therefore now consider asymmetric networks.

4.2 Core-periphery networks

We study a class of networks in which there is a core of highly connected agents surrounded by peripheral, less connected, agents who are mainly connected to the core. In a social context, we may think of the networks core as highly social agents, with lots of connections among themselves and to others. Such networks are thus asymmetric.[21]

For tractability, we study core-periphery networks in which all core agents have the same number of connections to other core agents, namely $d^C > 0$, and also the same number, $d^P > 0$ to peripheral agents. Each peripheral agent is connected to only one core agent. An example of a network with $d^C = 3$, $d^P = 3$ is shown in Figure 1. Note that d^P also

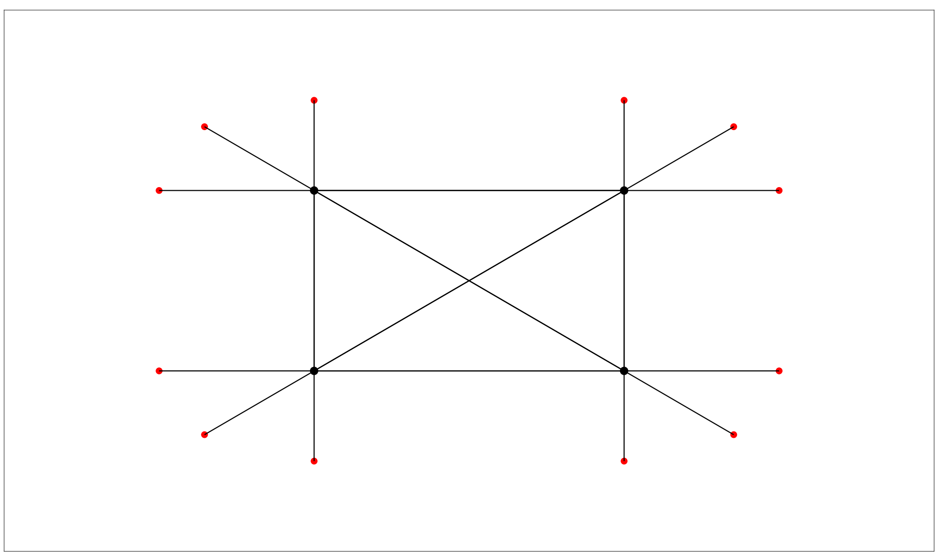

Figure 1: *Core-periphery network, with 4 (black) core agents in center and 12 (red) peripheral agents. Each core agent has $d^C = 3$ connections to other core agents, and $d^P = 3$ connections to peripheral agents.*

[21]Core-periphery networks arise in many different real world contexts, e.g., in over-the-counter dealer networks.

denotes the number of peripheral agents per core agent in the economy.

It follows from Definition 1 that equilibrium probability estimates of the core and peripheral agents, $\bar{p}^C$ and $\bar{p}^P$, satisfy

$$\bar{p}^C = \frac{p + (d^C + d^P)\xi S_\tau\left(\left(\frac{d^C}{d^C+d^P}\right)\bar{p}^C + \left(\frac{d^P}{d^C+d^P}\right)\bar{p}^P\right)}{1 + (d^C + d^P)\xi}, \tag{19}$$

$$\bar{p}^P = \frac{p + \xi S_\tau\left(\bar{p}^C\right)}{1+\xi}. \tag{20}$$

Also, the aggregate consumption in the economy is $\bar{c}_0 = \bar{p}\left(\frac{W}{2}\right)$, where

$$\bar{p} = \left(\frac{1}{d^P+1}\bar{p}^C\right) + \left(\frac{d^P}{d^P+1}\right)\bar{p}^P$$

is a weighted average of the individual agents' probability estimates. Under our assumption that $p > 1/2$, by Proposition 3 that equilibrium is unique. The following result shows how the structure of the core-periphery network determines equilibrium overconsumption.

Proposition 5 *Core agents consume more than peripheral agents, $\bar{p}^C > \bar{p}^P$, and aggregate consumption is increasing in the connectivity of core agents, d^C.*

Proposition 5 shows how the composition of the core-peripheral network influences the amount of aggregate overconsumption in the economy. If core agents are well-connected, overconsumption increases (Part 2). Trends in an economy toward more connected core agents will amplify overconsumption. Our finding that network asymmetry amplifies overconsumption is consistent with the conclusion of **?**) (using somewhat different assumptions) that the high observability of central agents causes aggregate behavior to become more extreme.

4.3 Policy interventions

The model suggests that a relatively simple policy intervention—saliently publicizing aggregate information about the consumption rates of peers—can help alleviate overconsumption. In the model people update based on overestimation of how optimistic others are, and how much others consume. Learning that peers actually save more, such pluralistic ignorance and mistaken updating is reduced.

This is not to say that such an intervention is without challenges. Statistical information, such as the average savings rate in the population, tends to be nonsalient. Even if people pay attention to the statistical information, they may have trouble applying it to their own consumption choices. For example, when someone sees others drinking at Starbucks, it can easily be inferred that others find it reasonable to spend on Starbucks rather than saving money by drinking coffee at home. But when someone is exposed to an abstract statistic, the aggregate savings rate, it is harder to translate that into a judgment about whether to drink at Starbucks.

Empirically, in tests covering a very wide range of activities, the intervention of providing accurate information about peers tends to cause behavior to conform more closely to the disseminated peer norm. For example, in Schroeder and Prentice (1998), college freshmen were informed of either the dangers of heavy drinking, or about the frequencies of the attitudes of other college students about heavy drinking ('peer oriented discussions'). Four to six months later, the discussions of dangers had no effect. In contrast, the students treated with peer-oriented discussions reported drinking less, and were less accepting of pro-drinking norms. The explanation offered by the authors was that students were conforming to a better and more realistic norm.

Other recent research confirms that people misperceive social norms, that these misperceptions have important effects on behaviors, and that correcting these misperceptions can improve outcomes. Bursztyn, González, and Yanagizawa-Drott (2018) report that a very large majority of young married men in Saudi Arabia support female labor force participation outside of home, but substantially underestimate how much similar men support this. In an incentivized experiment, randomly correcting these beliefs about other men's attitudes increases men's willingness to let their wives join the labor force, resulting in greater actual labor force participation by their wives.

If people overestimate the consumption of peers, this argument similarly suggests that salient reporting of actual consumption of peers would reduce consumption.[22]

Consider a variation of the network model, in which all agents receive unbiased information about aggregate consumption, by observing $\bar{p}$ (or an unbiased noisy version thereof), which they incorporate into their Bayesian posteriors. This leads to the following definition of network equilibrium:

Definition 2 *A network consumption equilibrium with public information about aggregate consumption is a vector,* $\bar{\mathbf{p}} = (\bar{p}_1, \bar{p}_2, \ldots, \bar{p}_N)' \in [0,1]^N$*, such that*

$$\bar{p}_n = \frac{p + d_n \xi S_\tau \left(\frac{1}{d_n} \sum_{m \in \mathcal{D}_n} \bar{p}_m\right) + d_n \alpha \bar{p}}{1 + d_n \xi + d_n \alpha}, \qquad n = 1, \ldots, N, \tag{21}$$

where $\bar{p} = \frac{1}{N} \sum_n \bar{p}_n$.

[22] Studies in which peer information promotes conformity toward the disclosed norm include Frey and Meier (2004), Cialdini et al. (2006), Salganik, Dodds, and Watts (2006), Goldstein, Cialdini, and Griskevicius (2008), Cai, Chen, and Fang (2009), Gerber and Rogers (2009), and Chen et al. (2010). However, sometimes people adjust their behavior away from the disclosed actions of others. In an experiment on retirement savings behavior in a large manufacturing firm, Beshears et al. (2015) document that information about the high savings rates of other employees can sometimes lead low-saving individuals to shift away from the disclosed savings rates, which Beshears et al. suggest may derive from a discouragement effect. This result holds only for the subpopulation of employees with low relative incomes who had never participated in the firm's 401(k) plan. Such employees may regard the higher-income employees who were plan participants as not truly peers. So such evidence is not incompatible with our theory.

In this variation, agents' posteriors are based on three components: their priors, their observations, and the public signal. The parameter $\alpha \geq 0$ determines how much weight the agents put on the public signal. When $\alpha = 0$, the extension reduces to the original network model.

Consistent with the previous discussion, one might expect that the presence of the public signal decreases equilibrium overconsumption. Counter-intuitively, however, for an important class of networks this intuition turns out to be false.

Proposition 6 *In any symmetric network, aggregate consumption is unaffected by the weight agents assign to the public signal,* $d\bar{p}/d\alpha = 0$.

The reason for this surprising outcome comes from the fact that an agent's equilibrium belief depends on the prior, not just on the agent's biased observation of others. Agents' consumption observations are higher than aggregate consumption because of visibility bias, but their posteriors are on average below what their observations of others suggest, as agents attribute part of the high observed consumption to randomness. Agents then consume based on posterior beliefs, which on average are equal to $\bar{p}$. It follows that on average the public signal just reconfirms these average posterior beliefs, and therefore has no effect on aggregate consumption.

Proposition 6 provides conditions under which publicizing aggregate consumption data does not help address overconsumption. However, this relies on a crucial assumption of symmetric networks. A key property of such networks is that the average posterior belief is consistent with actual aggregate consumption. This is in general not the case in asymmetric networks. As previously discussed, in our model central agents in asymmetric networks consume more, and also disproportionally influence the consumption of other agents. Therefore, the consumption of the average *observed* agent tends to be higher than the consumption of the average agent. This point is a reflection of the majority illusion in social networks (Lerman, Yan, and Wu 2016), wherein observers disproportionately see the characteristics of better-connected agents. The higher average consumption of observed agents in an asymmetric network makes the public signal informative. The public signal is below that of the average observed agent, so the public signal acts as a corrective to overconsumption.

We verify this effect in the core-periphery network in the previously studied case, where it is easy to verify that $\bar{p}$, and thereby also average consumption, is decreasing in the weight assigned to the public signal.

Result 1 *In a core-periphery network with* $d^C = 3$, $d^P = 3$, $\xi = 1$, $\tau = 2$, *and* $p = 3/5$, *it is easy to verify that* $\bar{p}$, *and thereby also average consumption, is decreasing in the weight assigned to the public signal,* α.

