Government Information Transparency*

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Abstract

This paper investigates how government transparency depends on economic distortions. In an abstract class of economies with positive externalities and with a benevolent social planner privately informed about future productivity shocks, we prove two results: first, if distortions are high, transparency cannot be an equilibrium; second, transparency is ex-ante Pareto superior to opaqueness whenever a convexity condition is satisfied; and yet, for the previous result, it may not arise in equilibrium. We next confirm and extend these results in tow applied contexts, in which monopoly power and income taxes are the specific sources of distortions.

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1 Introduction

Many governments are better informed than the private sector about future realizations of macroeconomic variables. Often they transparently convey this information to the public, but at other times they do not. For instance, the US government's announcements on current or future activity have a positive real effect on the economy, confirming the fact that individuals find them informative (Oh and Waldman, 1990; Rodríguez Mora and Schulstald, 2007). In contrast, the widespread skepticism on contemporary Argentine or Greek official statistics provides an example of non transparent and non credible government announcements. While there may be different opportunistic reasons for governments not to be transparent, in the present paper we investigate whether a benevolent government would always reveal its private information on real macroeconomic variables. For the sake of concreteness, we focus on the case in which the government has prior information on exogenous aggregate productivity shocks that produce uniform positive (in booms) or negative (in recessions) shifts in productivity. Would a benevolent government always fully reveal this information? Is it efficient to do so? What are the determinants of government information transparency?

In an otherwise perfectly competitive, first best economy a benevolent government would always reveal its private information. But, in a second best world with unavoidable distortions, a benevolent government might hope to increase social welfare by appropriately distorting information communication. For instance, suppose that monopoly power or income taxes make labor supply sub-optimal. If the government knows that the economy is hitting a recession and does not reveal such information, it may hope that the increase in labor supply caused by ignorance compensates the under-supply of labor provoked by the existence of distortions.

If individuals mechanically believe its announcements (if they are credulous), the government may even be able to restore the first best outcome through an appropriately over-optimistic communication strategy. However, if individuals are rational, this misleading information about a recession will make the government lose credibility. In particular, when the economy is hitting a boom and the government announces it, individuals will discount such announcement. This, in turn, will further worsen the under-supply of labor in booms, and thus reduce social welfare in good times.

In recessions, by hiding information, the government raises labor supply, relative to what it would be under perfect information, so that it may (at least partially) compensate for the welfare loss caused by the existing distortion. Yet, it may also raise labor supply so much, that it indeed causes an oversupply of labor (relative to the first best), whose welfare costs are higher than those due to the distortion under perfect information. The higher the distortion, the less likely it is that this happens. Thus, roughly, high levels of distortion would induce the government to hide negative information.

We start by making our essential point in an abstract model with externalities, in which a benevolent social planner has private information on productivity shocks and sends payoff-irrelevant messages to uninformed individuals. We characterize the equilibria of this cheap talk game and find that non informative equilibria always exist, whereas an informative equilibrium exists if and only if externalities are sufficiently small. In a non informative equilibrium, government announcements convey no information. In an informative equilibrium, the government is transparent (i.e., its announcements fully reveal its private information) and credible (in the sense that, if announcements have a literal meaning, this naturally coincides with their equilibrium interpretation).

Transparency allows individuals to react to different information in different states of the world. Opaqueness in turn makes their action more stable, since different states of the world belong to the same information set. We show that transparency is Pareto optimal, from an ex ante point of view, if and only if full-information social welfare satisfies an appropriate convexity condition in productivity shocks. If this condition is satisfied, our results imply that, even with a benevolent social planner, opaqueness may be an equilibrium although transparency is ex ante desirable.

We next extend the abstract model and focus on two specific sources of externalities: monopoly power and income taxation. This extension shows the direct relevance of the mechanism we analyze in standard macroeconomic and public economics models.

In the monopoly power model, we again show that a non informative equilibrium always exists, whereas an informative equilibrium exists if and only if the monopolistic distortion is sufficiently small. An appropriate refinement uniquely selects the informative equilibrium whenever it exists, so that our comparative statics is conducted on the distortion threshold, below which it exists. The model shows that an increase in average productivity harms transparency, whereas an increase in shock magnitude favors transparency, at least when shocks are small. Thus, ceteris paribus, countries with more competitive product markets and larger shocks are more likely to have a truthful government, whereas there is no presumption that economic development per se brings about transparency. In the model labor supply depends on expected rather than actual wages. Therefore, even if the elasticity of labor supply to expected wages remains constant, actual labor supply fluctuates with actual (and expected) wages under transparency, whereas it does not fluctuate over the business cycle under opaqueness.

In the taxation model, results on existence, efficiency and equilibrium selection parallel those of the monopoly power model. Again, an increase in shock magnitude favors transparency, at least when shocks are small. Hence, ceteris paribus, countries with lower taxation and higher shocks are more likely to have a truthful government. The main novelty in the context of income taxation is that it is a natural environment to study the effects of labor income inequality on transparency. We show that such effects depend on labor supply elasticity. If labor supply is rigid, an increase in inequality favors transparency and the opposite if it is elastic (only with linear labor supply inequality does not affect transparency).

Both in the monopoly power and in the taxation model, transparency is ex ante desirable (since the convexity condition of social welfare in shocks is satisfied), but may not be feasible in equilibrium, because even a benevolent government may want to hide negative information. The policy implication is then straightforward: when distortions are substantial in magnitude and difficult to remove, the government should find some commitment device to transparency. For instance, announcements over the economic outlook might be delegated to an independent statistical office committed to transparency.[1]

The remainder of this paper is organized as follows. We survey the related literature in Section 2. Sections 3, 4 and 5 display the abstract model and the two extensions to monopoly power and to income taxation, respectively. Section 6 concludes. In the Appendix we present technical results for the two applied models.

2 Related literature

Our analysis is related to a number of literatures and open discussions. First, transparency and provision of accurate information have been very prominent

[1]This policy conclusion is conditional on the fact that in our context transparency is ex-ante efficient, a condition that may not hold in different models, for instance when the business cycle is driven by shocks to monopolistic markups or to labor wedges.

in recent debates on institutional and policy reform. For example, the Federal Open Market Committee (FOMC) announced in November 2007 that, consistently with its greater commitment to improving accountability, it will increase the frequency and expand the content of the economic projections released to the public.[2] In other countries, central banks and Statistics Offices have adopted a range of methods aimed at improving their communication.[3]

The policy emphasis on transparency and credibility has been accompanied by a huge economic literature, which, at least since Kydland and Prescott (1977), has mostly focused on their importance for central banks (a recent assesment can be found in Blinder et al., 2008).[4] Many of these contributions emphasize monetary channels and assume private information on at least two contradictory policy goals.[5] Two prominent examples, among others, are Cukierman and Meltzer (1986) and Stein (1989).[6] We differ from

[2]Projections on consumption will be included for the first time together with forecasts on gross domestic product (GDP) growth, the unemployment rate, and inflation. In addition, the projection horizon will be extended to three years, from two.

[3]These include timely announcements of policy actions, frequent public speeches at meetings with legislature, and the regular publication of reports about the real economy and monetary policy. The Reserve Bank of New Zealand and the Bank of England were early and enthusiastic leaders in this process towards greater transparency, together with the Norges Bank (the central bank of Norway) and Sveriges Riksbank (the central bank of Sweden). Finally, The European Central Bank has adopted a fully transparent communication strategy since it was created in 1998. Geraats (2009) shows that there has been a notable increase in economic transparency between 1998 and 2002, although the intensity varied across countries.

[4]In Faust and Svensson (2001), transparency takes the form of making public announcements more precise. Governments are credible if their announcements are believed to be true. Transparency builds credibility and, as a consequence, it has become an ingredient in the common wisdom of policy making (Faust and Svensson, 2002). This consensus is absolute among central bank authorities. As reported by Blinder (2000), central bankers consider transparency a "fine way to build credibility". Interestingly, when asked the same questions, non-central bank economists are not that enthusiastic about the importance of transparency. We do not investigate here any reputational incentives for transparency. Yet, the literature on this topic (e.g., Morris, 2001; Ottaviani and Sorensen, 2006) finds that in many cases reputation provides an incentive to hide rather than to reveal information.

[5]A smaller literature (see, e.g., Sleet, 2001) posits private government information about productivity shocks, as we do here, and investigates its consequences for time consistency of optimal monetary policy.

[6]The former paper investigates the central bank's incentive to maintain ambiguous procedures of monetary control, in order to be able to surprise rational agents whenever its policy goals shift. The latter uses a cheap-talk framework to emphasize the central bank's

this line of research in that we emphasize real rather than monetary channels and assume private information about the macroeconomic outlook rather than about policy goals. As argued above, both aspects appear to be relevant and worthy of analysis.[7] Perhaps more importantly, we show that the assumption of contradictory policy goals is not required to generate situations where the government cannot commit to transparent information.

A recent and important strand of the literature looks at how economic policy depends on transparency and informational asymmetries, finding that transparency may generate economic distortions. We tackle the complementary question and show how transparency is endogenously determined by pre-existing distortions.[8]

In an influential paper, Morris and Shin (2002) show that noisy public information, if used to coordinate actions, may lead individuals to disregard alternative valuable private information, so that more precise public information may reduce welfare.[9] Amador and Weill (2008) emphasize that

incentive to make imprecise announcements about its goals, exactly because precise announcements would induce it to lie (in order to manipulate expectations). More recently, Moscarini (2007) shows that monetary policy is more likely to be transparent the greater the competence of the central bank.

[7]The fact that central authorities have an informational advantage over the private sector has been widely documented and has been mainly attributed to the fact that they devote substantially more resources to forecasting than private forecasters, and possibly use better forecasting methods (Romer and Romer, 2000; Kurz, 2005; Kohn and Sack, 2004; Athey et al., 2005). The fact that central authorities' announcements influence private behavior is also well documented (Oh and Waldman, 1990, 2005; Blinder et al., 2008).

[8]Several papers are concerned with the political economy of budget deficits and find that higher transparency reduces public debt (Milesi-Ferreti, 2004; Shi and Svensson, 2006). More recently, Gavazza and Lizzeri (2009a,b) concentrate on the effects of different types of transparency in presence of political competition, where voters are misinformed about aggregate government spending and either revenues (Gavazza and Lizzeri, 2009b) or the incumbent government's ability (Gavazza and Lizzeri, 2009a). These papers show that, although transparency of spending is beneficial, higher transparency of either revenues or incumbent's ability may lead to wasteful spending and higher public debt. See also Barigozzi and Villeneuve (2006), where taxes have a signaling value, and Angeletos and Pavan (2009), who investigate how optimal taxation, by taking into account the information structure, allows individuals to make a better use of both private and public information.

[9]This reasoning has been used to warn against Central Bank transparency (Amato et al., 2002), a conclusion that has been disputed in a lively recent debate, developed both in the abstract context of 'beauty contest' models (Svensson, 2006; Morris et al., 2006; James and Lawler, 2011) and in the applied context of New Keynesian models (Woodford, 2003;

releasing public information would jeopardize the price system's ability to aggregate and transmit private information, which could result in welfare losses. Angeletos and Pavan (2007) clarify the welfare effects of public information about unobservable fundamentals, in the context of an abstract class of linear-quadratic games, in which heterogeneous private information is also available. They show how such effects crucially depend on the type of inefficiency characterizing the economy, on whether individual actions exhibit strategic complementarity or substitutability, and on the covariance between full-information equilibrium strategies and the efficiency gap (the difference between first best and full-information equilibrium strategies).[10] Angeletos et al. (2011) show that, in the context of a micro-founded DSGE model with dispersed information, more precise public information raises welfare if the business cycle is driven by technology or preference shocks, but not necessarily if it is driven by shocks to monopoly markups or to labor wedges.[11]

Relative to this literature, we abstract from both dispersed information and dynamic considerations. Moreover, in our framework there are externalities, but actions are neither strategic substitutes nor complements. Productivity shocks drive the business cycle, making public information welfare improving under a simple convexity condition, which is characterized in the abstract model and satisfied in the two extensions.[12] Abstracting from the above mentioned aspects allows us to focus on the main novelty of our contribution, which is the investigation of the ex-post incentives of the government to reveal private information, an issue that has been overlooked by the aforementioned literature. On this respect, we show that, although transparency is ex-ante optimal, it may not arise in equilibrium, because, when distortions are large, even a benevolent social planner would find revealing bad news ex-post sub-optimal.