There is a second reason why public disclosure of aggregate consumption can help reduce overconsumption without network asymmetry, which comes from the possibility that there is a smart group of agents. Consider the basic setting of Section 3.2, but suppose now that a fraction ϕ of agents are rational and adjust for visibility bias in their observations. Just as before, assume that the visibility-based agents assume that all agents are rational. Now the average population belief $\bar{p}$, and therefore aggregate consumption, reflects a balance of beliefs. Intuitively, it should be dragged down by the rational agents, and dragged up by the optimism of visibility-biased agents. This suggests that the beliefs of the visibility biased agents are above-average, $\bar{p}^v > \bar{p}$. So a salient disclosure that indicates that the average belief is $\bar{p}$ pulls down the beliefs of the visibility biased agents, and therefore pulls down $\bar{p}$, reducing overconsumption.

A similar point applies if everyone is equally subject to visibility bias, but the members of the ϕ group of agents have strong prior information about p (i.e., their priors reflects more signals). For example, these agents might have studied the statistics on the frequency of expensive illness or of job loss. Then their beliefs will tend to be close to p, and they won't update much when they learn the population average consumption. Once again, before public disclosure, the average population belief $\bar{p}$ should be dragged down by the well-informed agents (beliefs near p), and dragged up by the optimism of visibility-biased agents. A salient disclosure that indicates that the average belief is $\bar{p}$ pulls down the beliefs of the visibility biased agents substantially, and only modestly pulls up the beliefs of the well-informed agents. So overall $\bar{p}$ should decline, reducing overconsumption.

To formalize these intuitions minimally, consider the case in which the smart agents (whom we have described as either rational or as well-informed) know the true p. Then the biased agents observe $S_\tau(\phi p + (1-\phi)\bar{p}^{VB})$, and therefore update so that their average belief is $\bar{p}^{VB} = (p + \xi S_\tau(\phi p + (1-\phi)\bar{p}^{VB}))/(1+\xi)$. So publicizing a (potentially-noisy) public signal about $\bar{p} = \phi p + (1-\phi)\bar{p}^{VB} < \bar{p}^{VB}$ decreases aggregate consumption.

Proposition 7 *Consider the modification of the base model from Section 3.2 in which there is a fraction ϕ of agents who know the true probability p of no disasters. Then, average consumption is decreasing in the weight, α, that agents with visibility bias assign to the public signal.*

When we consider our extension to a setting with overlapping generations, we will see why a different kind of disclosure—of the consumption of only a subset of the population—can also help address the problem of overconsumption.

5 Extensions

Both to address the generality of our conclusions and to address interesting additional issues, we now consider extensions of the base model which, for tractability, make some stronger assumptions.

First, as a matter of robustness, we consider other utility functions in Appendix B.

Second, in reality people differ in age, and someone who has saved heavily when young will have more resources for consuming when old. This raises the question of whether overestimation of the consumption of the old might lead to an inference of high past saving and a *bad* state of the world instead of a good one. We address this topic in Subsection 5.1.

Third, we make a technical extension which is useful for the other extensions. Our base model made the assumption that when the agent is maximally optimistic, and therefore consumes $W/2$ at date 1, that this involves consumption in all bins. More generally consumption of $W/2$ might still leave some bins empty. We analyze this in Subsection 5.2.

Fourth, in reality people differ in their wealths, which changes the learning problem because observed consumption in many bins is an indication that the targets of observation have high wealth, not just favorable signals about the state. This leads to empirical implications about wealth dispersion and overconsumption in Subsection 5.3.

Finally, we have so far assumed a fixed riskfree interest rate. We extend the base model to include upward sloping supply of bonds in Subsection 5.4. We show that overconsumption is obtained in this setting too, and that interest rates are higher when visibility bias is present than when it is not.

For the variations we study in this section, we make the additional assumption that the number of prior and consumption observations, Q and M, are very large, so that agents' priors are very close to p and z_n is very close to $E[z]$. The fraction $\xi = \frac{M}{Q}$ is still an arbitrary positive number. We may think of this as studying the limit of a sequence of economies as $Q \to \infty$, with $M = \xi Q$ in each economy.

5.1 Age Differences: An Overlapping Generations Setting

In the base model all agents make their savings decision at the same time, and are homogeneous in age. In practice, we would expect young agents to observe the consumption of both young agents and old agents who saved earlier and are now consuming their savings. What inference does a young agent draw if old agents' consumption seems to be unexpectedly high? One possibility is that old agents saved a lot when they were young, because they viewed the risk of a wealth disaster as high. Alternatively, it could be that in the current period many old agents are experiencing the good state (no disaster), and therefore have high resources available for current consumption. These effects promote opposite inferences, so a priori it is unclear which effect dominates.

To address this issue, we extend the base model to include an overlapping generations (OLG) structure in which there are both young and old agents at any given point in time. Specifically, the fraction $\lambda \in [0, 1]$ of the population is young and the remaining fraction $1 - \lambda$ is old. The case $\lambda = 1$ corresponds to the base model. Since all agents live exactly two dates, we can think of λ as a summary statistic for population growth. The population pyramid will be such that λ is high in rapidly growing populations.

Young agents observe a random sample of consumption from each cohort, i.e., λM observations are from the young generation, and $(1 - \lambda)M$ from the old.[23] For each observation, they know which type they are observing. Visibility bias, as previously specified in (7), is present for both type of observations.

[23] More broadly, if people spend larger fractions of their lives as young people than as seniors, λ can be viewed as being a correspondingly larger than the fraction of young people, to reflect the fact that young people have a longer period to be targets of observation.

We study stationary equilibrium in which the average estimated probability of the good state, $\bar{p}$, is constant over time. Moreover, we assume that the ϵ shock is independent across agents (though still identical in distribution), to avoid systematic variations in aggregate consumption across time. Given a cohort's estimated $\bar{p}$ when young and their associated consumption of $\bar{p}\left(\frac{W}{2}\right)$, by the law of large numbers their average consumption in the next period, when old, is $(2p-\bar{p})\left(\frac{W}{2}\right)$, where p is the true probability. When $\bar{p} > p$, there is underconsumption by the old generation compared with the social optimum, $pW/2$, since $2p - \bar{p} < p$. Without visibility bias, by reasoning similar to that leading to (8) equilibrium average beliefs satisfy

$$\bar{p} = \frac{p + \xi[\lambda\bar{p} + (1-\lambda)(2p-\bar{p})]}{1+\xi}, \tag{22}$$

which has the unique solution $\bar{p} = p$. In this equilibrium, agents in both cohorts consume on average $pW/2$, observations of young and old consumption are consequently equally informative, and young agents update accordingly.

Intuitively, on the RHS, for given p, higher $\bar{p}$ is associated with higher consumption by the young, which increases the average inference from observation of the bins of the young (as reflected in the first term within the brackets). But higher $\bar{p}$ also reduces the consumption of the old, which contributes negatively to the inference (the second term within the brackets). These effects balance when $\bar{p} = p$.

When there is visibility bias, observation of the bins of the young and the old are biased toward full bins, as reflected in the S_τ function, so the equilibrium condition (22) is replaced by

$$\bar{p} = \frac{p + \xi S_\tau[\lambda\bar{p} + (1-\lambda)(2p-\bar{p})]}{1+\xi}. \tag{23}$$

This is the OLG extension of the model with visibility bias. The expression reduces to (22) when $\tau = 1$.

Proposition 8 *In the OLG extension of the model with visibility bias, there is a stationary equilibrium satisfying the following properties:*

1. *The equilibrium probability estimate of the young generation satisfies $\bar{p} > p$, so the younger generation overconsumes.*

2. *The equilibrium probability estimate, $\bar{p}$ is increasing in the fraction of young agents, λ.*

3. *When $\lambda = 0$,*

$$\begin{aligned} \bar{p} &= \frac{1 + \xi(\tau+1) + p(3+2\xi)(\tau-1) - \sqrt{V}}{2(1+\xi)(\tau-1)}, \qquad \textit{where} && (24)\\ V &= (1 + \xi(\tau+1) + p(3+2\xi)(\tau-1))^2 - \\ &- 4p(1+\xi)(\tau-1)(1+2p(\tau-1)+2\xi\tau). && (25) \end{aligned}$$

An implication of Proposition 8 is that we expect overconsumption to be more severe in economies with rapid population growth.

Figure 2 shows the equilibrium probability estimate, $\bar{p}$ as a function of the true probability, p, for the limiting cases $\lambda = 0$ (given by (24-25)) and $\lambda = 1$ (given by (12-13)). When $0 < \lambda < 1$, the equilibrium lies between the two increasing concave curves, and is increasing in λ for a fixed p.

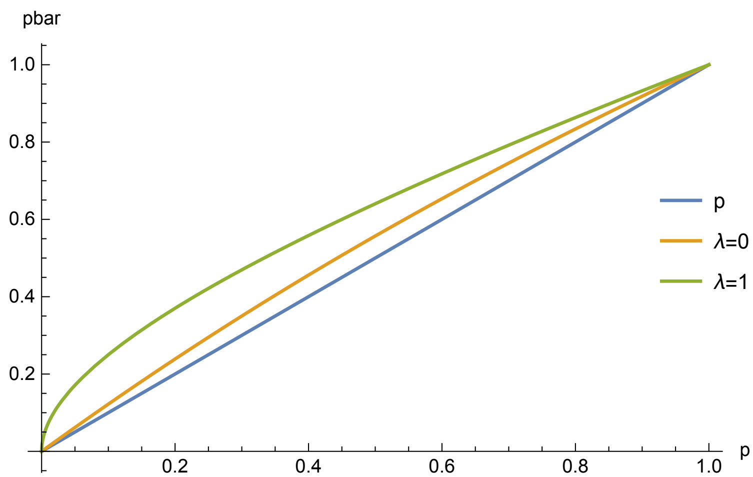

Figure 2: *Equilibrium overconsumption in OLG model with visibility bias. The figure shows equilibrium without overconsumption ($\bar{p} = p$; Parameter: $\tau = 1$), with overconsumption and large fraction of old ($\lambda = 0$), and with overconsumption and large fraction of young ($\lambda = 1$). When $0 < \lambda < 1$, the equilibrium lies between $\lambda = 0$ and $\lambda = 1$, and is increasing in λ. Parameters: $\tau = 2$, $\xi = 1$.*

At the start of this subsection we suggested that the inference drawn from observing the old is potentially mixed, but it turns out that the effect in equilibrium is unambiguous. Intuitively, consider the case when there is no visibility bias, and suppose that all agents (except for one focal agent that we set aside) overestimate the probability of no shock, $\bar{p} > p$. The focal agent who observes the consumption of other both young and old agents will be prone to overestimating p based on observing many full bins belonging to the overconsuming young, but underestimate p from observing many empty bins of the underconsuming old. The two effects offset each other so the focal agent will (in expectation) not overconsume. A similar point applies if $\bar{p} < p$, so the stability occurs when $\bar{p} = p$, corresponding to efficient equilibrium consumption.