Our theory builds on the cheap-talk literature. Farrell and Gibbons (1989) extend the standard cheap-talk game (Crawford and Sobel, 1982)

Hellwig, 2005; Roca, 2010).

[10]In economies that are inefficient even under complete information, they show that if this covariance is positive, then more precise public information is (ex ante) welfare increasing.

[11]Relatedly, Angeletos and La'O (2009) investigate the positive effects of dispersed information on the business cycle.

[12]Notice that, although we assume that the source of distortions (the elasticity of substitution and the tax rate) is a-cyclical, this is not true for the wedge between first-best and full-information labor supply, which is pro-cyclical in both of our applied models. This makes our results coherent with those of Angeletos and Pavan (2007), besides with those of Angeletos et al. (2011).

to two audiences and, restricting attention to two states and two actions, discuss the difference between private and public communication. We differ from their analysis because, while we also restrict to two states, we consider a continuum of heterogeneous receivers, each with a continuum of actions. This framework is more suitable to investigate public messages addressed to an entire population, beyond our specific model. Moreover, our analysis also yields some insights of technical interest for game theorists, since it shows that some of the results obtained for the two-audience and two-action case do not generalize.[13]

An important contribution of our paper is to reveal a connection between inequality and transparency. In this sense, our work also relates to the literature on the effects of inequality on resource allocation (and growth).[14] An important message of this literature is that in the presence of distortions (capital market imperfections in most papers), inequality aggravates the misallocation of resources. In our case too, an existing distortion such as income taxation induces a benevolent government to create an additional distortion in the transmission of information. The magnitude of this effect depends on income inequality and on labor supply elasticity. This result is in line with Esteban and Ray (2006) where the misallocation of resources created by an efficiency seeking government is positively associated with inequality.

Finally, in the concluding section we present a simple empirical exercise, showing a significant negative correlation between fiscal transparency and several measures of economic distortions. To the best of our knowledge, this relationship has not been studied by the literature. This is especially true for the emerging and burgeoning work on the causes and effects of fiscal transparency (e.g., Alt and Lowry, 2010; Alt et al., 2006; Alt and Lassen, 2006; Andreula et al., 2009; Ardanaz, 2011).

3 Transparency and distortions

In this section we shall abstract from the origin of the distortion in the allocation of resources. The distortion will be considered exogenous and

[13]Farrell and Gibbons (1989) show that in what they call a ‘coherent’ game, the sender prefers separating to pooling, ex post and therefore also ex ante. This is not true in our model, although, for a natural extension of their definition of ‘coherence’, our game is also coherent. Indeed, their argument critically depends on the two-action assumption.

[14]See the survey by Bénabou (1996).

affecting individual payoffs via individual choices. In the following sections we shall extend the analysis of two specific cases of distortion. This will permit to examine the link between the origin of the distortion and the government's information policy.

3.1 The economy

Consider an economy with a mass one of identical individuals, who make simultaneous choices. Individual $i \in [0,1]$ chooses an action $s_i \geq 0$ and obtains payoff $u(s_i, S, \lambda, \theta)$, where $S = \int_0^1 s_i \, \mathrm{d}i$ is the average (or aggregate) action in the population, $\lambda \geq 0$ is a parameter capturing distortions and θ is a random variable (an aggregate shock), which affects the productivity of individual actions. Using subscript numbers to denote a function's partial derivatives, we make the following assumptions on $u(s_i, S, \lambda, \theta)$, which are assumed to hold on the entire domain, unless otherwise specified.[15]

- The individual problem has an interior maximum:
  $u_{11} < 0$ and $\forall S, \lambda, \theta, \ \exists s > 0 : \ u_1(s, S, \lambda, \theta) = 0$.
- There are positive externalities: $u_2 \geq 0$, with equality only for $\lambda = 0$.
- There are no peer effects: $u_{12} = 0$.
- The social planner's problem has an interior maximum:
  $u_{11} + u_{22} < 0$ and $\forall \lambda, \theta, \ \exists s > 0 : \ u_1(s, s, \lambda, \theta) = 0$.
- λ strengthens externalities and reduces actions, but does not affect the social optimum: $u_{23} = -u_{13} > 0$.
- Luck is beneficial through own actions and externalities:
  $u_4(s, S, \lambda, \theta) > 0$ if either $s > 0$ or $S > 0$ and $\lambda > 0$.
- Luck boosts individual actions and makes externalities stronger:
  $u_{14} > 0$ and $u_{24} \geq 0$, with equality only for $\lambda = 0$.
- Given actions, luck has a linear effect on the payoff: $u_{44} = 0$.

[15] Rather than discussing these assumptions in the present abstract setting, we simply note that they generalize the two plausible and standard models of economies with monopoly power and taxation developed in the next sections.

Under perfect information on θ, each individual i would choose $s^*(\lambda, \theta) = \text{argmax}_s\, u(s, S, \lambda, \theta)$, determined by the first order condition $u_1(s, S, \lambda, \theta) = 0$ and satisfying $s^*_\lambda < 0$ and $s^*_\theta > 0$ and $s^*_S = 0$.[16] A benevolent social planner with a utilitarian welfare function would choose for each individual the same action $\hat{s}(\theta)$ by solving $\max_{\{s_i : i \in [0,1]\}} \int_0^1 u(s_i, S, \lambda, \theta)\, \mathrm{d}i$, which yields the FOC system $u_1(s_i, S, \lambda, \theta) + \int_0^1 u_2(s_j, S, \lambda, \theta)\, \mathrm{d}j = 0$ for all $i \in [0, 1]$. Given $u_{12} = 0$, this can be written as $u_1(s_i, S, \lambda, \theta) + u_2(s_i, S, \lambda, \theta) = 0$ for all $i \in [0, 1]$, which has a symmetric solution solving $u_1(s, s, \lambda, \theta) + u_2(s, s, \lambda, \theta) = 0$, and satisfying $\hat{s}_\theta > 0$ and $\hat{s}_\lambda = 0$. Notice that for any $\lambda > 0$, $s^*(\lambda, \theta) < s^*(0, \theta)$, so that λ introduces a downward distortion in actions relative to the social optimum.

3.2 The Announcements Game

We investigate what happens when the social planner knows the realization of θ, whereas individuals are not perfectly informed about it, and have to decide on the basis of beliefs, which in turn may be influenced by the planner's announcements. Specifically, we assume that information is as follows. First Nature draws θ from the following distribution, which is common knowledge:

$$\theta = \begin{cases} \vartheta & , \text{ with probability } p \\ -\vartheta & , \text{ with probability } (1-p) \end{cases}, \tag{1}$$

with $\vartheta > 0$ and $p \in (0, 1)$.[17] The planner observes the realization of θ and then chooses a (payoff irrelevant) message m from a set of feasible messages $M = \{L, H\}$. Individuals observe m, but not θ, and then simultaneously choose their actions to maximise expected payoff.

We consider a signaling equilibrium of this cheap talk game, with the additional but natural requirement that out of equilibrium beliefs are the same for everybody. Thus, a pure strategy *equilibrium* consists of: (i) a message function $m(\theta)$ mapping realizations of the random shock into messages, such that the planner's objective (ex-post social welfare) is maximized, given individual strategies; (ii) posterior beliefs $\Pr(\vartheta|m)$, which map each message into a subjective probability about the realization of the random variable,

[16] We use subscript letters instead of numbers to denote partial derivatives whenever this facilitates reading and does not create confusion.

[17] In this and in the following sections, the parameter ϑ can be interpreted as the amplitude of the cycle, which is assumed symmetric for analytical simplicity.

and which are derived from messaging strategies through Bayes' rule along the equilibrium path of play (and are the same for everybody following out-of-equilibrium messages); and (iii) individual strategies $s(m)$ mapping messages into actions, which maximize individual expected payoff, given posterior beliefs (and other individuals' strategies).[18]

3.3 Equilibrium with abstract distortions

Some notation will be useful throughout the paper. Let $\mu = \Pr(\theta = \vartheta | m = L)$ and $\nu = \Pr(\theta = \vartheta | m = H)$ describe individual posterior beliefs (for which we also use the notation $\Pr(\vartheta|m)$, for $m = L, H$). Let $E(x(\theta)|m) = \Pr(\vartheta|m)x(\vartheta) + [1 - \Pr(\vartheta|m)]x(-\vartheta)$ denote the expected value of a generic function $x(\theta)$, when expectations are based on posterior beliefs after receiving message $m = L, H$. And let $\bar{x}(\theta) = px(\vartheta) + (1-p)x(-\vartheta)$ denote its ex ante expected value, when expectations are based on prior beliefs.[19] Finally, let $\lambda^*(\mu, \nu)$ be the solution by λ of $u(s^*(L), s^*(L), \lambda, -\vartheta) = u(s^*(H), s^*(H), \lambda, -\vartheta)$, defined for $\mu \neq \nu$, where $s^*(m)$ is each individual's best response to message $m = L, H$.

The next proposition characterizes pure strategy equilibria (mixed strategy equilibria are characterized in footnote 21 and are not very insightful).

Proposition 1 (Equilibrium with abstract distortions)
An equilibrium in pure strategies always exists. Given μ and ν, individual strategies are $s^*(m) = \operatorname{argmax}_s E(u(s, S, \lambda, \theta)|m)$, for $m = L, H$. There are two possible types of pure strategy equilibrium.

- *At a pooling equilibrium $m^*(\vartheta) = m^*(-\vartheta) = H$ and $\mu \leq \nu = p$. A pooling equilibrium always exists.*

- *At a separating equilibrium $m^*(-\vartheta) = L$, $m^*(\vartheta) = H$, $\mu = 0$ and $\nu = 1$. A separating equilibrium exists if and only if $\lambda \leq \lambda^*(0, 1)$.*

Proof The proof consists of three steps: (i) given posterior beliefs, we determine individual best responses to the planner's messages, $s^*(m)$; (ii) we determine the planner's best response to individual strategies in each state of

[18] The mixed strategy extension is immediate.

[19] So expected utility after $m = L$ is $E(u(s, S, \lambda, \theta)|L) = \mu u(s, S, \lambda, \vartheta) + (1-\mu)u(s, S, \lambda, -\vartheta)$ and analogously for $E(u|H)$.

the world, $m^*(\theta)$; (iii) we impose that posterior beliefs are obtained through Bayes' rule along the equilibrium path of play.

1. Given μ and ν, $s^*(L)$ is the solution by s of $\mu u_1(s, S, \lambda, \vartheta) + (1-\mu)u_1(s, S, \lambda, -\vartheta) = 0$ and analogously, with ν in place of μ, for $s^*(H)$. Notice that S is immaterial to individual choices. Individual strategies $s^*(m)$ satisfy $s^*_\lambda(m) < 0$, for $m = L, H$, and $s^*_\mu(L) > 0$ and $s^*_\nu(H) > 0$.

2. $m^*(\theta) = \text{argmax}_{m\in\{L,H\}}\, u(s^*(m), s^*(m), \lambda, \theta)$. The planner is indifferent (and can thus randomize with any probability) between the two messages if $\mu = \nu$. If $\mu \neq \nu$, consider without loss of generality the case of $\mu < \nu$.

   In good times, $m^*(\vartheta) = H$. This is due to $s^*(L) < s^*(H) \leq \hat{s}(\vartheta)$, with the last inequality strict for $\lambda > 0$, and to $u_1(s, S, \lambda, \vartheta) > 0$ for $s < \hat{s}(\vartheta)$.

   In bad times, for any μ and ν such that $0 \leq \mu < \nu \leq 1$, there exists a unique $\lambda^*(\mu, \nu) > 0$, such that $m^*(-\vartheta) = L$ if $\lambda < \lambda^*(\mu, \nu)$, $m^*(-\vartheta) = H$ if $\lambda > \lambda^*(\mu, \nu)$ and the planner is indifferent between L and H if $\lambda = \lambda^*(\mu, \nu)$. To see this, let $W(s, \lambda, -\vartheta) = u(s, s, \lambda, -\vartheta)$ and notice that it is a continuous and inverted-U shaped function of s and that its point of maximum, $\hat{s}(-\vartheta)$, is independent of λ. The planner compares $W(s^*(L), \lambda, -\vartheta)$ with $W(s^*(H), \lambda, -\vartheta)$. Since $s^*(m)$ is strictly increasing in the posterior belief $\Pr(\vartheta|m)$, we have that $s^*(m) \in [s^0(\lambda), s^1(\lambda)]$, where $s^0(\lambda) = s^*(m)$ for $\Pr(\vartheta|m) = 0$ and $s^1(\lambda) = s^*(m)$ for $\Pr(\vartheta|m) = 1$, for $m = L, H$. Moreover, since $s^*(m)$ is strictly decreasing in λ, the same is true for $s^0(\lambda)$ and $s^1(\lambda)$. For $\lambda = 0$, we have $s^0(0) = \hat{s}(-\vartheta)$, so that $\forall \mu, \nu :\ 0 \leq \mu < \nu \leq 1,\ W(s^*(L), 0, -\vartheta) > W(s^*(H), 0, -\vartheta)$. For λ large enough, we have that eventually $s^1(\lambda) \leq \hat{s}(-\vartheta)$ (to see this, notice that $u_1(s^1(\lambda), s^1(\lambda), \lambda, -\vartheta) + u_2(s^1(\lambda), s^1(\lambda), \lambda, -\vartheta) > 0$, because both terms are strictly positive), so that $\forall \mu, \nu :\ 0 \leq \mu < \nu \leq 1,\ W(s^*(L), \lambda, -\vartheta) < W(s^*(H), \lambda, -\vartheta)$. The result is then proven by observing that, given any $\mu, \nu :\ 0 \leq \mu < \nu \leq 1$, we have that for any finite λ, $s^*(L) < s^*(H)$, and that both $s^*(L)$ and $s^*(H)$ decrease continuously in λ, passing from being both above $\hat{s}(-\vartheta)$ (at least weakly for $s^*(L)$) when $\lambda = 0$ to being both below it (at least weakly for $s^*(H)$) when λ is sufficiently large. Therefore there exists a unique $\lambda^*(\mu, \nu)$, such that for $\lambda = \lambda^*(\mu, \nu)$, $s^*(L) < \hat{s}(-\vartheta) < s^*(H)$ and $W(s^*(L), \lambda, -\vartheta) = W(s^*(H), \lambda, -\vartheta)$. And we have that $\lambda^*(\mu, \nu) > 0$;

that $m^*(-\vartheta) = L$ if $\lambda < \lambda^*(\mu, \nu)$; that $m^*(-\vartheta) = H$ if $\lambda > \lambda^*(\mu, \nu)$; and that the planner is indifferent between L and H if $\lambda = \lambda^*(\mu, \nu)$.

3. Consider a candidate pooling equilibrium. The planner sends the same message H in both states of the world. Along the equilibrium path of play, i.e., upon receiving H, individuals do not learn anything and have to base decisions on their prior beliefs: Bayes' rule implies $\nu = p$. Then by the previous point, the planner does not deviate in good times if and only if $\mu \leq p$. The pooling equilibrium is babbling if $\mu = \nu$ and non babbling if $\mu < \nu$.[20] If $\mu < p$, the planner does not deviate in bad times if and only if $\lambda \geq \lambda^*(\mu, p)$. In turn, if $\mu = \nu$, the planner never deviates in bad times. So a babbling equilibrium always exists.

   Now consider a candidate separating equilibrium. The planner announces H in good times and L in bad times. Bayes' rule then implies $\mu = 0$ and $\nu = 1$. Given this, the planner never deviates in good times. It does not deviate in bad times either, if and only if $\lambda \leq \lambda^*(0, 1)$.[21]

■

Proposition 1 shows that there always exists an equilibrium in which the planner is non informative. Furthermore, a transparent equilibrium in which the planner reveals its private information also exists if and only if distortions are sufficiently small. If distortions are large, and thus individual actions are

[20] A babbling equilibrium is an equilibrium in which individual strategies disregard the planner's announcement, and the planner's signaling strategy disregards the realization of the shock. The only difference between babbling and non babbling pooling equilibria is in terms of out of equilibrium beliefs.

[21] There are only two possible types of mixed strategy equilibria: (i) babbling equilibria, in which the planner randomizes with any $\Pr(m(-\vartheta) = H) = \Pr(m(\vartheta) = H) = \rho \in (0, 1)$ and $\mu = \nu = p$; and (ii) semi-separating equilibria, in which $m(\vartheta) = H$ and the planner randomizes in bad times with some $\Pr(m(-\vartheta) = H) = \rho \in (0, 1)$, with posterior beliefs $\mu = 0$ and $\nu = \frac{p}{p+(1-p)\rho}$. Mixed strategies babbling equilibria always exist. A semi-separating equilibrium exists if and only if $\lambda = \lambda^*\left(0, \frac{p}{p+(1-p)\rho}\right)$. To see this, notice that in good times the planner is willing to mix if and only if $\mu = \nu$, which is only compatible with babbling equilibria. So, without loss of generality, non babbling equilibria in mixed strategies imply $\mu < \nu$ and $m(\vartheta) = H$, i.e., they may only be semi-separating. For $\rho \in \{0, 1\}$, we have the two pure strategy equilibria considered above. For $\rho \in (0, 1)$, Bayes' rule implies $\mu = 0$ and $\nu = \frac{p}{p+(1-p)\rho}$. Given this, the planner does not deviate in good times. It does not deviate in recessions either, if and only if $\lambda = \lambda^*\left(0, \frac{p}{p+(1-p)\rho}\right)$.

seriously downward distorted with respect to the social optimum, a benevolent planner has a strong incentive to hide bad news, and this disrupts the possibility that in equilibrium it is transparent.

3.4 Efficiency

Let us now compare the pooling and the separating equilibria from an ex ante point of view, that is, when averages (or expected values) are based on the prior distribution of shocks. Let $\bar{u}^S$ and $\bar{u}^P$ denote the ex ante expected levels of social welfare (equivalently, of individual payoff), at a separating and at a pooling equilibrium, respectively.

Proposition 2 (Ex ante Pareto dominance)
The separating equilibrium ex ante Pareto dominates the pooling equilibrium ($\bar{u}^S > \bar{u}^P$), if and only if equilibrium payoff under perfect information is a convex function of the random variable θ.

Proof Let $u^S(\theta)$ and $u^P(\theta)$ be social welfare at a separating and at a pooling equilibrium, respectively, when the state of the world is θ. Let $s^S(\theta)$ be the action chosen under perfect information about the state of the world (as it happens at a separating equilibrium), which solves by s $u_1(s, S, \lambda, \theta) = 0$. Let s^P be the action chosen at a pooling equilibrium. Linearity of the payoff in θ ($u_4 > 0$ and $u_{44} = 0$) implies linearity of the marginal payoff in θ ($u_{14} > 0$ and $u_{144} = 0$) and so it implies that $s^P = s^S(\bar{\theta})$, since it solves $pu_1(s, S, \lambda, \vartheta) + (1 - p)u_1(s, S, \lambda, -\vartheta) = u_1(s, S, \lambda, \bar{\theta}) = 0$, where $\bar{\theta} = p\vartheta + (1 - p)(-\vartheta)$. It also implies that $\bar{u}^P = u^S(\bar{\theta})$. To see this, observe that $u^S(\bar{\theta}) = u(s^S(\bar{\theta}), s^S(\bar{\theta}), \lambda, \bar{\theta}) = pu(s^P, s^P, \lambda, \vartheta) + (1-p)u(s^P, s^P, \lambda, -\vartheta)$. Consider now the function $W(\theta) = u(s^S(\theta), s^S(\theta), \lambda, \theta)$. We have that $\bar{u}^S = pW(\vartheta) + (1-p)W(-\vartheta)$ and $\bar{u}^P = W(\bar{\theta})$, so that $\bar{u}^S > \bar{u}^P \iff W''(\theta) > 0$. ■

Proposition 2 implies that a benevolent planner ex-ante sees transparency as preferable to opaqueness if and only if the shocks, if publicly observed, would have a convex effect on the equilibrium payoff. In this case, opaqueness would induce actions responding to the expected values of the random variable yielding a lower payoff because of the convexity condition. Because of the same argument, concavity would make opaqueness ex ante preferable.

3.5 Implications of the main results

We have assumed an economy subject to a distortion and that experiences random shocks, over which the planner has private information. The planner decides on its information policy in view to maximize social welfare. Notice that the most preferred policy before knowing the realization of the random shock might be different from the one preferred after knowing it. We assume that the government cannot credibly commit and hence chooses the policy that maximizes ex-post social welfare. Our results say that if the distortion is large enough, the only equilibrium policy entails opaqueness because the planner always finds it ex-post preferable to hide negative shocks. The consequence of this is that individuals in equilibrium fully distrust the planner's announcements. If the distortion is small, truth-telling can be an equilibrium, together with opaqueness.[22] However, transparency will be ex ante seen as preferable to opaqueness if and only if, under full information, the individual payoff is convex in the random variable. If this condition is satisfied, the planner would ex ante prefer to be transparent, but, if distortions are substantial in magnitude, will be opaque in equilibrium. In this case, delegating information policy to a separate agency, committed to transparency, would be beneficial.

In the next sections we examine two different potential sources of distortions and apply our general results to obtain the corresponding equilibrium information policy.

4 Transparency and monopoly power

In the first extension of the abstract model we consider an economy with a monopolistic distortion. The model is a simplified version of the canonical RBC model with no capital and a continuum of differentiated goods. To focus on the information analysis, we abstract from dynamic considerations.[23]

[22] Note that this result has a clear "second best" flavor. Hiding information is in itself a distortion, relative to full information. However, given the presence of other distortions in the economy, it may well be that this additional distortion ends up increasing aggregate welfare.

[23] See, e.g., Angeletos and La'O (2009). Relative to their analysis, we also abstract from dispersed information (as we did in our abstract model).

4.1 The economy

There is a mass one of identical individuals, who work, consume and own shares of a mass one of firms, each producing a different variety of a consumption good. Utility depends on consumption and labor:

$$u(c, \ell) = c - \frac{\ell^\delta}{\delta}, \tag{2}$$

where c is the Dixit-Stiglitz aggregator $c = \left(\int_0^1 c_i^{\frac{\sigma-1}{\sigma}} \mathrm{d}i\right)^{\frac{\sigma}{\sigma-1}}$, c_i represents consumption of variety i, the parameter $\sigma > 1$ is the elasticity of substitution between any two varieties and the parameter $\delta > 1$ captures the degree of convexity of labor supply, which is linear in the wage for $\delta = 2$, strictly convex for $\delta \in (1, 2)$ and strictly concave for $\delta > 2$. Firms produce with an identical linear technology: by using ℓ_i units of labor, firm i produces $y_i = A\ell_i$ units of its variety of good. Labor productivity is $A = \tilde{A} + \theta$, so it is the same for every firm, but it depends on two factors: the observable component $\tilde{A} > 0$ and the ex-ante unobservable component θ (say, being in a boom or in recession), distributed according to (1). We assume $\vartheta \in (0, \tilde{A})$ to assure that productivity is always positive.[24]

Under perfect information on θ, the equilibrium of this economy is very simple. Individuals choose $\{c_i : \ i \in [0, 1]\}$ and ℓ to maximise $u(c, \ell)$ under the budget constraint $\int_0^1 p_i c_i \,\mathrm{d}i = w\ell + \pi$, taking the wage rate w, prices p_i's and distributed profits π as given.[25] Their labor supply is $\ell = \left(\frac{w}{P}\right)^{\frac{1}{\delta-1}}$, where $P = \left(\int_0^1 p_i^{1-\sigma} di\right)^{\frac{1}{1-\sigma}}$ is the aggregate price index. Their demand of good i is $c_i = \left(\frac{p_i}{P}\right)^{-\sigma} c$.

Each firm i sets price p_i to maximise profits $\pi_i = p_i y_i - w\ell_i$, taking technology, demand, other firms' prices and the wage rate as given. It thus prices according to the mark-up rule $p_i = \frac{\sigma}{\sigma-1}\frac{w}{A}$ and demands labor $\ell_i = \frac{c_i}{A}$. Since prices are the same for every firm, the same holds for quantities:

[24] It is immediate to extend the model to the case in which firm productivity is heterogeneous. We present the identical firms version for expositional simplicity, as it is sufficient to convey the main insights.

[25] Here we assume that individuals are identical both in productivity and in shareholding. We discuss the role of heterogeneous productivity in the next section. Heterogeneity in shareholding would make no relevant changes in the present model, since it would affect the distribution of income but not individual behavior, as individuals take distributed profits as given.