When visibility bias is present, the focal agent observes the fraction $S_\tau(\lambda\bar{p} + (1 - \lambda)(2p - \bar{p}))$. A higher $\bar{p}$ leads to more observed bins with consumption of the young (the $\lambda\bar{p}$ term), pushing the focal agent's estimate higher, and fewer of the old (the $(1 - \lambda)(2p - \bar{p})$ term), pushing it down. So superficially it might seem that the effect of visibility bias on equilibrium consumption is ambiguous.

To understand why underconsumption is ruled out in equilibrium, recall that optimally agents split in half their expected wealth (net of disasters) between the two dates. So it is when p is high that, in a rational equilibrium, average consumption of the old is high. (Recall that all agents think they are living in this rational world.) Owing to visibility bias, the young think they see evidence of heavy consumption by others. Suppose, for example, that $\lambda = 0$ so that observers only see the old. Owing to visibility bias, there is on average a conclusion of heavy consumption by the old (corresponding to high p). In particular, the young will on average infer $\bar{p} > p$.[24] So young observers conclude that p must be high (i.e., their average inference is $\bar{p} > p$, and that the old consumed equally heavily when young, i.e., that past saving was low. Based on their average overestimate of p, the young overconsume.

This intuition makes clear why in equilibrium, overconsumption is greater when observation is more heavily tilted toward the young (λ high). Relative to observation of the young, observation of the old acts as a partial reality-check on belief bias. Observers mistakenly think that on average consumption is equally divided between an agent's youth and old age, but owing to overconsumption, in equilibrium average consumption is actually lower when agents are old. So observations of the young are on average higher than observations of the old. This leads to more favorable inferences about p, and therefore greater overconsumption.

This intuition can also be verified with more detailed correspondence to updating formulas. Assume in contradiction to our result that $\bar{p} < p$ and consider the $\lambda = 0$ case, so that the young exclusively observe the old. It follows that $S_\tau(\lambda\bar{p} + (1-\lambda)(2p - \bar{p})) \geq \lambda\bar{p} + (1-\lambda)(2p - \bar{p}) = (2p - \bar{p}) > p$. The focal young agent therefore draws an optimistic inference about p and overconsumes. The young agent understands that the apparent high consumption of the old is due in part to high saving by the old when young. But the young also view high consumption of the old as reflecting favorable evidence that few of the old were hit by disaster. Overall, owing to visibility bias, the young think the old are consuming heavily, which results in a favorable inference about disaster risk. Since this argument can be made for each agent when young, the average probability estimate $\bar{p}$ must be greater than p, contradicting the original assumption, so $\bar{p} > p$.[25] Since equilibrium consumption is increasing in λ, there is also overconsumption when $\lambda > 0$.

These findings suggest that salient public disclosure of the consumption of the old can help address the problem of overconsumption. This intervention differs from that considered earlier, as it involves disclosing the average consumption of a subset of the population, not of the entire population. The effect of such disclosure is effectively to push the model in the direction of low λ (in which there is more observation of consumption of the old). As

[24]To see this, suppose that despite visbility bias, the average inference were $\bar{p} < p$. This could only happen if the old had a low level of current consumption. That in turn can only happen if they saved little, so that their consumption when young correspondend to a belief $\bar{p} > p$. This is inconsistent with a steady state outcome.

[25]In contrast, when $\bar{p} > p$ and $\lambda = 0$, $(2p - \bar{p}) < p$, but since $S_\tau(x) > x$, it can still be the case that $S_\tau(\lambda\bar{p}+(1-\lambda)(2p-\bar{p})) > p$, so the focal agent may still tend to overconsume when there is underconsumption of the old. Overconsumption can therefore be sustained in equilibrium.

we have shown, lower λ decreases aggregate consumption. It is interesting that even when disclosing aggregate consumption does not help, disclosing the consumption of the right subset of the population does help–but does not fully remedy the problem. At best it only reduces consumption to that of the $\lambda = 0$ case.

The parameter λ may not only depend on the population pyramid. The young might, for example, disproportionately observe each other rather than the old, owing to homophily (the tendency for people to interact with others who are similar), leading to lower λ. On the other hand, the old may act as role models for the young, leading to higher λ. In either case, there is overconsumption in equilibrium. As we have seen, observation of the young drives greater overconsumption, but even if the young were to observe only the old (so that $\lambda = 0$), overconsumption occurs in equilibrium.

5.2 Different fraction of consumption bins

The assumption that an agent consumes in all bins when $c_0 = W/2$ makes the analysis tractable, since the calculus of Bayesian updates with Beta distributed priors and observations is straightforward. A generalization is to assume that when $c_0 = W/2$, a fraction $0 < f \leq 1$ of the bins are full. This allows us in subsequent sections to analyze situations where there is heterogeneity in consumption behavior, for example, because of wealth dispersion. Specifically, if a rich agent with probability estimate $\hat{p} = 1$ consumes in 100% of the consumption bins, then a poor agent with the same probability estimate will consume strictly less. The base model assumes $f = 1$, leading to the posterior estimate (8).

The following proposition covers the case when $f < 1$:

Proposition 9 *The posterior expected probability of high consumption of an agent with prior p, who observes fraction z of bins being full, where each bin is full with probability pf, is*

$$\begin{aligned} \hat{p} &= R(p, z, \xi, f) \\ &= \frac{1}{2f(1+\xi)}\Big(1 + fp + f\xi + z\xi - \\ &- \sqrt{(1 + fp + f\xi + z\xi)^2 - 4f(1+\xi)(p + z\xi)}\Big). \end{aligned} \tag{26}$$

It is easy to verify that when $f = 1$, (26) reduces to the base model formula, $\hat{p} = \frac{p+\xi z}{1+\xi}$. Also, when $z = fp$, the formula reduces to $\hat{p} = p$, since the fraction of full bin observations is consistent with the prior in this case. Moreover, R is increasing in p and z, and is decreasing in f, since the lower f is, the lower the expected value of z is for a given prior p, which makes any given number z of observed full bins a more favorable indication about p.

Using similar arguments as before, an equilibrium probability estimate when visibility bias is present is then defined as a solution to the fixed point equation:

$$\bar{p} = R(p, S_\tau(\bar{p}f), \xi, f). \tag{27}$$

We now have

Proposition 10 *There exists a unique equilibrium with overconsumption, in which the equilibrium probability estimate is*

$$\bar{p} \;=\; B(1 + f(\tau - 1), p, \xi), \tag{28}$$

where the function B *is defined in (11,12).*

The comparative statics from the base model therefore also hold in this variation. Moreover, increasing f has the same effect as increasing τ. Both lead to more overconsumption in equilibrium.

Corollary 2 *The equilibrium probability estimate,* $\bar{p}$ *is increasing in the consumption fraction,* $\partial\bar{p}/\partial f > 0$*, as is the overconsumption factor,* $\bar{p}/p$*.*

5.3 Information Asymmetry about Wealth

So far, we have assumed that all agents have the same initial wealth, W. We now generalize to allow for wealth dispersion in the population, and ingnorance of the wealths of others. Intuitively, the inference an observer draws about the information of others based on observation of another's consumption is weaker if the observer does not know the target's wealth, because when someone observes high consumption, this could come from either a favorable signal about the state or from high wealth of the target(s) of observation. They will therefore not revise their estimate of p as aggressively upward when they observe "too much" consumption as they do when there is no wealth dispersion. Wealth dispersion therefore reduces equilibrium overconsumption. This contrasts sharply with the Veblen wealth-signaling approach, in which it is precisely the fact that there is uncertainty about wealth that causes overconsumption to serve as a signal.

To explore the effects of wealth dispersion, we study an economy in which the consumption fraction is $f < 1$. Moreover, a fraction λ of the population has wealth $(1 + \Delta)W$ (the wealthy fraction), where $\Delta > 0$, and $(1 + \Delta)f < 1$, a fraction λ has wealth $(1 - \Delta)W/2$ (the poor fraction), and the remaining fraction $1 - 2\lambda$ has wealth W (the medium fraction). The average wealth is then still W, but the higher Δ is, the higher the economy's wealth dispersion. The consumption fraction must be less than one, as otherwise the wealthy group would potentially consume more than 100% of the consumption bins. We therefore assume that Δ is not too large. Specifically, we assume that

$$\Delta \leq \frac{1}{1 + \frac{1}{(\tau-1)\left(1-\frac{p}{2}\right)}}. \tag{29}$$

For large τ, this restriction is very weak, basically implying that no agent has negative wealth or wealth very close to zero.

Agents know the economy's wealth distribution (λ and Δ), and for simplicity we assume that all their consumption bin observations come from observing the same wealth type (e.g., they may only observe the consumption of one other agent). An agent who observes the consumption fraction z then forms his posterior beliefs about p, taking into account that when observing higher consumption than expected it may be due to the observed agents being wealthier than average.

The following lemma characterizes the equilibrium probability estimate:

Lemma 1 *The equilibrium probability estimate is the solution to the equation*

$$\begin{aligned}\bar{p} &= qR(p, S_\tau(f\bar{p}(1-\Delta)), \xi, f(1+\Delta)) \\ &+ (1-2q)R(p, S_\tau(f\bar{p}), \xi, f(1+\Delta)) \\ &+ qR(p, S_\tau(f\bar{p}(1+\Delta)), \xi, f(1+\Delta)). \end{aligned} \tag{30}$$

The lemma states that an agent who observes higher-than-expected consumption updates beliefs based on the possibility that the agent is observing wealthy agents (who consume the fraction $\bar{p}f(1+\Delta)$ of bins rather than the average, $\bar{p}f$). The reason why the agent updates completely toward observing wealthy agents is that the number of observations Q and M are large. The observer finds the strength of the evidence of high consumption very surprising; the likelihood is low under the hypothesis that observations are of either high or low wealth agents. But the likelihood is especially low when the observation targets have low wealth, so the posterior belief puts all the weight on observing wealthy agents.