$\forall i,\ p_i = P$ and $c_i = c$. The real wage $\frac{w}{P} = \frac{\sigma-1}{\sigma}A$ is below labor productivity. Labor supply is then $\ell = \left(\frac{\sigma-1}{\sigma}A\right)^{\frac{1}{\delta-1}}$, consumption is $c = \left(\frac{\sigma-1}{\sigma}\right)^{\frac{1}{\delta-1}} A^{\frac{\delta}{\delta-1}}$, real profits are $\frac{\pi}{P} = \frac{c}{\sigma}$ and equilibrium utility is $u(c,\ell) = \left(\frac{\sigma-1}{\sigma}\right)^{\frac{1}{\delta-1}} A^{\frac{\delta}{\delta-1}} \left(1 - \frac{\sigma-1}{\delta\sigma}\right)$. Taking c as the numeraire, so that $P = 1$, the nominal part of the economy is also easily determined.

Three observations are in order. First, monopoly power drives a wedge between real wage and productivity, imposing a suboptimal downward distortion in individual labor supply, relative to the (first best) social optimum, which would require $\ell = A^{\frac{1}{\delta-1}}$. Second, this distortion is higher, the lower the elasticity of substitution σ. Indeed, profit distribution creates a positive externality from labor supply, which is not taken into account by individual choices, and (real) profits are decreasing in σ. Third, equilibrium utility is convex in A and therefore in θ. This last observation makes planner transparency Pareto-superior to opaqueness from an ex-ante point of view, since, as it is easy to check, this model adds economic structure to the specification of actions and their relation to utility, but it satisfies all the assumptions of the previous one.

4.2 The Announcements Game

Consider now imperfect information, with the following structure. First Nature draws θ from distribution (1), which is common knowledge. The planner observes the realization of θ and then chooses a (payoff irrelevant) message $m \in \{L, H\}$ to maximize (ex post) social welfare. Individuals observe m, but not θ, and then simultaneously choose their labor supply to maximize expected utility. Next, production takes place and reveals the realization of θ to everybody, so that prices p_i's, consumption choices c_i's, the wage rate w, and profits π are all determined under full information. Ex post social welfare is $W(\theta, m) = \int_0^1 u(c(\theta, m, \ell^*(m)), \ell^*(m))\,\mathrm{d}i$, where $c(\theta, m, \ell^*(m))$ and $\ell^*(m)$ are the equilibrium values of consumption and labor supply.

4.3 Equilibrium with monopoly power

The following proposition parallels Proposition 1. Let

$$
\begin{aligned}
x_\mu &= E(A|L)^{\frac{1}{\delta-1}} = [\tilde{A} + (2\mu - 1)\vartheta]^{\frac{1}{\delta-1}} \\
x_\nu &= E(A|H)^{\frac{1}{\delta-1}} = [\tilde{A} + (2\nu - 1)\vartheta]^{\frac{1}{\delta-1}}
\end{aligned}
$$

and, for $\mu \neq \nu$, let

$$
\sigma^*(\mu, \nu) = \frac{x_\nu^\delta - x_\mu^\delta}{x_\nu^\delta - x_\mu^\delta - \delta(x_\nu - x_\mu)(\tilde{A} - \vartheta)}. \tag{3}
$$

Proposition 3 (Equilibrium with monopoly power)
Given μ and ν, individuals' strategies are
$\ell^*(m) = E\left(\frac{w}{P}|m\right)^{\frac{1}{\delta-1}} = \left\{\left(\frac{\sigma-1}{\sigma}\right)\left[\tilde{A} + E(\theta|m)\right]\right\}^{\frac{1}{\delta-1}}$ *and*
$c_i(\theta, m, \ell) = \left[\frac{p_i(\theta,m,\ell)}{P(\theta,m,\ell)}\right]^{-\sigma} c(\theta, m, \ell)$.
Firms' strategies are $p_i(\theta, m, \ell) = \frac{\sigma}{\sigma-1}\frac{w(\theta,m,\ell)}{\tilde{A}+\theta}$.
There are two possible types of pure strategy equilibrium.

- *At a pooling equilibrium $m(\vartheta) = m(-\vartheta) = H$ and $\mu \leq \nu = p$. A pooling equilibrium always exists.*

- *At a separating equilibrium $m(-\vartheta) = L$, $m(\vartheta) = H$, $\mu = 0$ and $\nu = 1$. A separating equilibrium exists if and only if $\sigma \geq \sigma^*(0, 1)$.*

Proof At the last stage of the game, individuals demand $c_i(\theta, m, \ell) = \left[\frac{p_i(\theta,m,\ell)}{P(\theta,m,\ell)}\right]^{-\sigma} c(\theta, m, \ell)$ of each good i, where ℓ denotes aggregate labor supply, which they take as given. Firms set prices $p_i(\theta, m, \ell) = \frac{\sigma}{\sigma-1}\frac{w(\theta,m,\ell)}{\tilde{A}+\theta}$, and demand labor $\ell_i(\theta, m, \ell) = \frac{c_i(\theta,m,\ell)}{\tilde{A}+\theta}$, for any i. This implies that for all θ, m, ℓ and for all i, $p_i(\theta, m, \ell) = P(\theta, m, \ell)$, $c_i(\theta, m, \ell) = c(\theta, m, \ell)$ and $\ell_i(\theta, m, \ell) = \ell = \frac{c(\theta,m,\ell)}{\tilde{A}+\theta}$, so that $\frac{w(\theta,m,\ell)}{P(\theta,m,\ell)} = \left(\frac{\sigma-1}{\sigma}\right)(\tilde{A} + \theta)$ and $\frac{\pi(\theta,m,\ell)}{P(\theta,m,\ell)} = \frac{c(\theta,m,\ell)}{\sigma}$. Taking c as numeraire (across different states, that is, setting $P(\theta, m, \ell) = 1$ for all θ, m, ℓ), all nominal prices are immediately determined as well.

At the previous stage of the game, individuals' labor supply is given by $\ell^*(m) = \text{argmax}_\ell \left[E(c|m) - \frac{\ell^\delta}{\delta}\right] = \text{argmax}_\ell \left[E(\frac{w\ell+\pi}{P}|m) - \frac{\ell^\delta}{\delta}\right]$, for $m = L, H$, where ℓ now denotes individual labor supply. Since there is a mass one of identical individuals, $\ell^*(m)$ is both individual and aggregate labor supply, implying that later consumption is $c(\theta, m, \ell^*(m)) = (\tilde{A} + \theta)\ell^*(m) = (\tilde{A} + \theta)\left\{\left(\frac{\sigma-1}{\sigma}\right)\left[\tilde{A} + E(\theta|m)\right]\right\}^{\frac{1}{\delta-1}}$. Social welfare and individual utility are thus $W(\theta, m) = u(c(\theta, m, \ell^*(m)), \ell^*(m)) = (\tilde{A} + \theta)\left\{\left(\frac{\sigma-1}{\sigma}\right)\left[\tilde{A} + E(\theta|m)\right]\right\}^{\frac{1}{\delta-1}} - \frac{1}{\delta}\left\{\left(\frac{\sigma-1}{\sigma}\right)\left[\tilde{A} + E(\theta|m)\right]\right\}^{\frac{\delta}{\delta-1}}$.

In each state of the world, the planner is indifferent between the two messages if $\mu = \nu$. If $\mu \neq \nu$, consider without loss of generality $\mu < \nu$.

In booms, given $\mu < \nu$, we have $m(\vartheta) = H$. To see this, notice that $W(\vartheta, H) > W(\vartheta, L) \iff \left(\frac{\sigma-1}{\sigma}\right)^{\frac{1}{\delta-1}}(\tilde{A}+\vartheta)(x_\nu - x_\mu) > \frac{1}{\delta}\left(\frac{\sigma-1}{\sigma}\right)^{\frac{\delta}{\delta-1}}\left(x_\nu^\delta - x_\mu^\delta\right)$. Letting $X = \frac{x_\nu^\delta - x_\mu^\delta}{\delta(x_\nu - x_\mu)}$, this condition is equivalent to $\left(\frac{\sigma}{\sigma-1}\right)(\tilde{A} + \vartheta) > X$. Convexity of the function $\frac{x^\delta}{\delta}$ implies that $X < x_\nu^{\delta-1} = E(A|H)$, so that $W(\vartheta, H) > W(\vartheta, L)$.

In recessions, given $\mu < \nu$, we have $m(-\vartheta) = L$ if $\sigma > \sigma^*(\mu, \nu)$ and $m(-\vartheta) = H$ if $\sigma < \sigma^*(\mu, \nu)$. To see this, notice that $W(-\vartheta, H) > W(-\vartheta, L) \iff \left(\frac{\sigma}{\sigma-1}\right)(\tilde{A} - \vartheta) > X$. The left hand side ($LHS$) of the last inequality is decreasing in σ, with $\lim_{\sigma\to 1} LHS = \infty$, whereas X is finite and independent of σ. By convexity of the function $\frac{x^\delta}{\delta}$, we have $X > x_\mu^{\delta-1} = E(A|L)$. Since $\lim_{\sigma\to\infty} LHS \leq E(A|L)$, we have that $W(-\vartheta, H) = W(-\vartheta, L)$ for $\sigma = \sigma^*(\mu, \nu)$, that this threshold is above 1 and that the planner in recessions announces H for $\sigma < \sigma^*(\mu, \nu)$ and L for $\sigma > \sigma^*(\mu, \nu)$.

Consider a candidate pooling equilibrium. The planner sends the same message H both in booms and in recessions. Along the equilibrium path of play, Bayes' rule implies $\nu = p$. The planner does not deviate in booms if and only if $\mu \leq p$. If $\mu < \nu$, the planner does not deviate in recessions if and only if $\sigma \leq \sigma^*(\mu, p)$. In turn, if $\mu = \nu$, the planner never deviates in recessions, the equilibrium is babbling and it always exists.

Now consider a candidate separating equilibrium. The planner announces H in booms and L in recessions. Bayes' rule then implies $\mu = 0$ and $\nu = 1$. Given this, the planner does not deviate in booms. It does not deviate in recessions either, if and only if $\sigma \geq \sigma^*(0, 1)$.[26] ■

[26] The structure of mixed strategy equilibria is analogous to that of the abstract model and is not reported.

4.4 Efficiency

Let us now compare the different equilibria from an ex ante point of view. Let $\bar{\ell}^S$, $\bar{y}^S$, $\bar{u}^S$, and $\bar{\ell}^P$, $\bar{y}^P$, $\bar{u}^P$, denote the ex ante expected levels of labor supply, production and indirect utility, at a separating and at a pooling equilibrium, respectively. Independently of equilibrium existence, the following holds.

Proposition 4 (Ex ante Pareto dominance)
For any parameter constellation, the following holds: (i) $\bar{\ell}^S < \bar{\ell}^P \iff \delta > 2$; (ii) $\bar{y}^S > \bar{y}^P$; (iii) $\bar{u}^S > \bar{u}^P$.

Proof Ex ante expected levels of labor supply, production (equivalently, consumption) and indirect utility (equivalently, social welfare) at the two equilibria are, respectively,

$$\begin{aligned}
\bar{\ell}^S &= \left(\frac{\sigma-1}{\sigma}\right)^{\frac{1}{\delta-1}} \left[p(\tilde{A}+\vartheta)^{\frac{1}{\delta-1}} + (1-p)(\tilde{A}-\vartheta)^{\frac{1}{\delta-1}}\right] \\
\bar{\ell}^P &= \ell^P = \left(\frac{\sigma-1}{\sigma}\right)^{\frac{1}{\delta-1}} \left[(\tilde{A}+\bar{\theta})^{\frac{1}{\delta-1}}\right] \\
\bar{y}^S &= \left(\frac{\sigma-1}{\sigma}\right)^{\frac{1}{\delta-1}} \left[p(\tilde{A}+\vartheta)^{\frac{\delta}{\delta-1}} + (1-p)(\tilde{A}-\vartheta)^{\frac{\delta}{\delta-1}}\right] \\
\bar{y}^P &= \left(\frac{\sigma-1}{\sigma}\right)^{\frac{1}{\delta-1}} (\tilde{A}+\bar{\theta})^{\frac{\delta}{\delta-1}} \\
\bar{u}^S &= \left(\frac{\sigma-1}{\sigma}\right)^{\frac{1}{\delta-1}} \left[1-\frac{1}{\delta}\left(\frac{\sigma-1}{\sigma}\right)^{\frac{\delta}{\delta-1}}\right] \left[p(\tilde{A}+\vartheta)^{\frac{\delta}{\delta-1}} + (1-p)(\tilde{A}-\vartheta)^{\frac{\delta}{\delta-1}}\right] \\
\bar{u}^P &= \left(\frac{\sigma-1}{\sigma}\right)^{\frac{1}{\delta-1}} \left[1-\frac{1}{\delta}\left(\frac{\sigma-1}{\sigma}\right)^{\frac{\delta}{\delta-1}}\right] (\tilde{A}+\bar{\theta})^{\frac{\delta}{\delta-1}}.
\end{aligned}$$

Points (i), (ii) and (iii) then immediately follow by convexity (or concavity). Point (iii) can also be seen as a corollary of Proposition 2. ■

Proposition 4 establishes that, for any degree of monopoly power, transparent and credible revelation of information is ex ante Pareto superior to information hiding. Yet, as we already know from the previous analysis, high monopoly power may prevent the transparent outcome from materializing in equilibrium.[27] The intuition is very simple. Transparency allows individuals to work more when they are more productive and less when they are less productive. This unequivocally raises the ex ante level of production (and welfare), relative to no information disclosure. Although it also raises the ex ante level of disutility from labor (since workers dislike fluctuations in labor effort), this latter effect is always more than compensated by the higher expected level of consumption (hence the effect on welfare).[28]

4.5 Equilibrium selection

As in the abstract model, when distortions are not too large, i.e., here, for $\sigma \geq \sigma^*(0,1)$, both a separating and a pooling equilibrium exist. It is then natural to ask which equilibrium is more plausible in this case.

Ex ante Pareto dominance selects the separating equilibrium whenever it exists, but it is not (always) a good selection criterion in the present context, because, whenever $\sigma \in [\sigma^*(0,1), \sigma^*(0,p)]$, planner's preferences over equilibria are reversed in different states of the world: in booms the planner would prefer to be in a separating equilibrium, in which it reveals its private information, thus boosting labor supply and welfare; in recessions it would prefer to be in a pooling equilibrium, in which information is not revealed, so that labor supply and welfare are higher than with perfect information.[29] It is therefore worthwhile to look at different equilibrium refinements.

In cheap talk games, standard refinements based on Kohlberg and Mertens (1986), which restrict off-the-equilibrium-path beliefs have little power, because mixed strategy babbling equilibria always survive them. We consider a recent refinement, explicitly introduced by Chen et al. (2008) to select equilibria in cheap-talk games, called No Incentive to Separate (NITS); and a stronger refinement, the Neologism Proof equilibrium, proposed by Farrell

[27] Notice that, for any parameter constellation, ex ante expected levels of individual labor supply, production and indirect utility, whose relationships are identified in Proposition 4, are well defined, independently of whether a separating equilibrium exists.

[28] Transparency raises expected leisure time if the elasticity of labor supply is $\gamma = \frac{1}{\delta-1} < 1$ (i.e., for $\delta > 2$). In this case, labor supply is a concave function of expected wages. This implies that, relative to the case of no information, labor supply reductions in recessions are more pronounced than increases in booms. If the elasticity of labor supply is $\gamma > 1$ (i.e., for $\delta < 2$), by contrast, labor supply is a convex function of expected wages. In this case, transparency raises expected labor supply, relative to information hiding.

[29] The proof of this claim immediately follows from the proof of Lemma 2 in Appendix, whereas the fact that $\sigma^*(0,p) > \sigma^*(0,1)$ follows from Lemma 1 in Appendix.

(1993). In the Appendix we define such concepts in the context of our model and show that, whenever it exists, the separating equilibrium satisfies both NITS and NP. Moreover, whenever existing, it is the only NP equilibrium.

The implication is that, for $\sigma \geq \sigma^*(0,1)$, the separating equilibrium appears the most natural prediction of the game. In light of this, we conduct the following comparative statics exercises assuming that the economy coordinates on the transparent equilibrium whenever it exists.

4.6 Transparency, productivity and shock intensity

We have obtained that there is a threshold level $\sigma^*(0,1)$ such that if the elasticity is above —i.e., the distortion is "small"— information transparency is an equilibrium policy (indeed, the most natural prediction of the game). We refer to the interval $[\sigma^*(0,1),\infty)$ as to the support of transparency and say that parameter changes favor (reduce) transparency if they decrease (increase) $\sigma^*(0,1)$.

One might expect that an increase in productivity favors transparency and an increase in shock magnitude harms it. To show in the simplest way that exactly the opposite may be true, it is convenient to focus on the case of linear labor supply ($\delta = 2$). In this case expression (3) simplifies to $\sigma^*(0,1) = \frac{\tilde{A}}{\vartheta}$, making clear that only relative shock magnitude matters for transparency and that economies subject to relatively higher shocks have a larger support for transparency. While this may be surprising, from the theoretical point of view it is a direct consequence of the way in which the support for transparency is determined, namely by the welfare comparison that a credible planner makes between revealing or not information on a recession. When $\sigma = \sigma^*(0,1)$, a credible planner is indifferent between the two alternatives. This is because the monopolistic distortion (the underwork caused by monopoly power under truthful revelation) is equivalent (in welfare terms) to the information distortion (the overwork arising if the planner lies). An increase in relative shock magnitude raises the information distortion relative to the monopolistic distortion, and therefore raises the relative cost of lying and expands the support for transparency. The full generalization of this result to arbitrary parameter values proves complex, but for small shocks it is easy to show that, for any parameter constellation (not only for $\delta = 2$), an increase in shock magnitude favors transparency.[30] While shock

[30]To prove this result, write $\sigma^*(0,1) = \frac{1}{1-q(0,1)}$ as in Lemma 1 in Appendix and observe

magnitude matters for transparency, shock frequency does not, because the threshold $\sigma^*(0,1)$ is determined conditionally on being in recession.

It is interesting to notice that our model features a fixed elasticity of labor supply to expected wages, equal to $\gamma = \frac{1}{\delta - 1}$. Yet, while actual wages do not depend on whether equilibrium information is transparent or not, expected wages, and thus actual labor supply, do depend on the information regime. In particular, they fluctuate over the business cycle under transparency but not under opaqueness. As a result, the elasticity of labor supply to actual wages over the business cycle is zero for an economy with large monopolistic distortions and therefore opaque information, whereas it is positive and equal to γ for an economy with the same value of δ, but with lower monopoly power and therefore transparent information. As a consequence, all else equal, the model predicts that income fluctuations over the business cycle will also be more pronounced in economies with more competitive product markets and therefore transparent rather than opaque information. The importance of information and expectations is an aspect that tends to be overlooked in the empirical debate on the estimates of labor supply elasticity, which in our view deserves more attention.

5 Transparency, taxation and inequality

As a second extension of the abstract model, consider now an economy in which distortions arise from taxation rather than from monopoly power. Income taxes push net wages below individual productivity and thus make labor effort inefficiently low, as individuals do not internalize the externality emerging from the redistribution of tax revenues, exactly as they did not internalize the externality arising from the distribution of firms' profits in the previous model. An important advantage of this approach is that it provides the natural environment to discuss the role of inequality and its effects on transparency.

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that $\frac{\partial \sigma^*(0,1)}{\partial \vartheta}$ is equal in sign to $\frac{\partial q(0,1)}{\partial \vartheta}$. By applying L'Hôpital's rule it is easy to obtain that $\lim_{\vartheta \to 0} \frac{\partial q(0,1)}{\partial \vartheta} = -\frac{1}{\bar{A}} < 0$, so that $\left.\frac{\partial \sigma^*(0,1)}{\partial \vartheta}\right|_{\vartheta=0} < 0$.

5.1 The economy

There is a mass one of individuals, who have identical preferences over a homogeneous consumption good c and over labor effort ℓ, described by (2), but who differ in productivity. Individuals earn competitive wages and produce with a linear technology, so that labor income y (equivalently, production, taken as numeraire) is simply equal to individual supply of efficiency units of labor. Individual productivity depends on two factors: an idiosyncratic observable component (ability or human capital), denoted β and distributed according to the cumulative distribution function F, with support on the non empty interval $[b, B) \subset \mathbb{R}_+$; and the aggregate, ex-ante unobservable, random component θ (being in boom or in recession), distributed according to (1), with $\vartheta \in (0, b)$ to assure that individual productivity is always positive.

Individual labor income therefore depends on effort, ability and aggregate conditions, $y_\beta = (\beta + \theta)\ell_\beta$. Labor income is taxed at a constant marginal rate $t \in (0, 1)$ and tax revenues $T = \int_b^B t y_\beta dF(\beta)$ are equally redistributed, so that individual consumption is equal to $c_\beta = (1 - t)y_\beta + T$. Since the population is continuous, each individual takes T as given.[31]

From our assumption on preferences it is immediate to obtain that, if individuals could observe the realization of θ before choosing their effort level, they would choose $\ell_\beta = [(1 - t)(\beta + \theta)]^{\frac{1}{\delta-1}}$ and produce $y_\beta = (1 - t)^{\frac{1}{\delta-1}}(\beta + \theta)^{\frac{\delta}{\delta-1}}$. Taxes impose a downward distortion in individual effort supply, relative to the social optimum, which would require $\ell_\beta = (\beta + \theta)^{\frac{1}{\delta-1}}$. Equilibrium social welfare under perfect information is $W = \int_b^B u_\beta dF(\beta) = \left(\frac{\delta-1+t}{\delta}\right)(1 - t)^{\frac{1}{\delta-1}} \int_b^B (\beta + \theta)^{\frac{\delta}{\delta-1}} dF(\beta)$, which is convex in θ. Therefore, we can expect transparency to be Pareto-superior to opaqueness from an ex-ante point of view.

5.2 The Announcements Game

Consider now imperfect information. First Nature draws θ from (1). Both F and the distribution of θ are common knowledge. The planner observes the realization of θ and then chooses a (payoff irrelevant) message $m \in \{L, H\}$.

[31] The tax collection per capita T will depend on the realization of θ. Therefore, individuals will entertain conjectures about their value. As we shall see, because of our assumption on individual preferences these conjectures are immaterial because they have no effect on labor supply.

Individuals observe m, but not θ, and then simultaneously choose their labor effort to maximize utility. Ex-post the realization of θ is observed by all individuals, who are paid accordingly. The aim of the planner is to maximise social welfare $W = \int_b^B u_\beta dF(\beta)$, where u_β denotes the utility of an individual with ability β and depends on t, on θ, on individual labor effort ℓ_β, and on the labor effort chosen by the entire population (since T depends on it). The equilibrium concept and the notation on beliefs and expectations is as above.

5.3 Equilibrium with taxation and inequality

The following proposition parallels Propositions 1 and 3. With a slight abuse of notation, but in the same spirit as in the previous section, let

$$\begin{aligned} x_\mu &= [\beta + E(\theta|L)]^{\frac{1}{\delta-1}} = [\beta + (2\mu - 1)\vartheta]^{\frac{1}{\delta-1}}, \\ x_\nu &= [\beta + E(\theta|H)]^{\frac{1}{\delta-1}} = [\beta + (2\nu - 1)\vartheta]^{\frac{1}{\delta-1}} \end{aligned}$$

and, for $\mu \neq \nu$,

$$t^*(\mu, \nu) = 1 - \frac{\int_b^B (\beta - \vartheta)(x_\nu - x_\mu)\, \mathrm{d}F(\beta)}{\int_b^B \frac{1}{\delta}(x_\nu^\delta - x_\mu^\delta)\, \mathrm{d}F(\beta)} \tag{4}$$

Proposition 5 (Equilibrium with taxation and inequality)
Given μ and ν, equilibrium labor supply strategies are described by $\ell_\beta^*(m) = \{(1-t)\,[\beta + E(\theta|m)]\}^{\frac{1}{\delta-1}}$.
There are two possible types of pure strategy equilibrium.

- *At a pooling equilibrium $m(\vartheta) = m(-\vartheta) = H$ and $\mu \leq \nu = p$. A pooling equilibrium always exists.*

- *At a separating equilibrium $m(-\vartheta) = L,\ m(\vartheta) = H,\ \mu = 0$ and $\nu = 1$. A separating equilibrium exists if and only if $t \leq t^*(0, 1)$.*

Proof Given posterior beliefs, individuals' best response to planner's announcements are immediate to derive.