The following proposition confirms the intuition that wealth dispersion reduces overconsumption:

Proposition 11 *The equilibrium probability estimate $\bar{p}$ is decreasing in wealth dispersion, $\partial\bar{p}/\partial\Delta < 0$, as is the overconsumption fraction.*

Proposition 11 predicts that savings rates increase with wealth dispersion. This is the opposite of what is expected based upon Veblen wealth-signaling considerations. In the Veblen approach to overconsumption, people consume more in order to signal the level of wealth to others (Bagwell and Bernheim 1996; Corneo and Jeanne 1997). Greater information asymmetry about wealth intensifies the effect, by increasing the potential improvement in wealth perceptions that can be achieved by signaling. This is reflected, for example, in the finding of Charles, Hurst, and Roussanov (2009) that an increase in wealth dispersion that takes the form of a reduction in the lower support of wealth results in greater signaling. What we expect to apply quite generally in Veblen-style models is that wealth signaling through consumption vanishes when wealth dispersion is zero. So such models reflect a general tendency for greater wealth dispersion to induce greater overconsumption, though not necessarily monotonically.[26]

For example, in the limiting case of no information asymmetry, the Veblen effect would disappear and people would consume only for their direct utility benefits. More generally,

[26] Consistent with this idea, Charles, Hurst, and Roussanov (2009) find that greater dispersion of reference group income is associated with higher visible spending for minorities. On the other hand, they report that higher dispersion in reference group income significantly lowers White visible spending. The latter result is consistent with our theory.

in a simple setting in which the upper bound of the support of the wealth distribution becomes higher, then the range of possible equilibrium consumption signal levels is higher, so there will be more overconsumption on average.

Using survey evidence from Chinese urban households, Jin, Li, and Wu (2011) find that greater income inequality is associated with lower consumption and with greater investment in education, where income inequality is measured within age groups by province. Similarly, using high geographical resolution 2001-12 data, Coibion et al. (2014) provide strong evidence that low-income households in high-inequality U.S. locations accumulated less debt (relative to income) than their counterparts in lower-inequality locations. These findings are consistent with the visibility bias approach, in contrast with the implication of wealth-signaling via consumption, or with the intuitive idea that low income individuals borrow and consume more in order to try to keep up with high income households.[27]

Our approach also implies contagion in consumption across individuals with different wealths. Using state-level survey data, Bertrand and Morse (2016) document that increased income of the top quintile or decile in the income distribution is associated with more consumption by less wealthy individuals. In our approach, when the wealths of others are imperfectly observable, such contagion in consumption occurs because individuals who see high consumption of others attribute this in part to low disaster risk rather than high wealth. The authors further find that non-rich households' consumption of more visible goods and services is especially responsive to increases in top-end wealth, consistent with visibility bias effects of the type that we model. However, contagion in consumption is also implied by some versions of the Veblen and keeping-up-with-the-Joneses approaches to overconsumption.

Several studies report that wealth dispersion has increased in the United States since the 1980s (e.g. Card and DiNardo (2002), Piketty and Saez (2003), Lemieux (2006)). Given an increase in wealth dispersion, all else equal, Proposition 11 counterfactually implies a rising savings rate. However, all else was not equal. We believe that a much more important shift (from the standpoint of the effects in our model) has been the dramatic transformation of electronic communications and social networks. As discussed in Section 3.2, this has increased the visibility of the consumption activities of others (both absolutely, and relative to non-consumption), which implies greater overconsumption in our model.

Furthermore, the effects of wealth dispersion here derive from the unobservability of others' wealths rather than dispersion per se. In some countries, the rise of the internet has made obsersvation of others' wealths or incomes easier than in the past through search of government or other archives. A reduction in information asymmetry about wealth implies greater overconsumption, because people attribute their high observations of others'

[27]We are not aware of any results in the standard keeping-up-with-Joneses model relating overconsumption to wealth dispersion (especially holding constant the average level of wealth). A variant of the keeping-up-with-Joneses approach where a given household's consumption is directly positively affected by the consumption of the households whose income is just above theirs can generate an expenditure cascade, resulting in a negative relationship between income inequality and the savings rate of non-rich households (Bertrand and Morse 2016).

consumption to favorable information possessed by others rather than to high wealths. This wealth dispersion effect actually reinforces the other effects we've described, implying a shift over time toward greater overconsumption.

Another approach that can lead to overconsumption derives from expectations of profiting based upon disagreement, as pointed out in Heyerdahl-Larsen and Walden (2016). If agents have heterogeneous beliefs and speculate against each other in the market, they may all believe that they will be wealthy in the future, although they cannot all be correct. If agents' elasticity of intertemporal substitution is less than one, this wealth effect will lead to overconsumption compared the aggregate consumption level that all agents know is optimal from a societal perspective. This is thus a speculation effect.

Although our model allows for difference in beliefs, our overconsumption finding is not driven by this speculative effect. In our model agents are borrowing and lending, but not speculating on the occurrence of wealth disasters.[28]

As in this paper, in their model the speculation effect will be less pronounced when there is high wealth dispersion. When wealth is concentrated, there are less opportunities for the wealthiest agents—who disproportionally determine aggregate consumption—to speculate, since they own such a large fraction of total wealth. So the two approaches share the prediction that higher wealth dispersion is associated with higher overconsumption. The two explanations can be distinguished empirically by relating consumption rates to proxies for speculative belief disagreement in the market. For example, trading volume in the stock market and open interest in options markets have been used as proxies for disagreement. Overconsumption should then be positively related to measures of heterogeneous beliefs if speculation is its cause, whereas no relation is predicted if visibility bias is the cause of overconsumption. At the individual investor level, overconsumption should be more prevalent among agents that participate in speculative (e.g., options) markets, whereas there is no such link under visibility bias. Also, our model derives a variety of other distinctive implications about how social network connections affect overconsumption, and the effects of pluralistic ignorance and disclosure.

5.4 The Equilibrium Interest Rate

In the base model, the riskfree rate is exogenously set to zero. This corresponds to having storable consumption or, equivalently, to having riskfree bonds in perfectly elastic supply offered at a zero interest rate. We now modify the model to allow for endogenous determination of the interest rate.

The base model is highly tractable, but when the interest rate can vary, potentially a high interest rate could imply negative date 0 consumption. That does not correspond well with the idea that at worst all consumption bins are empty. We therefore make further adjustments to the model to prevent this possibility.

[28]Even if wealth disasters were systematic, apart from random variations (which can be very small if Q and M are large), agents have essentially the same (wrong) beliefs about p, and will therefore not bet against each other. Neither will they buy insurance against ϵ shocks at the unbiased market value.

As in the base model, agent utility is defined by

$$U = c_0 - \left(\frac{\alpha}{2}\right) c_0^2 + E\left[c_1 - \left(\frac{\alpha}{2}\right) c_1^2\right], \tag{31}$$

where we focus on the case where $\alpha = 1/2$. Given a one-period interest rate of r, an agent's budget constraint is now

$$c_1 = (1+r)(W - c_0) - \epsilon, \tag{32}$$

For tractability, in this section we assume a less severe bad outcome than in the base model, so that time-0 consumption remains nonnegative for a larger range of interest rates. We therefore assume that

$$\epsilon = \begin{cases} 0 & \text{with probability } p \\ \frac{W}{2} & \text{with probability } 1-p, \end{cases} \tag{33}$$

and without loss of generality we focus on the case $W = 1$.

Solving for the optimum of an agent whose probability estimate for a high outcome is $\hat{p}$ yields consumption

$$\frac{1 - r + 2r^2 + (1+r)\hat{p}}{4 + 4r + 2r^2} \stackrel{\text{def}}{=} g + f\hat{p}, \tag{34}$$

with g and f defined in the obvious way. With average agent probability estimate of $\bar{p}$, aggregate per capita consumption is then

$$\bar{c}_0 = g + f\bar{p}. \tag{35}$$

We assume that there is an equally large set of investors who are not exposed to ϵ risk, i.e., for whom $c_1 = (1+r)(1-c_0)$. We can think of them as institutional investors. Since they have no disaster risk, their consumption does not depend on their inferences about p. Their main role in the model is to provide someone for the other investors to trade with, so that even in our exchange economy, beliefs can have an effect upon the per capita consumption of the focal agents. In othe words, when individual investors become overoptimistic, in addition to any equilibrium effect on the interest rate, they can in equilibrium potentially borrow more and overconsume.

Institutional investors investors are willing to lend to (or borrow from) the agents that are the main focus of our analysis. Since they have no disaster risk, the optimal time-0 consumption of institutions, given r, is

$$\bar{c}_0^I = \frac{1 + r^2}{2 + 2r + r^2}. \tag{36}$$

We assume free disposal of the consumption good, so the equilibrium interest rates satisfies $r \geq -1$. We focus on the region of interest rates in which the institutional investors' lending increases in the interest rate, and therefore require that $r \leq 1/2$.[29]

[29]For $r > 1/2$ it is easy to verify that lending decreases in the interest rate. This comes from the standard result in intertemporal choice that an increase in the interest rate has both a substitution effect (which encourages lending) and a wealth effect (which can discourage lending). To illustrate basic insights simply, we focus on the case in which the substitution effect, which is highly intuitive, dominates.

The aggregate endowed quantity of the time-0 consumption good per individual investor, $\bar{c}^e$ is fixed. Specifically, we assume that the total endowment is such that in an equilibrium with unbiased beliefs (i.e., $\bar{p} = p$), the market clears at interest rate $r = 0$. The market clearing condition is

$$\bar{c}^e = \bar{c}_0^I + \bar{c}_0, \tag{37}$$

where the terms on the right are functions of r. By (35,36), and by our assumption the endowment is such that when $r = 0$ a market with unbiased investors would clear, we have

$$\bar{c}^e = \frac{1}{2} + \frac{1+p}{4}, \tag{38}$$

so the general market clearing condition becomes

$$\bar{c}_0^I + \bar{c}_0 = \frac{1}{2} + \frac{1+p}{4}. \tag{39}$$

The LHS is the aggregate per capita endowed consumption.

If, owing to visibility bias, $\bar{p} \neq p$, market clearing implies that r must adjust so that aggregate demand is unchanged, i.e., is equal to the endowment, so in equilibrium

$$\bar{p} = \frac{(8-5r)r + p(2+2r+r^2)}{2(1+r)}. \tag{40}$$

It is easy to verify that $\bar{p}$ is strictly increasing in r in the relevant region of r.

Along the lines of the arguments in the base model, given r and $\bar{p}$, the fraction of bins that contain consumption is given by (35). Since agents suffer from visibility bias, they *observe* the fraction $S_\tau(g + f\bar{p})$. By Bayes rule, the agents then arrive at the posterior probability estimate

$$\hat{p} = R(p, z, \xi, f, g), \tag{41}$$

given that the fraction of bins that agents observe are full is z, where the function R is defined in the appendix (see the proof of Proposition 12). An equilibrium is then an outcome in which markets clear, so that (35) holds, and agents' posterior beliefs are in line with their biased observations, $\bar{p} = R(p, S_\tau(g + f\bar{p}), \xi, f, g)$. For tractability, we focus on the case when $\xi = 1$ (so that agents put comparable weight on prior information and on social observations).