In booms, the planner announces H if and only if $\nu \geq \mu$, since it wants to induce the highest expected value of θ and therefore the highest level of labor supply. So if H is the signal sent in booms, then it is necessarily the case that in equilibrium $\mu \leq \nu$.

In recessions, the welfare difference between announcing L and H is

$$\begin{aligned} \Delta W &\equiv W(L, \ell^* | -\vartheta) - W(H, \ell^* | -\vartheta) = \\ &= \int_b^B \left[u^*_\beta(L| -\vartheta) - u^*_\beta(H| -\vartheta)\right] dF(\beta) = \\ &= (1-t)^{\frac{1}{\delta-1}} Z(t), \end{aligned}$$

where

$$Z(t) = \frac{1-t}{\delta} \int_b^B \left(x_\nu^\delta - x_\mu^\delta\right) dF(\beta) - \int_b^B (\beta - \vartheta)\left(x_\nu - x_\mu\right) dF(\beta).^{32} \qquad (5)$$

If $\mu = \nu$, then $Z(t) = 0$ for any t. Now consider $\mu < \nu$. For $t = 1$, work effort is zero for any pair of posterior beliefs and we have $\Delta W = 0$. For $t < 1$, the sign of ΔW is equal to the sign of $Z(t)$. $Z(t)$ is a continuous function, strictly decreasing in t and with $Z(1) < 0$. We now prove that $Z(0) > 0$. Given $\mu < \nu$, we have $x_\mu < x_\nu$, so we can write $Z(0) = \int_b^B (x_\nu - x_\mu) \left[\frac{x_\nu^\delta - x_\mu^\delta}{\delta(x_\nu - x_\nu)} - (\beta - \vartheta)\right] dF(\beta)$.

Convexity of the function $\frac{x^\delta}{\delta}$ implies $x_\mu^{\delta-1} < \frac{x_\nu^\delta - x_\mu^\delta}{\delta(x_\nu - x_\nu)} < x_\nu^{\delta-1}$. From the first inequality, recalling that $x_\mu^{\delta-1} = (\beta - \vartheta + 2\mu\vartheta)$, we have $\left[\frac{x_\nu^\delta - x_\mu^\delta}{\delta(x_\nu - x_\nu)} - (\beta - \vartheta)\right] > 2\mu\vartheta$, so that $Z(0) > 2\mu\vartheta \int_b^B (x_\nu - x_\mu)\, dF(\beta) > 0$. Hence, $\forall(\mu, \nu):\ 0 \leq \mu < \nu \leq 1$, there is a unique value of $t \in (0, 1)$, which we call $t^*(\mu, \nu)$, such that $Z(t^*(\mu, \nu)) = 0$. Explicit calculation yields (4). Hence, in recessions,

[32] In detail, individual utility given $\ell^*_\beta(m)$, for $m = L, H$, is

$$\begin{aligned} u^*_\beta(L| -\vartheta) &= (1-t)(\beta - \vartheta)(1-t)^{\frac{1}{\delta-1}} x_\mu + T^*(L| -\vartheta) - \frac{1}{\delta}\left[(1-t)^{\frac{1}{\delta-1}} x_\mu\right]^\delta, \\ u^*_\beta(H| -\vartheta) &= (1-t)(\beta - \vartheta)(1-t)^{\frac{1}{\delta-1}} x_\nu + T^*(H| -\vartheta) - \frac{1}{\delta}\left[(1-t)^{\frac{1}{\delta-1}} x_\nu\right]^\delta, \\ T^*(L| -\vartheta) &= t \int_b^B (\beta - \vartheta)(1-t)^{\frac{1}{\delta-1}} x_\mu dF(\beta), \\ T^*(H| -\vartheta) &= t \int_b^B (\beta - \vartheta)(1-t)^{\frac{1}{\delta-1}} x_\nu dF(\beta). \end{aligned}$$

for $t \in (0, t^*(\mu, \nu))$, $\Delta W > 0$ and the planner strictly prefers to announce L; for $t = t^*(\mu, \nu)$, $\Delta W = 0$ and the planner is indifferent between the two signals, so that any randomization is a best response; and for $t \in (t^*(\mu, \nu), 1)$, $\Delta W < 0$ and the planner strictly prefers to announce H.

Consider now a candidate pooling equilibrium. Along the equilibrium path of play, Bayes' rule implies $\nu = p$. Then the planner does not deviate in booms if and only if $\mu \leq p$. The pooling equilibrium is babbling if $\mu = \nu$ and non babbling if $\mu < \nu$. If $\mu < p$, the planner does not deviate in recessions if and only if $t \geq t^*(\mu, p)$. In turn, if $\mu = \nu$, the planner never deviates in recessions. So a babbling equilibrium always exists.

Now consider a candidate separating equilibrium. The planner announces H in booms and L in recessions. Bayes' rule then implies $\mu = 0$ and $\nu = 1$. Given this, the planner does not deviate in booms. It does not deviate in recessions either, if and only if $t \leq t^*(0, 1)$. ■

5.4 Efficiency

Let us now compare the different equilibria from an ex ante point of view. For an individual with ability β, let $\bar{\ell}^S_\beta$, $\bar{y}^S_\beta$, $\bar{u}^S_\beta$, and $\bar{\ell}^P_\beta$, $\bar{y}^P_\beta$, $\bar{u}^P_\beta$, denote the ex ante expected levels of labor supply, production and indirect utility, at a separating and at a pooling equilibrium, respectively. Independently of equilibrium existence, the following holds.

Proposition 6 (Ex ante Pareto dominance)
For any parameter constellation, any ability distribution, and any level β of individual ability, the following holds: (i) $\bar{\ell}^S_\beta < \bar{\ell}^P_\beta \iff \delta > 2$; (ii) $\bar{y}^S_\beta > \bar{y}^P_\beta$; (iii) $\bar{u}^S_\beta > \bar{u}^P_\beta$.

Proof Labor supply by an individual with ability β, when the state of the world is θ, is $\ell^S_\beta(\theta) = (1-t)^{\frac{1}{\delta-1}}(\beta+\theta)^{\frac{1}{\delta-1}}$ at a separating equilibrium and $\ell^P_\beta(\theta) = \ell^P_\beta = (1-t)^{\frac{1}{\delta-1}}\left(\beta+\bar{\theta}\right)^{\frac{1}{\delta-1}}$ at a pooling equilibrium. $y^S_\beta(\theta) = (\beta+\theta)\ell^S_\beta(\theta)$ and $y^P_\beta(\theta) = (\beta+\theta)\ell^P_\beta$ are the corresponding production levels; and $u^S_\beta(\theta) = (1-t)y^S_\beta(\theta) - \frac{[\ell^S_\beta(\theta)]^\delta}{\delta} + t\int_b^B y^S_\beta(\theta)dF(\beta)$ and $u^P_\beta(\theta) = (1-t)y^P_\beta(\theta) - \frac{(\ell^P_\beta)^\delta}{\delta} + t\int_b^B y^P_\beta(\theta)dF(\beta)$ are the corresponding levels of indirect utility. Ex ante expected levels of individual labor supply, individual production and individual indirect utility at the two equilibria are then, respectively, $\bar{\ell}^S_\beta = (1-t)^{\frac{1}{\delta-1}} \left[p(\beta+\vartheta)^{\frac{1}{\delta-1}} + (1-p)(\beta-\vartheta)^{\frac{1}{\delta-1}} \right]$ and $\bar{\ell}^P_\beta = \ell^P_\beta$; $\bar{y}^S_\beta = (1-t)^{\frac{1}{\delta-1}} \left[p(\beta+\vartheta)^{\frac{\delta}{\delta-1}} + (1-p)(\beta-\vartheta)^{\frac{\delta}{\delta-1}} \right]$ and $\bar{y}^P_\beta = (1-t)^{\frac{1}{\delta-1}} [\beta+\bar{\theta}]^{\frac{\delta}{\delta-1}}$; and $\bar{u}^S_\beta = \left(\frac{\delta-1}{\delta}\right)(1-t)\bar{y}^S_\beta + t\int_b^B \bar{y}^S_\beta dF(\beta)$ and $\bar{u}^P_\beta = \left(\frac{\delta-1}{\delta}\right)(1-t)\bar{y}^P_\beta + t\int_b^B \bar{y}^P_\beta dF(\beta)$. Points (i) and (ii) then immediately follow by convexity (or concavity), and point (iii) is a corollary of point (ii). ■

The results in Proposition 6 parallel those already obtained in Propositions 2 and 4.

5.5 Equilibrium selection

Results for equilibrium selection are also very close to those obtained in the context of the monopoly power model and are therefore not reported here. We refer the interested reader to Albornoz et al. (2009), where they are discussed in detail. In the Appendix of the present paper we provide a summary of the formal results obtained there. Again, the main insight is that, whenever existing, i.e., for $t \leq t^*(0,1)$, the separating equilibrium appears the most natural prediction of the game. In light of this, for the remainder of the paper we assume that the economy coordinates on the separating equilibrium whenever it exists.

5.6 Transparency, shocks and inequality

The main comparative statics exercise then amounts to investigate how the relevant threshold for existence of a separating equilibrium, $t^*(0,1)$, moves in response to parameter or distributional changes. We refer to the tax rate interval $[0, t^*(0,1)]$ as to the support of transparency, and say that parameter or distributional changes favor (reduce) transparency if they increase (decrease) $t^*(0,1)$.[33]

It is easy to show that, if shocks are small, then an increase in shock magnitude, ϑ, favors transparency, because it raises the distortion caused by information hiding in recessions, relative to the tax distortion suffered

[33] Recall that in Proposition 5 the tax rate $t^*(0,1)$ is the one that make $Z(t) = 0$ for $\mu = 0$ and $\nu = 1$. The first term of $Z(t)$ reflects the overall leisure utility gain caused by announcing L, relative to H, in recessions; the second term reflects the corresponding overall consumption utility loss.

under transparency.[34] Notice that while shock magnitude is important, the frequency of booms and recessions is irrelevant for transparency, because $t^*(0,1)$ is determined by the welfare comparison between announcing L and H, conditional upon being in recession.[35] Moreover, whether labor supply elasticity favors transparency or not cannot be established in general terms.[36]

More interesting are the effects of inequality on transparency. In the next proposition we use Lorenz dominance (second order stochastic dominance) as a criterion to establish whether a distribution has more inequality than another one. Let $\gamma = \frac{1}{\delta-1}$ be the elasticity of labor supply.

Proposition 7 (Effects of inequality)
For any parameter constellation and distributional assumption, the effects of skill inequality on transparency depend on labor supply elasticity. In particular, consider a shift from skill distribution F to a more unequal distribution G, dominated by F with respect to second order stochastic dominance.

- *If $\gamma = 1$, such an increase in inequality has no effects on transparency.*
- *If $\gamma < 1$, it favors transparency.*
- *If $\gamma > 1$, letting $\hat{\gamma} = \frac{2}{1-t^*(0,1)} > 2$, we have that $\gamma \in (1, \hat{\gamma}]$ is a sufficient condition for it to reduce transparency.*

---

[34] Using (4) we can obtain

$$t^*(0,1) = 1 - \frac{\int_b^B (\beta - \vartheta) \left[(\beta+\vartheta)^{\frac{1}{\delta-1}} - (\beta-\vartheta)^{\frac{1}{\delta-1}} \right] dF(\beta)}{\int_b^B \frac{1}{\delta} \left[(\beta+\vartheta)^{\frac{\delta}{\delta-1}} - (\beta-\vartheta)^{\frac{\delta}{\delta-1}} \right] dF(\beta)}.$$

As an aside, notice that for $\delta = 2$ we have that $t^*(0,1) = \frac{\vartheta}{E(\beta)}$, where $E(\beta) = \int_b^B \beta dF(\beta)$. Applying L'Hôpital's rule, one can easily obtain that, for any distribution $F(\beta)$ with $E(\beta^{\frac{2-\delta}{\delta-1}}) < \infty$, $\lim_{\vartheta \to 0} t^*(0,1) = 0$ for all $\delta > 1$. Differentiating $t^*(0,1)$ with respect to ϑ and evaluating it at $\vartheta = 0$ —and applying again L'Hôpital's rule, we also find that, provided $E(\beta^{\frac{3-2\delta}{\delta-1}}) < \infty$, $\frac{\partial t^*(0,1)}{\partial \vartheta}\Big|_{\vartheta=0} = \frac{E(\beta^{\frac{2-\delta}{\delta-1}})}{E(\beta^{\frac{1}{\delta-1}})} > 0$.

[35] Notice that this implies no discontinuity of equilibrium informational policy as fluctuation frequency vanishes. The reason is that the non informative equilibrium then converges to the informative one, since along the equilibrium path posterior beliefs are $\nu = p$, and approach perfect information as p converges to either zero or one.

[36] In Albornoz et al. (2009) we present some numerical results on the effects of γ.

Proof Given posterior beliefs $\mu = 0$ and $\nu = 1$, from equation (5), we can write

$$Z(t) = \int_b^B z(\beta) dF(\beta),$$

where

$$z(\beta) = \frac{1-t}{\delta}\left[(\beta+\vartheta)^{\frac{\delta}{\delta-1}} - (\beta-\vartheta)^{\frac{\delta}{\delta-1}}\right] - (\beta-\vartheta)\left[(\beta+\vartheta)^{\frac{1}{\delta-1}} - (\beta-\vartheta)^{\frac{1}{\delta-1}}\right].$$

By Jensen's inequality, if $z(\beta)$ is a convex function of β at $t = t^*(0,1)$, then an increase in inequality (in the distribution of productivity) will determine a rise in $Z(t)$ and consequently a rise in $t^*(0,1)$. By contrast, if $z(\beta)$ is concave at $t = t^*(0,1)$, then inequality will reduce $t^*(0,1)$. The proposition is then a corollary of Lemma 4 in Appendix, which shows that $z(\beta)$ is linear for $\delta = 2$, strictly convex for $\delta > 2$ and strictly concave for $\delta \in \left[\frac{3-t}{2}, 2\right)$. Just recall that $\gamma = \frac{1}{\delta-1}$, so that $\gamma \lesseqgtr 1 \iff \delta \gtreqless 2$. Moreover, $t^*(0,1) \in (0,1)$ and, for any $t \in (0,1)$, $\delta \geq \frac{3-t}{2} \iff \gamma \leq \frac{2}{1-t}$. ■

First notice that most of the literature on information transparency assumes $\gamma = 1$ (which means linear labor supply) and thus assumes away the effects of inequality. Yet, the general picture is that inequality matters for transparency and that the way it does depends on the shape of the labor supply curve. In particular, if labor supply is rigid (i.e., for $\gamma < 1$), as most micro-estimates suggest, inequality favors transparency. Yet, if labor supply is elastic, as many macro models assume, inequality harms transparency.[37]

To grasp the intuition of this result, notice that $t^*(0,1)$ depends on the welfare comparison between (credibly) revealing and not revealing information, conditional on being in a recession.[38] Relative to information hiding, transparency in recessions raises leisure and reduces consumption for each individual. It is therefore useful to disentangle the effects of inequality on $t^*(0,1)$ into those working through the consumption differential and those working through the leisure differential between transparency and opaqueness.

Given the complementarity between skills and effort, an increase in skill

[37]For evidence on labor supply elasticity see, e.g., Fiorito and Zanella (2011).

[38]The relative social welfare gain to transparency in recessions depends on the tax rate: it is positive for low tax distortions and negative in the opposite case. The formal details on such comparison are provided in footnote 51 in Appendix.

inequality raises mean income and therefore mean consumption, independently of labor supply elasticity.[39] Since higher consumption is what drives the welfare advantage to opaqueness over transparency, by raising aggregate consumption, inequality favors opaqueness. Yet, utility depends on leisure besides on consumption, and the effects of inequality on leisure are more interesting.

In our model labor supply is concave (in wage or ability) whenever it is rigid ($\gamma < 1$). With rigid labor supply, an increase in skill inequality therefore raises aggregate leisure time. Since higher leisure is what drives the welfare advantage to transparency over opaqueness, by raising aggregate leisure, inequality favors transparency. Thus, under rigid labor supply, the two welfare effects of inequality, through consumption and through leisure, work in opposite directions: one favors opaqueness and the other one transparency. The overall effect depends on which force dominates. What we show is that, with rigid labor supply, the leisure channel dominates and skill inequality indeed favors transparency.

In contrast, with elastic (and therefore convex in ability) labor supply ($\gamma > 1$), an increase in skill inequality raises aggregate labor time and thus, besides increasing aggregate consumption, it reduces aggregate leisure. Both effects now work in the same direction, making skill inequality favor opaqueness.

Finally, as the monopoly power model, the taxation model also predicts that, all else equal, output and hours worked fluctuate more when the government is transparent.[40]

6 Concluding discussion

This paper investigates how government transparency depends on economic distortions. Distortions drive a wedge between the social optimum and the full-information equilibrium. As a consequence, a benevolent government,

[39] While at first sight surprising, the fact that skill inequality is welfare increasing is a direct consequence of the above mentioned complementarity, paired with a Benthamite social welfare function.

[40] This is consistent with the evidence provided by Demertzis and Hughes-Hallett (2007) and with the recently uncovered negative relationship between taxation and output volatility (Debrun et al., 2008). Yet, since the government tends to be transparent when aggregate shocks are relatively large, the ceteris paribus condition should not be forgotten.

with welfare-relevant private information, has an incentive to manipulate communication.

In an abstract class of economies with positive externalities and with a benevolent social planner, privately informed about productivity shocks (section 3), we prove two results: first, if distortions are high, transparency cannot be an equilibrium; second, we characterize the convexity condition under which transparency is ex-ante Pareto superior to opaqueness (and yet, for the previous result, it may not arise in equilibrium). We next consider two extensions of the model, in which monopoly power (section 4) and income taxes (section 5) are the specific sources of distortions. Positive externalities arise from profit distribution and income redistribution, respectively, giving economic substance to the abstract model, but maintaining the main implications: in both extensions the convexity condition is satisfied, so transparency is ex-ante desirable; yet, it is not an equilibrium when distortions are high.

Our results suggest that, all else equal, we should expect a negative relationship between government transparency and economic distortions. A comprehensive analysis of the empirical determinants of transparency is beyond the scope of this paper, but one simple way to bring this prediction to the data is to look at government fiscal transparency and regress it on several measures of economic distortions.[41] Fiscal transparency is relevant because productivity shocks affect government budget (through tax revenues and, although not modeled here, through welfare expenditure), even in the absence of any change in fiscal policy. When governments form their budget, they formulate expectations, conditional on the information they have, on the consequences of their fiscal policy. Thus, announcements of future surplus or deficit (and their size) are a concrete way of conveying information on future shocks.

The "Open Budget Index", developed by the International Budget Partnership (IBP), measures (on a 0-100 scale) the degree to which the budget procedure conveys information transparently. It is the most comprehensive index of transparency, as it provides information for 94 countries on clarity, public availability and accuracy of government budget information (including government estimates for the budget year and beyond). It is also highly correlated with other indices based on the IMF Report on the Observance

[41] As discussed in section 2, we are not aware of any previous investigation of the impact of distortions on fiscal transparency.

of Standards and Codes (Ardanaz, 2011).[42] We match this information with measures of economic distortions related to the degree of competition and to taxation. In particular, we use the "Time to Start Business" (in days), which is a measure of entry barriers, and the "Ease of Doing Business" (rank among 183 countries, with 1being the best), which measures the obstacles to business activity, both provided by the World Bank (International Financial Corporation). Moreover, we use three measures of taxes (top marginal tax rate on labor income, taxes on goods and taxes on international trade), obtained from the OECD World Tax Indicators.

Table 1 reports the results of OLS regressions of fiscal transparency (the Open Budget Index) on each measure of distortions (and a constant), for a cross-section of countries in 2008. All estimated coefficients are negative and significant, confirming the expected negative correlation.[43] These results provide suggestive evidence about the empirical relevance of the link between economic distortions and government transparency, but we are of course very cautious in their interpretation. We leave a deeper empirical analysis of this relationship for future work.

Our theory highlights the limits of equilibrium transparency when the government is benevolent, individuals are rational and no credible commitment is possible. We leave the analysis of transparency outside these assumptions for future investigation.[44] Within our framework, it is worth noting that precisely when the government 'lies' (in the sense that, in recessions, it sends the same message it sends in booms), individuals are ex post happy that it 'lied'. Therefore, the fact that the government's private information is ex post verifiable is not problematic. Moreover, the fact that we restrict to two elements both the state and message space polarizes equilibria on either full revelation or no revelation at all. An extension to the continuum case would generate equilibria with partial revelation and would thus allow to study the degree of information precision, but it would not affect the main intuition and the main results.[45]

[42] More information can be found at http://internationalbudget.org (IBP) and (http://www.imf.org/external/np/fad/trans/ (IMF).

[43] We obtain similar results if we use the IMF indicators of transparency as dependent variables and if we control for world regional dummies.

[44] For instance, an incumbent government might want to be over-optimistic in order to influence individuals' beliefs on its ability, beyond the motives emphasized in this paper. While this would provide an extra incentive to hide bad news, we expect that it would not change our main results.

[45] This can be seen most clearly in Albornoz et al. (2009), where mixed strategies allow for

Table 1: Transparency and Economic Distortions

	(1)	(2)	(3)	(4)	(5)
Ease of Doing Business§	-0.298***				
	(0.046)				
Time to Start Business†		-0.218***			
		(0.087)			
Taxes on International Trade††			-0.840**		
			(0.423)		
Top Tax Rate‡				-0.011*	
				(0.006)	
Tax on Goods‡‡					-0.471**
					(0.235)
Constant	67.8***	47.3***	53.0***	3.1***	63.9***
	(4.77)	(3.76)	(4.01)	(0.21)	(8.47)
Observations	80	54	57	55	80
R-squared	0.35	0.08	0.07	0.06	0.07

OLS regressions of fiscal transparency on economic distortions across countries in 2008.
Dependent variable: Open Budget Index (1 to 100), International Budget Partnership.
§: Ease of doing business index (1=easiest to 183=most difficult), World Bank.
†: Time required to start a business (days), World Bank.
††: Taxes on international trade (% of revenue), OECD World Tax Indicators.
‡: Top marginal tax rate (%), OECD World Tax Indicators.
‡‡: Taxes on goods and services (% of revenue), OECD World Tax Indicators.
Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Perhaps the most interesting extensions of the present framework concern the various possible forms of interaction between economic distortions and transparency. First, while we assumed that the driver of the business cycle, on which the government has private information, is a productivity shock, one might also imagine that the government's private information concerns shocks to monopoly mark-ups or to labor wedges, as in Angeletos et al. (2011). This might change our results and make opaqueness ex-ante desirable. Second, we have assumed that distortions are persistent and the government cannot directly eliminate them. The investigation of the political economy reasons behind this difficulty is a promising research avenue. For instance, an elected government might be influenced by lobbying activity or by a demand for redistribution. In Albornoz et al. (2009) we explore this last possibility and show that inequality harms transparency because it generates higher taxes. This modifies the results obtained in section 5 above, where we

a semi-separating equilibrium.

show how the effects of inequality on transparency depend on labor supply elasticity. Third, we have assumed that the government influences individual choices only through its informational policy, but how the latter interacts with monetary and fiscal policy is certainly worth investigating, since the direction and size of the shock may well depend on policy actions. Fourth, while we have assumed that the government perfectly observes the shock and that there individuals have no other source of information, a natural extension would be to look at government incentives to put a privately observed noisy signal of the shock in the public domain, when individuals also have dispersed and noisy information. These lines of research remain open.

The main message of the paper goes well beyond the specific applications we study. The general idea that a benevolent government may manipulate information to undo an existing distortion can be extended to any principal-agent problem, in which the principal has private information on the relation between individual actions and results and can manipulate it to counterbalance the agent's suboptimal behavior.

Appendix

Technical results for monopoly power

Lemma 1 (Monotonicity of $\sigma^*(\mu,\nu)$)
For any parameter constellation, and any μ and ν such that $0 \leq \mu < \nu \leq 1$, it holds that $\sigma^*(\mu,\nu)$ is strictly decreasing in its arguments.