As a benchmark for comparison, suppose that consumption can be stored, and that institutional investors are excluded from the model. Then equilibrium can be solved for using an approach similar to that in Section 5.2.

The analysis is similar to that in the base model, except that the Bayesian updating rule used by agents is based on the bin observations having probability $g + fp$ of containing consumption, with $g = \frac{1}{4}$ and $f = \frac{1}{4}$ (rather than $g = 0$ and $f = 1$ in the base model). It is straightforward to verify that equilibrium consumption in this benchmark case is

$$\bar{p}^B = B_g(1 + f(\tau - 1), p, 1, 1 + g(\tau - 1)), \tag{42}$$

where the function B_g was defined in (14,15), and where the superscript "B" stands for "Benchmark." It is also straightforward to verify that the behavior of $\bar{p}^B$ is very similar to that in the base model. For example, it is increasing in τ.

It is now possible to show the existence of equilibrium with the following properties:

Proposition 12 *Under the above assumptions:*

1. *The average estimated probability of the good state lies between the unbiased $\tau = 1$ outcome, p, and the benchmark outcome, $\bar{p}^B$, i.e., there is overconsumption.*

2. *The average estimated probability of the good state is strictly increasing in visibility bias, τ.*

3. *The interest rate, r, is positive and strictly increasing in visibility bias, τ.*

6 Concluding Remarks

We examine how social influence endogenously shapes how people trade off current versus future consumption. In our model, people observe the consumption activities of others and use this to update beliefs about whether there is a high or low need to save for the future. Consumption is more salient than non-consumption, resulting in greater observation and cognitive encoding of others' consumption activities. This visibility bias makes episodes of high consumption by others more salient and easier to retrieve from memory than episodes of low consumption. So owing to neglect of selection bias (and a well-known manifestation of it, the availability heuristic), people infer that low saving is a good idea. This effect is self-reinforcing at the social level, resulting in overconsumption and high interest rates. With many opportunities to observe others, this feedback effect can be arbitrarily strong. The effects in the model can also bring about pluralistic ignorance about the savings rates of others, wherein people think that others are consuming even more heavily than they really are.

The visibility bias approach offers a simple explanation for one of the most puzzling and important stylized facts about household finance: the dramatic drop in personal saving rates in the U.S. and many other OECD countries over the last 30 years. In the model, greater observability of the consumption of others intensifies the effects of visibility bias, and therefore increases overconsumption. We argue that over the last thirty years the decline in costs of long-distance telephony, the rise of cell phones, cable television and urbanization, and subsequently the rise of the internet, dramatically increased the extent to which people observe possible personal consumption activities of others by television enactment, phone, email, blogging, and social networking. Specifically, this communication is biased toward making the decision to engage rather than not engage in such activities more salient to others, because travel, dining out, or buying a car tend to be relatively noteworthy to report upon.

In contrast with the present bias (hyperbolic discounting) theory of overconsumption, the effects here are induced by social observation and interaction. Our approach can therefore be distinguished from present bias using proxies for sociability and observability, such as urban versus rural, and survey responses about sociability (see, e.g., Hong, Kubik, and Stein (2004), Brown et al. (2008), Christelis, Georgarakos, and Haliassos (2011), and Georgarakos and Pasini (2011)). Our approach also differs in offering predictions about how population-level characteristics such as wealth variance affect consumption.

Also, our visibility bias approach is not based on a link between an agent's participation in speculative markets and his overconsumption, in contrast to overconsumption associated with heterogeneous beliefs as in Heyerdahl-Larsen and Walden (2016).

The effect of wealth dispersion in our model contrasts with the implications of the Veblen and keeping-up-with-the-Joneses approaches. In at least some versions of the latter approach, wealth dispersion encourages the poor to consume more in emulation of the wealthy. The Veblen wealth-signaling approach broadly implies that a comparative statics shift from certainty to information asymmetry about others' wealths (i.e., a rise in wealth dispersion) implies greater overconsumption. In our setting greater information asymmetry dilutes the inference from high observed consumption that others have favorable information about the risk of a wealth disaster. In consequence, equilibrium consumption is *lower*, the opposite prediction. The visibility bias approach also helps explain high variation in savings rates across countries and ethnic groups, because even modest differences in beliefs can be amplified through social influence.

In contrast with the signaling, preference-based, and speculative disagreement approaches, our social learning bias approach implies that a relatively simple policy intervention can potentially increase saving. The relevant intervention is to provide—in highly salient form—accurate information about how much peers save, or their attitudes toward consumption. Indeed, there is evidence discussed earlier supporting this implication in specialized settings, such as the decisions of college students of how much to drink.

Advertising and media biases can further reinforce overconsumption for reasons very similar to those that we model. Advertisers have an obvious incentive to depict consumers using their products heavily. News media serve their clientele by highlighting interesting high-end products or of consumption events (consider, e.g., the 'Travel' section of newspapers). These further contribute to the higher visibility of consumption than nonconsumption. Of course, there is advertising of financial saving vehicles as well. But it is much easier to vividly depict individuals consuming heavily at restaurants or exotic locations than to depict individuals saving heavily.

The model in this paper is static. An interesting extension would be to consider a dynamic model in which agents update and consume over time, potentially leading to cyclical shifts in overconsumption. An interesting question is whether such fluctuations can help explain local consumption booms, and dynamics features of the macroeconomy such as business cycles. This might potentially provide an interesting contrast to Keynesian ideas about business cycles deriving from resource underutilitization and underconsumption.

Appendices

A Proofs:

Proof of Proposition 1: Part 1 follows from noting that (11,12) implies that $\bar{p} = p$ if and only if $-4(1-p)p(\tau-1)^2\xi(1+\xi) = 0$, which holds if and only if $\tau = 1$. Now that $\frac{\partial \bar{p}}{\partial \tau} > 0$ can be seen by substituting $x = \frac{1}{\tau - 1}$, noting that x is decreasing in τ, and taking the derivative w.r.t. x, leading to $\frac{\partial \bar{p}}{\partial x} = \left(x + p - \xi + 2p\xi - \sqrt{(p - x + \xi)^2 + 4px(1+\xi)}\right) r(x)$, where $r(x) > 0$. It then follows from the fact that $(x + p - \xi + 2p\xi)^2 - ((p - x + \xi)^2 + 4px(1+\xi)) = -4(1-p)p\xi(1+\xi) < 0$, that $\frac{\partial \bar{p}}{\partial x} < 0$, and thus $\frac{\partial \bar{p}}{\partial \tau} > 0$. Parts 2 and 4 follow immediately by taking the limit of (11,12) as ξ and τ become large. To show Part 3, note that $\bar{p}$ can be written as

$$\bar{p} = \frac{m + \sqrt{m^2 + 4(k+m)p}}{2(k+m)} \stackrel{\text{def}}{=} V(m),$$

where $m = (p + \xi)(\tau - 1) - 1 > -1$, and $k = (1-p)(\tau - 1) + 1 > 1$. Since $\frac{\partial m}{\partial \xi} > 0$, it is therefore sufficient to show that $V'(m) > 0$ when $m > -1$. By calculating $V'(m)$, it follows that $-2mp + k(m - 2p + \sqrt{m^2 + 4p(k+m)}) > 0$ is necessary and sufficient for $V'(m) > 0$ to hold. For $m = 0$, the expression evaluates to $V'(0) = k(-2p + 2\sqrt{kp}) > 0$. Moreover, the solution to $V'(m) = -2mp + k(m - 2p + \sqrt{m^2 + 4kp + 4mp}) = 0$ is $m_{+/-} = -k < -1$. Thus, since V' is a continuous function of m, $V'(m) > 0$ for all $m \geq -1$. We also verify the informal statement in the text after the proposition about increasing p by calculating $\frac{\partial \bar{p}}{\partial p} = \frac{1}{2(1+\xi)} + \frac{1}{2\sqrt{V}}\left(2 + \frac{1}{1+\xi}((\tau - 1)(p + \xi) - 1)\right)$, which is obviously positive for $p \in [0, 1]$, since $2 + \frac{1}{1+\xi}((\tau-1)(p+\xi) - 1) \geq 2 + \frac{1}{1+\xi}((\tau - 1)\xi - 1) = 2 + \frac{\tau\xi}{1+\xi} - 1 > 0$ for such p. ∎

Proof of Proposition 3: 1. Define the mapping $F : \mathbb{R}_+^N \to \mathbb{R}_+^N$ by

$$(F(w))_n = \frac{p + d_n \xi S\left(\frac{1}{d_n}\sum_{m \in \mathcal{D}_n} w_m\right)}{1 + d_n \xi}, \qquad n = 1, \ldots, N. \tag{43}$$

An equilibrium is then a fixed point to this mapping, $\bar{p} = F(\bar{p})$. It is easy to see that F is nondecreasing in each of its arguments: $w^2 \geq w^1 \to F(w^2) \geq F(w^1)$, that $F(p, p, \ldots, p) = \left(\frac{p + d_1\xi S(p)}{1 + d_1\xi}, \ldots, \frac{p + d_N \xi S(p)}{1 + d_N \xi}\right)' \stackrel{\text{def}}{=} z \geq (p, p, \ldots, p)'$, and that $F(1, 1, \ldots, 1) = \left(\frac{p + d_1\xi}{1 + d_1\xi}, \frac{p + d_2\xi}{1 + d_2\xi}, \ldots, \frac{p + d_N\xi}{1 + d_N\xi}\right)' \stackrel{\text{def}}{=} y \leq (1, 1, \ldots, 1)'$. It follows that F maps the convex compact set $S \stackrel{\text{def}}{=} [z, y]^N$ into itself. Since F is a continuous mapping, Brouwer's theorem implies that F has a fixed point, i.e., that there exists an equilibrium in S, and since $S \subset [p, 1]^N$, the existence result follows.

For $\tau = 1$, (17) reduces to the linear algebraic equation

$$\bar{p} = (I + \xi \, diag(d_1, \ldots, d_N))^{-1}(p\mathbf{1} + \xi E \bar{p}),$$

or equivalently,

$$(I + \xi\, diag(d_1, \ldots, d_N) - \xi E)\bar{p} = p\mathbf{1}.$$

Here, the $\mathbf{1}$ is a vector of ones, $\mathbf{1} = (1, \ldots, 1)' \in \mathbb{R}^N$. It is easy to verify that $\bar{p} = p\mathbf{1}$ is a solution. Since the matrix $A \stackrel{\text{def}}{=} (I + \xi\, diag(d_1, \ldots, d_N) - \xi E)$ is diagonally dominant ($A_{nn} - \sum_{m \neq n} |A_{mn}| = 1 > 0$, $n = 1, \ldots, N$), it is invertible, so this solution is unique when $\tau = 1$. When $\tau > 1$, it also immediately follows that $p\mathbf{1}$ is not a solution, since $z \gg p\mathbf{1}$ in this case, and the solution must lie in $S = [z, y]^N$.

2. The case $\tau = 1$ is already covered in part 1 of the proof, so w.l.o.g. assume that $\tau > 1$. Consider the function $G : (0, 1)^N \to \mathbb{R}$, defined by

$$G(x) = \sum_{n=1}^{N} d_n R_n \log(x_n) + \frac{1}{2} \sum_{n,m=1}^{N} x_n E_{nm} x_m - \sum_{n=1}^{N} g_n x_n, \tag{44}$$

$$R_n = \frac{d_n \xi \tau}{(1 + d_n \xi)(\tau - 1)^2}, \tag{45}$$

$$g_n = \frac{d_n}{\tau - 1} + \sum_{m \in \mathcal{D}_n} f_m, \tag{46}$$

$$f_n = \frac{p}{1 + d_n \xi} + \frac{d_n \xi \tau}{(1 + d_n \xi)(\tau - 1)}. \tag{47}$$

The gradient of G is $\nabla G(x) \in \mathbb{R}^N = a + Ex - g$, where $a = (a_1, \ldots, a_N)'$, $a_n = \frac{d_n R_n}{x_n}$, $(Ex)_n = \sum_{m \in \mathcal{D}_n} x_m$, and $g = (g_1, \ldots, g_N)'$. A stationary point of G satisfies $\nabla G(x) = 0$. Defining the bijection $\bar{p} \leftrightarrow x$, via $\bar{p}_n \stackrel{\text{def}}{=} f_n - x_n$, it follows that at such a stationary point $\frac{d_n R_n}{f_n - \bar{p}_n} = g_n - \sum_{m \in \mathcal{D}_n} f_m + \sum_{m \in \mathcal{D}_n} \bar{p}_m = \frac{d_n}{\tau - 1} + \sum_{m \in \mathcal{D}_n} \bar{p}_m$, or equivalently

$$\begin{aligned}
\bar{p}_n &= f_n - \frac{d_n R_n}{\frac{d_n}{\tau-1} + \sum_{m \in \mathcal{D}_n} \bar{p}_m} \\
&= \frac{p}{1 + d_n \xi} + \frac{d_n \xi \tau}{(1 + d_n \xi)(\tau - 1)} - \frac{R_n}{\frac{1}{\tau-1} + \frac{1}{d_n} \sum_{m \in \mathcal{D}_n} \bar{p}_m} \\
&= \frac{p}{1 + d_n \xi} + \frac{d_n \xi}{1 + d_n \xi} \left(\frac{1}{1 - \frac{1}{\tau}} - \frac{1}{\left(1 - \frac{1}{\tau}\right)(\tau - 1)\left(\frac{1}{\tau-1} + \frac{1}{d_n} \sum_{m \in \mathcal{D}_n} \bar{p}_m\right)} \right) \\
&= \frac{p}{1 + d_n \xi} + \frac{d_n \xi}{1 + d_n \xi} \left(\frac{(\tau - 1)\left(\frac{1}{\tau-1} + \frac{1}{d_n} \sum_{m \in \mathcal{D}_n} \bar{p}_m\right) - 1}{\left(1 - \frac{1}{\tau}\right)(\tau - 1)\left(\frac{1}{\tau-1} + \frac{1}{d_n} \sum_{m \in \mathcal{D}_n} \bar{p}_m\right)} \right) \\
&= \frac{p}{1 + d_n \xi} + \frac{d_n \xi}{1 + d_n \xi} \left(\frac{\frac{1}{d_n} \sum_{m \in \mathcal{D}_n} \bar{p}_m}{\left(1 - \frac{1}{\tau}\right) \frac{1}{d_n} \sum_{m \in \mathcal{D}_n} \bar{p}_m + \frac{1}{\tau}} \right) \\
&= (F(\bar{p}))_n.
\end{aligned}$$

Thus, every equilibrium point, $\bar{p}$, is equivalent to a stationary point of G, x, under the mapping $\bar{p} \leftrightarrow x$, with

$$x_n = \frac{p}{1+d_n\xi} + \frac{d_n\xi\tau}{(1+d_n\xi)(\tau-1)} - \bar{p}_n.$$

It also follows that the set S under the $\bar{p} \leftrightarrow x$ mapping corresponds to the set

$$\begin{aligned}\{x\} \in U \quad &\stackrel{\text{def}}{=} \quad \left[0, \frac{d_1\xi}{1+d_1\xi}\left(\frac{\tau}{\tau-1} - \frac{\tau p}{(\tau-1)p+1}\right)\right] \times \left[0, \frac{d_2\xi}{1+d_2\xi}\left(\frac{\tau}{\tau-1} - \frac{\tau p}{(\tau-1)p+1}\right)\right] \\ &\times \quad \cdots \times \left[0, \frac{d_N\xi}{1+d_N\xi}\left(\frac{\tau}{\tau-1} - \frac{\tau p}{(\tau-1)p+1}\right)\right].\end{aligned}$$

Thus, if there is a unique stationary point of G in U, then the corresponding equilibrium vector $\bar{p}$ is unique in $[p, 1]^N$.

It is easy to check that the Hessian of G, $H_G(x) \in \mathbb{R}^{N\times N}$, has elements

$$[H_G(x)]_{nm} = \begin{cases} -\frac{d_n R_n}{x_n^2}, & n = m, \\ E_{nm} & n \neq m. \end{cases}$$

It follows that for $x_n \in \left[0, \frac{d_n\xi}{1+d_n\xi}\left(\frac{\tau}{\tau-1} - \frac{\tau p}{(\tau-1)p+1}\right)\right]$,

$$\begin{aligned}[H_G(x)]_{nn} \quad &\leq \quad -\frac{d_n R_n}{\left(\frac{d_n\xi}{1+d_n\xi}\left(\frac{\tau}{\tau-1} - \frac{\tau p}{(\tau-1)p+1}\right)\right)^2} \\ &= \quad -\frac{d_n \frac{d_n\xi\tau}{(1+d_n\xi)(\tau-1)^2}}{\left(\frac{d_n\xi}{1+d_n\xi}\left(\frac{\tau}{\tau-1}\right)\left(\frac{1}{(\tau-1)p+1}\right)\right)^2} \\ &= \quad -d_n\left(\frac{1+d_n\xi}{d_n\xi}\right)\left(\frac{1}{\tau}\right)\left((\tau-1)p+1\right)^2.\end{aligned}$$

Since $\sum_m E_{nm} = d_n$ for all n, it follows that if

$$\left(\frac{1+D\xi}{D\xi}\right)\left(\frac{1}{\tau}\right)\left((\tau-1)p+1\right)^2 > 1, \tag{48}$$

then H_G is diagonally dominant with negative diagonal elements, in the whole of U and thus the Hessian is negative definite in this region. Standard theory of optimization then in turn implies that a stationary point of G is unique in U, and thus that $\bar{p}$ is unique in S, and therefore also in $[p, 1]^N$. The condition (48) is obviously equivalent to (18).

3. The result follows immediately from the fact that when $\tau \to \infty$, both z_n and y_n, as defined in part 1 of the proposition, converge to $\frac{p+d_n\xi}{1+d_n\xi}$ for all n. ∎

Proof of Proposition 4: Conjecture an equilibrium in which $\bar{p}_1 = \bar{p}_2 = \cdots = \bar{p}_N = w$, Since $\frac{1}{d_n}\sum_{m\in\mathcal{D}_n} \bar{p}_m = w$ for all n, (17) reduces to the condition $\bar{p}_n = \frac{p+d\xi S_\tau(\bar{p}_n)}{1+d\xi}$, which has solution $\bar{p}_n = B(\tau, p, d\xi)$, $n = 1, \ldots, N$. ∎

Proof of Proposition 5: As evident from Proposition 3, equilibrium consumption satisfies $\bar{p}^P > p$, $\bar{p}^C > p$. Assume that $\bar{p}^P \geq \bar{p}^C$. It follows that $\zeta = \frac{d^C}{d^C+d^P}\bar{p}^C + \frac{d^P}{d^C+d^P}\bar{p}^P$ satisfies $p^C \leq \zeta \leq p^P$, and consequently that $S_\tau(\zeta) \geq S_\tau(p^C)$. Consequently (since $d^C + d^P > 1$),

$$\frac{p + (d^C + d^P)\xi S_\tau(\eta)}{1 + (d^C + d^P)\xi} > \frac{p + \xi S_\tau\left(\bar{p}^C\right)}{1+\xi},$$

and thus $\bar{p}^C > \bar{p}^P$, leading to a contradiction. It follows that $\bar{p}^C > \bar{p}^P$.

For the second part of the theorem, note that it follows from $(19, 20)$ that in equilibrium $F(\bar{p}^C, d^C) = 0$, where

$$\begin{aligned} F(\bar{p}^C, d^C) &= p + (d^C + d^P)\xi S_\tau\left(\frac{d^C}{d^C+d^P}\bar{p}^C + \frac{d^P}{d^C+d^P}\left(\frac{p+\xi S_\tau\left(\bar{p}^C\right)}{1+\xi}\right)\right) - p^C(1 + (d^C + d^P)\xi) \\ &= p + d\xi S_\tau(\zeta) - p^C(1 + d\xi), \end{aligned}$$

where $d = d^C + d^P$. Now,

$$\begin{aligned} \frac{\partial F}{\partial p^C} &= d\xi S'_\tau(\eta)\left(\frac{d^C}{d^C+d^P} + \frac{d^P}{d^C+d^P}\frac{\xi}{1+\xi}S'_\tau\left(\bar{p}^C\right)\right) - (1 + d\xi) \\ &\leq d\xi - (1 + d\xi) \\ &< 0, \end{aligned}$$

where the inequality follows from the fact that $\bar{p}^C > \frac{1}{2}$, $\eta > \frac{1}{2}$, and $S'_\tau(x) < 1$ when $x > \frac{1}{2}$.

Moreover,

$$\begin{aligned} \frac{\partial F}{\partial d^C} &= \xi S_\tau(\zeta) + d\xi S'_\tau(\zeta)\frac{d\zeta}{dd^C} - \bar{p}^C\xi \\ &> 0 \end{aligned}$$

which follows from the fact that $S_\tau(\zeta) \geq \bar{p}^C$ (which in turn follows from (19)), and that $\frac{d\zeta}{dd^C} = \frac{1}{d^2}(1 - \bar{p}^D) > 0$. Therefore, by the inverse function theorem, $\frac{d\bar{p}^C}{dd^C} = -\frac{\frac{\partial F}{\partial p^C}}{\frac{\partial F}{\partial d^C}} > 0$. Finally, from (20) it follows that $\bar{p}^D$ is strictly increasing in $\bar{p}^C$. Both $\bar{p}^C$ and $\bar{p}^D$ are therefore increasing in d^C, as is then aggregate consumption. We are done. ∎

Proof of Proposition 6: For a symmetric network, equation (21) reduces to

$$\bar{p} = \frac{p + d\xi S_\tau(\bar{p}) + d\alpha\bar{p}}{1 + d\xi + d\alpha}. \tag{49}$$

since $\bar{p}_n = \bar{p}$ and $d_n = d$ for all agents. It follows immediately that any solution to (49) equivalently satisfies

$$\bar{p} = \frac{p + d\xi S_\tau(\bar{p})}{1 + d\xi}, \tag{50}$$

i.e., is also an equilibrium in the economy without public signal. ∎

Proof of Proposition 8: It is easy to verify that the solution to the equilibrium condition (23) is

$$\begin{aligned}\bar{p} &= \frac{-1}{2(2\lambda-1)(1+\xi)(\tau-1)}\Big(1-3p+4\lambda p+\xi-2p\xi+2\lambda p\xi+3p\tau- \\ &- 4\lambda p\tau+\xi\tau+2p\xi\tau-2\lambda p\xi\tau-\sqrt{V}\Big),\end{aligned} \tag{51}$$

where

$$\begin{aligned}V &= -4(2\lambda-1)p(1+\xi)(\tau-1)\Big(-1+2(\lambda-1)p(\tau-1)+2(\lambda-1)\xi\tau\Big)+ \\ &+ \Big(1-p(-3-2\xi+2\lambda(2+\xi)(\tau-1)+\xi(1+\tau-2\lambda\tau)\Big)^2.\end{aligned}$$

It is also easy to verify that the solution reduces to (24,25) when $\lambda=0$, and to (11,12) when $\lambda=1$. Moreover, it is easy to verify that $\bar{p}^{\lambda=0}>p$, and that for any $\lambda\in[0,1]$, $\bar{p}^{\lambda}=p\Rightarrow p\in\{0,1\}$. It also follows immediately that $\bar{p}$ is a continuous function of λ, except possibly at $\lambda=1/2$.

We next define $x=2\lambda-1\in[-1,1]$, and rewrite (51) as

$$\begin{aligned}\bar{p} &= a+\frac{b(\sqrt{1-cx+dx^2}-1)}{2x(\tau-1)}, \qquad \text{where} \\ a &= \frac{p(2+\xi)(\tau-1)+\xi\tau}{2(1+\xi)(\tau-1)}, \\ b &= 1+p(\tau-1) \\ c &= \frac{2\xi(-p(\tau-1)^2+p^2(\tau-1)^2+\tau)}{(1+\xi)(1+p(\tau-1))^2}, \\ d &= \frac{\xi^2(p(1-\tau)+\tau)^2}{(1+\xi)^2(1+p(\tau-1))^2}.\end{aligned}$$

A Taylor expansion of $\sqrt{1+cx+dx^2}-1$ around $x=0$ i.e., $\lambda=1/2$, yields $\sqrt{1+cx+dx^2}-1=\frac{1}{2}cx+O(x^2)$, and thus $\bar{p}$ is a continuous function of λ at $\lambda=1/2$ too. Thus, since $\bar{p}^{\lambda=1}>p$, and $\bar{p}^{\lambda}$ depends continuously on λ, $\bar{p}^{\lambda}>p$ for all $\lambda\in[0,1]$. We have shown $\bar{p}>p$, i.e., (1), and (3).

To show (2), we note that

$$\frac{d\bar{p}}{dx}=\frac{b}{4(\tau-1)}\times\frac{\sqrt{1-cx+dx^2}+\frac{c}{2}x-1}{\sqrt{1-cx+dx^2}},$$

so $\sqrt{1-cx+dx^2}>1-\frac{c}{2}x$ is necessary and sufficient for $\frac{d\bar{p}}{dx}>0$. This implies the following sufficient condition:

$$1-cx+dx^2>\Big(1-\frac{c}{2}x\Big)^2=1-cx+\frac{c^2}{4}x^2,$$

or equivalently,

$$4d^2 - c^2 > 0.$$

It is easy to verify that

$$4d^2 - c^2 = \frac{16(1-p)p\xi^2(\tau-1)^2\tau}{(1+\xi)^2(1+p(\tau-1))^2} > 0,$$

so the condition is indeed satisfied. ∎

Proof of Proposition 9: Define

$$J(\alpha,\beta,\xi,f,Q,x) = \int_0^1 t^{\alpha Q-1+x}(1-t)^{(1-\alpha)Q-1}(ft)^{\beta\xi Q}(1-ft)^{(1-\beta)\xi Q}dt.$$

Using standard properties of Beta distributions, it follows that

$$R(\alpha,\beta,\xi,f) = \lim_{Q\to\infty} \frac{J(\alpha,\beta,\xi,f,Q,1)}{J(\alpha,\beta,\xi,f,Q,0)}, \tag{52}$$

and that an agent who updates according to Bayes rule will arrive at the posterior estimate $\hat{p} = R(p,z,\xi,f)$ when Q is very large. ∎

Proof of Proposition 10: Plugging in the definition of R into the fixed point problem (26) yields a cubic equation in $\bar{p}$, two roots of which are outside of the unit interval $(0,1)$. The remaining root has the prescribed form. ∎

Proof of Lemma 1: For $\alpha,\beta,f_1,f_2 \in (0,1]$, $\xi > 0$, define

$$L(\alpha,\beta,\xi,f_1,f_2) \quad = \quad \lim_{Q\to\infty} \frac{J(\alpha,\beta,\xi,f_1,Q,0)}{J(\alpha,\beta,\xi,f_2,Q,0)},$$

where J was previously defined. It follows from standard properties of Beta distributions, that

$$L(\alpha,\beta,\xi,f_1,f_2) = \begin{cases} \infty, & \left|f_1 - \frac{\beta}{\alpha}\right| < \left|f_2 - \frac{\beta}{\alpha}\right|, \\ \\ 0, & \left|f_1 - \frac{\beta}{\alpha}\right| > \left|f_2 - \frac{\beta}{\alpha}\right|. \end{cases} \tag{53}$$

An agent with prior p, who observes a fraction β of bins with consumption, believing that the observations provide an unbiased estimate of the consumption of others, and who believes that the distribution of wealth groups (poor, medium, rich) among the population is $(q, 1-2q, q)$ who consume the fraction $(f(1-\Delta), f, f(1+\Delta))$ of the bins, respectively, will update—using Bayes rule—to the posterior:

$$\begin{aligned}
\hat{p} \quad &= \quad \frac{qJ(\alpha,\beta,\,\xi,(1-\Delta)f,Q,1) + (1-2q)J(\alpha,\beta,\xi,f,Q,1) + qJ(\alpha,\beta,\xi,(1-\Delta)f,Q,1)}{qJ(\alpha,\beta,\xi,(1+\Delta)f,Q,0) + (1-2q)J(\alpha,\beta,\xi,f,Q,0) + qJ(\alpha,\beta,\xi,(1+\Delta)f,Q,0)} \\
&= \quad \frac{J(\alpha,\beta,\xi,(1-\Delta)f,Q,1)}{J(\alpha,\beta,\xi,(1-\Delta)f,Q,0)}g_1 + \frac{J(\alpha,\beta,\xi,f,Q,1)}{J(\alpha,\beta,\xi,f,Q,0)}g_2 + \frac{J(\alpha,\beta,\xi,(1+\Delta)f,Q,1)}{J(\alpha,\beta,\xi,(1+\Delta)f,Q,0)}g_3,
\end{aligned}$$

where

$$
\begin{aligned}
g_1 &= \frac{qJ(\alpha,\beta,\xi,(1-\Delta)f,Q,0)}{qJ(\alpha,\beta,\xi,(1-\Delta)f,Q,0)+(1-2q)J(\alpha,\beta,\xi,f,Q,0)+qJ(\alpha,\beta,\xi,(1+\Delta)f,Q,0)},\\
g_2 &= \frac{(1-2q)J(\alpha,\beta,\xi,f,Q,0)}{qJ(\alpha,\beta,\xi,(1-\Delta)f,Q,0)+(1-2q)J(\alpha,\beta,\xi,f,Q,0)+qJ(\alpha,\beta,\xi,(1+\Delta)f,Q,0)},\\
g_3 &= \frac{qJ(\alpha,\beta,\xi,(1+\Delta)f,Q,0)}{qJ(\alpha,\beta,\xi,(1-\Delta)f,Q,0)+(1-2q)J(\alpha,\beta,\xi,f,Q,0)+qJ(\alpha,\beta,\xi,(1+\Delta)f,Q,0).}
\end{aligned}
$$

It follows from (53) and assumption (29), that as $Q\to\infty$, $g_1, g_2\to 0$ and $g_3\to 1$. In words, the observing agent puts all the weight on having observed a wealthy agent's consumption, regardless of which agent he actually observes. Moreover, from (52) and it follows that an agent observing poor, average, and wealthy agents consuming based on posterior beliefs $\bar{p}$ will have posterior belief

$$\hat{p} = R(\alpha,\beta,\xi,(1+\Delta)f),$$

where β equals $S_\tau((1-\Delta)f\bar{p})$, $S_\tau(f\bar{p})$, and $S_\tau((1+\Delta)f\bar{p})$ with probabilities q, $1-2q$, and q, respectively. The fixed point problem that matches aggregate posterior beliefs with agents' updating is therefore (30).

Existence of a solution to (30) follows from the easily verifiable fact that $R(p, S_\tau(g\times 0),\xi,f)>0$ and $R(p,S_\tau(g\times 1),\xi,f)<1$, regardless of $g,p,f\in(0,1)$, and $\xi>0$. Therefore, the r.h.s of (30), which is a continuous function, is strictly greater than $\bar{p}$ when $\bar{p}$ close to zero, and strictly less than $\bar{p}$ when $\bar{p}$ is close to one. Existence therefore follows from the intermediate value theorem.

∎

Proof of Proposition 11: It is straightforward to verify that the function R satisfies $\frac{\partial R}{\partial z}>0$, since

$$\frac{\partial R}{\partial z} = \frac{\xi(1+c)}{2f(1+\xi)},$$

where

$$c^2 = \frac{(-1-z\xi+f(2-p+\xi))^2}{(f^2(p+\xi)^2+(1+\beta\xi)^2+2f(\xi-\beta\xi(2+\xi)+\alpha(-1+(\beta-2)\xi))}<1,$$

implying positivity of the derivative. It also follows that $\frac{\partial^2 R}{\partial z^2} = -\frac{2(1-f)(1-p)\xi^2}{((1+fp+f\xi+z\xi)^2-4f(1+\xi)(p+z\xi))^{3/2}} < 0$, so R is concave in z.

Moreover, one can show that $\frac{\partial R}{\partial f}<0$. Specifically, it is easy to verify that $\frac{\partial R}{\partial f} = \frac{\kappa_1}{\kappa_2 f^2}$, where the function $\kappa_2>0$, and $\kappa_1 = 0 \Leftrightarrow f=0$ on $f\in[0,1]$, for the smooth function κ_1. Thus,R is a monotone function for positive $0\le f\le 1$. A Taylor expansion of κ_1 in f around $f=0$ implies that κ_1 is on the form $R'(f) = -c_1 f^2 + O(f^3)$, where the constant $c_1>0$, altogether implying that $\frac{\partial R}{\partial f}<0$ for small positive f, and thereby for all $0\le f\le 1$ (since R is monotone).

Now, we use these properties of R to show that the total derivative of the r.h.s. of (30) w.r.t. Δ is negative. Specifically, using the notation R_i for the partial derivative of the function R w.r.t. its ith argument, from the calculus of total derivatives it follows that this r.h.s. derivative is on the form

$$q\bar{p}f\left(-S'_\tau(f\bar{p}(1-\Delta))R_2(\cdot) + -S'_\tau(f\bar{p}(1-\Delta))R_2(\cdot)\right) + \bar{p}f(qR_4(\cdot) + (1-2q)R_4(\cdot) + qR_4(\cdot)).$$

Now, since $R_4(\cdot) < 0$, the second part of of this expression is negative. Moreover, S_τ is concave and R is concave in its second argument, so the first part of the expression is also negative. Thus, the r.h.s. of (30) is decreasing in Δ.

Because R is increasing and concave in its second argument, it follows that the r.h.s. of (30) is concave and increasing in $\bar{p}$, and since $R(p, 0, \xi, f) > 0$, it follows that at the equilibrium point $0 < \frac{\partial R}{\partial \bar{p}} < 1$. Altogether, the inverse function theorem then implies that $\frac{\partial \bar{p}}{\partial \Delta} < 0$ for the fixed point $\bar{p}$ defined by (30). ∎

Proof of Proposition 12: The proof of the Bayesian updating follows similar lines as in Proposition 9. Define

$$J(\alpha, \beta, \xi, f, g, Q, x) = \int_0^1 t^{\alpha Q - 1 + x}(1-t)^{(1-\alpha)Q-1}(g+ft)^{\beta\xi Q}(1-g-ft)^{(1-\beta)\xi Q}dt. \quad (54)$$

Standard properties of Beta distributions, implies that an agent's posterior estimate is

$$\hat{p} = R(\alpha, \beta, \xi, f, g) \stackrel{\text{def}}{=} \lim_{Q\to\infty} \frac{J(\alpha, \beta, \xi, f, g, Q, 1)}{J(\alpha, \beta, \xi, f, g, Q, 0)}, \quad (55)$$

when Q is very large. Moreover, taking the derivative of the term inside the integral of (54) with respect to t, and using the factor that for large Q, J converges to a scaled Dirac distribution, it follows that $\hat{p}$ satisfies:

$$\frac{\alpha}{\hat{p}} - \frac{1-\alpha}{1-\hat{p}} + f\left(\frac{\beta\xi}{g+f\hat{p}} - \frac{1-\beta)\xi}{1-g-f\hat{p}}\right) = 0 \quad (56)$$

for large Q. Plugging in the equilibrium condition $\hat{p} = \bar{p}$, $\bar{p}$ as a function of r defined in (39), setting $\alpha = p$, $\beta = S_\tau(g + f\bar{p})$, $\xi = 1$, f and g as defined in (34), and solving for τ in (56) leads to the functional relation:

$$\begin{aligned} \tau(p,r) &= \Big(2p + 2p^2 - 32r + 20pr + 4p^2r + 36r^2 + 3pr^2 + \\ &+ \ 5p^2r^2 - 50r^3 - 5pr^3 + 3p^2r^3 + 25r^4 - 10pr^4 + p^2r^4\Big) \\ &/ \ \Big(-2p + 2p^2 + 20pr + 4p^2r + 48r^2 + 7pr^2 + \\ &+ \ 5p^2r^2 - 54r^3 - pr^3 + 3p^2r^3 + 15r^4 - 8pr^4 + p^2r^4\Big). \end{aligned} \quad (57)$$

This relation thus represents the level of visibility bias that is consistent with equilibrium, given p and r.

It is easy to verify that $\tau(p,0) = 1$, and thus that the unbiased equilibrium with $r = 0$ is obtained in this case. Moreover, one verifies that τ is strictly increasing in r in a neighborhood of the origin, regardless of p, and that τ approaches infinity for some $r(p) < 1/2$, so equilibrium is defined for all parameter values p and τ, and r increases in τ, as does then $\bar{p}$. This shows the first and third part of the proposition.

Finally, for the first part of the proposition, by backing out $r(\bar{p})$ in (40) and plugging into (57), we write τ as a function of p and $\bar{p}$, and compare with the benchmark τ, $\tau^B = (p(\bar{p}-3) - 2(\bar{p}-2)\bar{p})/(p + p\bar{p} - 2\bar{p}^2)$, verifying that $\tau(p,\bar{p}) - \tau^B(p,\bar{p}) > 0$. Since $\bar{p}$ is increasing in τ, it then follows that $\bar{p}^B > \bar{p}$.

∎

B Other Utility Functions

The combination in the base model of the utility specification in (1), which leads to a linear consumption function in wealth (5), and the assumption that when $\frac{W}{2}$ is consumed at time 0 all bins contain consumption, makes the relationship between $\bar{p}$ and $E[z]$ in (9) especially tractable, which allows for a strong characterization of equilibrium.

We now verify that qualitatively similar results as in Proposition 1 also hold under more common utility specifications. For example, consider the case in which agents have power utility, $U = \frac{c_0^{1-\gamma}}{1-\gamma} + \frac{c_1^{1-\gamma}}{1-\gamma}$, with risk aversion coefficient $\gamma \geq 1$ (where in the case $\gamma = 1$, log-utility is used). The consumption shock, ϵ is assumed to take on value $\frac{W}{2}$ with probability $1-p$ (to avoid negatively infinite utility), and 0 with probability p. As before, the agent's estimated probability for a high outcome is $\hat{p}$

The agent's first order condition is in this case is

$$c_0^{-\gamma} = \hat{p}(W - c_0)^{-\gamma} + (1-\hat{p})\left(\frac{W}{2} - c_0\right)^{-\gamma},$$

leading to the mapping $c_0 = G(\hat{p})\frac{W}{2}$. In the base model case with quadratic utility, $G(\hat{p}) = \hat{p}$. In case of of power utility, G is a nonlinear function for which a closed form solution is not available, bare a few special values of γ.[30] However, the following behavior of G is easy to show:

Lemma 2 *The function G satisfies $G(0) = \frac{1}{2}$, $G(1) = 1$, and is strictly increasing and convex. Its inverse is*

$$G^{-1}(c) = \frac{\left(1-\frac{c}{2}\right)^{\gamma}\left(\frac{c}{2}\right)^{-\gamma}\left(\left(\frac{c}{2}\right)^{\gamma} - \left(\frac{1}{2} - \left(\frac{c}{2}\right)\right)^{\gamma}\right)}{\left(1-\frac{c}{2}\right)^{\gamma} - \left(\frac{1}{2} - \frac{c}{2}\right)^{\gamma}}.$$

[30] For the special case when $\gamma = 1$, the closed form solution is $G(\bar{p}) = \frac{5}{4}\left(5 - \bar{p} - \sqrt{9 - 10\bar{p} + \bar{p}^2}\right)$.

Proof: The form of G^{-1} follows immediately from the f.o.c. Differentiation of G^{-1} implies that G^{-1} is strictly increasing and concave on $c \in (1/2, 1)$. Moreover, $G^{-1}(1/2) = 0$, and $G^{-1}(1) = 1$. It follows that $G(0) = 1/2$, $G(1) = 1$, and from the inverse function theorem that G is invertible on $p \in (0, 1)$, being increasing and convex. ∎

If an agent observes a fraction x of consumption bins, his posterior expected value of p is

$$\hat{p} = \frac{p + \xi G^{-1}(x)}{1 + \xi}.$$

Owing to visibility bias, if other agents' consumptions are based on the posterior expected probability $\bar{p}$, then $x = S_\tau(G(\bar{p}))$. Finally, in equilibrium, $\hat{p} = \bar{p}$, leading to the following fixed point equilibrium condition:

$$\bar{p} = \frac{p + \xi G^{-1}(S_\tau(G(\bar{p})))}{1 + \xi}. \tag{58}$$

The following proposition shows the existence of an equilibrium with over consumption in this setting:

Proposition 13 *For $\tau > 1$, there exists an equilibrium probability estimate, $\bar{p} > p$, with associated consumption $G(\bar{p})\frac{W}{2} > G(p)\frac{W}{2}$.*

Proof: Note that $y = G(\bar{p}) \in \left(\frac{1}{2}, 1\right)$ satisfies

$$G^{-1}(y) = \frac{p + \xi G^{-1}(S_\tau(y)))}{1 + \xi}. \tag{59}$$

To show the existence of an $y \in (G(p), 1)$ solving (59), we note that

$$p = G^{-1}(G(p)) < \frac{p + \xi G^{-1}(G(p))}{1 + \xi} < \frac{p + \xi G^{-1}(S_\tau(G(p)))}{1 + \xi},$$

and that

$$1 = G^{-1}(G(1)) > \frac{p + \xi G^{-1}(S_\tau(G(1)))}{1 + \xi} = \frac{p + \xi}{1 + \xi}.$$

By the intermediate value theorem, there is therefore a $y \in (G(p), 1)$ that solves (59), with associated equilibrium probability estimate $\bar{p} = G^{-1}(y) > G^{-1}(G(p)) = p$. ∎

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