Proof In order to prove this result, let us write (3) as

$$\sigma^*(\mu,\nu) = \frac{1}{1-q(\mu,\nu)}, \text{ where } q(\mu,\nu) \equiv \frac{\delta(x_\nu - x_\mu)(\tilde{A}-\vartheta)}{x_\nu^\delta - x_\mu^\delta}.$$

We thus have that

$$\frac{\partial \sigma^*}{\partial \mu} = \frac{1}{[1-q(\mu,\nu)]^2}\frac{\partial q}{\partial x_\mu}\frac{\partial x_\mu}{\partial \mu}$$

and

$$\frac{\partial \sigma^*}{\partial \nu} = \frac{1}{[1-q(\mu,\nu)]^2}\frac{\partial q}{\partial x_\nu}\frac{\partial x_\nu}{\partial \nu}.$$

Clearly, the sign of the derivatives of σ^* with respect to (μ, ν) is the same as the derivative of q with respect to the same variables.

Differentiating q with respect to μ we have

$$\frac{\partial q}{\partial x_\mu}\frac{\partial x_\mu}{\partial \mu} = -\frac{\delta(\tilde{A}-\vartheta)}{[x_\nu^\delta - x_\mu^\delta]^2}\left[(x_\nu^\delta - x_\mu^\delta) - \delta x_\mu^{\delta-1}(x_\nu - x_\mu)\right]\frac{\partial x_\mu}{\partial \mu},$$

and with respect to ν

$$\frac{\partial q}{\partial x_\nu}\frac{\partial x_\nu}{\partial \nu} = -\frac{\delta(\tilde{A}-\vartheta)}{[x_\nu^\delta - x_\mu^\delta]^2}\left[-(x_\nu^\delta - x_\mu^\delta) + \delta x_\nu^{\delta-1}(x_\nu - x_\mu)\right]\frac{\partial x_\nu}{\partial \nu}.$$

Taking into account that x^δ is a strictly convex function for $\delta > 1$ and that $\frac{\partial x_\mu}{\partial \mu} > 0$ and $\frac{\partial x_\nu}{\partial \nu} > 0$, we can deduce that $\frac{\partial \sigma^*}{\partial \mu} < 0$ and $\frac{\partial \sigma^*}{\partial \nu} < 0$. ■

Let us now consider the two refinements mentioned in the text: No Incentive to Separate (NITS) (Chen et al., 2008) and Neologism-Proof (NP) equilibrium (Farrell, 1993).[46] The NITS criterion requires that the 'lowest type' of sender does at least as well in equilibrium as it would if it could fully reveal its type (and the receiver responded optimally). The idea is that, if this condition does not hold, then the 'lowest type' of sender would have an incentive to separate and would find a way to fully reveal its type, and since the receiver would understand such incentive, this revelation would be credible and would be used, thus breaking the equilibrium under consideration. In the present context, an equilibrium satisfies NITS if in recessions social welfare is (weakly) higher in equilibrium than it would be if workers were perfectly informed about the recession (and responded optimally).[47] The following remark shows that the NITS criterion, while ruling out some equilibria, is not very selective in our context.

Lemma 2 (NITS)
The separating equilibrium satisfies NITS whenever it exists.
A pooling equilibrium satisfies NITS if and only if $\sigma \le \sigma^*(0, p)$.

[46] Both refinements are introduced for (two player) cheap talk games, with infinite type and message spaces. By contrast, our game features a continuum of workers and just two types and messages. None of these differences appears to matter for the following argument.

[47] There is no ambiguity here about the fact that the 'lowest type' is a government in recession.

Proof Let $\theta = -\vartheta$. Social welfare in recessions under workers' optimal response to perfect information is the same as social welfare at the separating equilibrium, $W^S(-\vartheta) = \left(\frac{\sigma-1}{\sigma}\right)^{\frac{1}{\delta-1}} (\tilde{A} - \vartheta)^{\frac{\delta}{\delta-1}} \left[1 - \frac{1}{\delta}\left(\frac{\sigma-1}{\sigma}\right)^{\frac{\delta}{\delta-1}}\right]$, so the separating equilibrium satisfies NITS. At a pooling equilibrium social welfare in recessions is $W^P(-\vartheta) = \left(\frac{\sigma-1}{\sigma}\right)^{\frac{1}{\delta-1}} (\tilde{A} - \vartheta)(\tilde{A} + \bar{\theta})^{\frac{1}{\delta-1}} - \frac{1}{\delta}\left(\frac{\sigma-1}{\sigma}\right)^{\frac{\delta}{\delta-1}} (\tilde{A} + \bar{\theta})^{\frac{\delta}{\delta-1}}$. A pooling equilibrium satisfies NITS if and only if $W^P(-\vartheta) \geq W^S(-\vartheta)$, which is equivalent to $W(-\vartheta, H) \geq W(-\vartheta, L)$ for $\mu = 0$ and $\nu = p$, that is to $\sigma \leq \sigma^*(0, p)$.[48] ∎

For low degrees of monopoly power, namely for $\sigma > \sigma^*(0, 1)$, NITS thus selects the separating equilibrium, but, due to the monotonicity outlined in Lemma 1, there is an intermediate range of monopoly power, $\sigma \in [\sigma^*(0, 1), \sigma^*(0, p)]$ in which it is not selective: both pooling and separating equilibria exist and both satisfy NITS.

The Neologism Proof (NP) criterion requires that there does not exist any self-signalling set. A self-signalling set is a (non empty) subset of 'types' (here, states of the world), which contains all and only those types who strictly gain, relative to their equilibrium outcome, by inducing the best response to the information that that they belong to that set. The idea is that, if such a set existed, this would destroy an equilibrium, since a neologism claiming "My type belongs to this set", if interpreted literally, would be used by all the types in the set, who are the only ones who strictly gain by inducing a best response to the neologism's literal meaning; this use, in turn, would justify the literal interpretation; but the credible use of the neologism would indeed destroy the considered equilibrium.

Lemma 3 (Neologism Proof)
Whenever the separating equilibrium exists, it is the only NP equilibrium.

Proof For each equilibrium, we need to check that there does not exist any self-signalling set. In our model, a self-signalling set is a (non empty) set $G \subseteq \{-\vartheta, \vartheta\}$ such that $G = \{\theta : \ W(\ell^*(G)|\theta) > W^*(\theta)\}$, where $W(\ell^*(G)|\theta)$ denotes social welfare when the state of the world is θ and workers best respond to the information that $\theta \in G$, whereas $W^*(\theta)$ is social welfare when the type is θ in the considered equilibrium. We denote equilibrium social

[48] It is immediate to extend the analysis to mixed strategy equilibria and show that the semi-separating equilibrium also satisfies NITS.

welfare when the type is θ, $W^*(\theta)$, by $W^S(\theta)$ and $W^P(\theta)$at a separating and at a pooling equilibrium, respectively.

For the separating equilibrium, $G = \{\vartheta\}$ and $G = \{-\vartheta\}$ are trivially not self-signalling, since $W(\ell^*(\{\theta\})|\theta) = W^S(\theta)$, for $\theta = -\vartheta, \vartheta$. $G = \{-\vartheta, \vartheta\}$ is also not self-signalling, because $\vartheta \notin G$, since $W(\ell^*(\{-\vartheta, \vartheta\})|\vartheta) = W^P(\vartheta)$, and we know that $W^S(\vartheta) > W^P(\vartheta)$, contradicting the definition of a self-signalling set.

For pooling equilibria, $G = \{-\vartheta, \vartheta\}$ is trivially not self-signalling, since $W(\ell^*(\{-\vartheta, \vartheta\})|\theta) = W^P(\theta)$, for $\theta = -\vartheta, \vartheta$. In turn, $G = \{\vartheta\}$ is self-signalling if and only if $\sigma > \sigma^*(p, 1)$; and $G = \{-\vartheta\}$ is self-signalling if and only if $\sigma > \sigma^*(0, p)$. To see this, consider first $G = \{\vartheta\}$. We have $\vartheta \in G$ since $W^S(\vartheta) > W^P(\vartheta)$; and we have $-\vartheta \notin G \iff W^P(-\vartheta) \geq W(\ell^*(\{\vartheta\})| -\vartheta)$, which holds if and only if $\sigma \geq \sigma^*(p, 1)$. Now consider $G = \{-\vartheta\}$. We have $\vartheta \notin G$ since $W^P(\vartheta) > W(\ell^*(\{-\vartheta\})|\vartheta)$; and we have $-\vartheta \in G \iff W^S(-\vartheta) > W^P(-\vartheta) \iff \sigma > \sigma^*(0, p)$. Thus, a pooling equilibrium is NP if and only if both $\sigma \leq \sigma^*(0, p)$ and $\sigma < \sigma^*(p, 1)$. Due to Lemma 1, we have that $\sigma^*(p, 1) < \sigma^*(0, 1) < \sigma^*(0, p)$, implying that pooling equilibria are NP if and only if $\sigma < \sigma^*(p, 1)$, that is, only when the separating equilibrium does not exist.[49] ■

The main intuition for the fact that the pooling equilibrium is not NP for low monopoly distortions is that, in in that case, social welfare in booms would be strictly higher than in equilibrium if the government could find a credible neologism that fully reveals the boom, and in turn this neologism would be credible because, in recessions, the government would not use it, since cheating workers, if believed, would induce overwork and reduce social welfare below its equilibrium level.

[49]For $\sigma \in [\sigma^*(p, 1), \sigma^*(0, 1))$, there doesn't exist any NP equilibrium. The fact that an NP equilibrium may fail to exist often raises the concern that it is too strong a refinement. Yet we find it convincing that, whenever existing, the separating equilibrium always satisfies even this strong refinement, and that the NP criterion univocally selects the separating equilibrium whenever existing. Extending the argument to mixed strategies shows that semi-separating equilibria are never NP.

Technical results for taxation

Monotonicity of $t^*(\mu, \nu)$ and equilibrium selection

In Albornoz et al. (2009) we prove a result that parallels Lemma 1: we show that, for any distributional assumption, if either $\delta = 2$ or $\delta = \frac{3}{2}$, then for any constellation of other parameters, any ability distribution with finite mean and variance,[50] and any values of μ and ν such that $0 \leq \mu < \nu \leq 1$, $t^*(\mu, \nu)$ is strictly increasing in its arguments. Moreover, we show numerically that this result extends to several other values of δ, and it holds for several constellations of other parameters and distributional assumptions.

As was true in the monopoly power model, this result helps have unique selection of the separating equilibrium whenever it exists. In particular, in Albornoz et al. (2009) we also prove the following results. First, although ex ante Pareto dominance selects the separating equilibrium whenever it exists, it is not (always) a good selection criterion, because, whenever $t \in [t^*(0, p), t^*(0, 1)]$, the planner's preferences over equilibria are reversed in different states of the world: in booms and in recessions the planner would prefer to be in a separating and in a pooling equilibrium, respectively.[51] Second, whenever it exists, the separating equilibrium satisfies both NITS and NP. Moreover, NITS is only selective for $t < t^*(0, p)$, in which case it selects the separating equilibrium. Finally, if $t^*(\mu, \nu)$ is strictly increasing in its arguments (which, as argued above, is the case for a great variety of parameter constellations and distributional assumptions), then whenever the separating equilibrium exists, i.e. for $t \leq t^*(0, 1)$, it is the only NP equilibrium. The implication is that, for $t \leq t^*(0, 1)$, the separating equilibrium appears the most natural prediction of the game.

Convexity and concavity in the Proof of Proposition 7

Lemma 4 (Convexity/concavity of $z(\beta)$)
For any $t \in (0, 1)$, the function of β

$$z(\beta) = \frac{1-t}{\delta} \left[(\beta + \vartheta)^{\frac{\delta}{\delta - 1}} - (\beta - \vartheta)^{\frac{\delta}{\delta - 1}} \right] - (\beta - \vartheta) \left[(\beta + \vartheta)^{\frac{1}{\delta - 1}} - (\beta - \vartheta)^{\frac{1}{\delta - 1}} \right]$$

[50] For $\delta = 2$ (but not for $\delta = \frac{3}{2}$) the result also extends to distributions with infinite variance.

[51] The proof of this claim follows from Proposition 5 and from the fact that, letting $W^P(-\vartheta)$ and $W^S(-\vartheta)$ denote social welfare in recession at a pooling and at a separating equilibrium, respectively, and using equations (4) and (5), we have that $W^P(-\vartheta) \geq W^S(-\vartheta) \iff [Z(t) \leq 0 \text{ for } \mu = 0 \text{ and } \nu = p] \iff t \geq t^*(0, p)$.

is linear for $\delta = 2$, strictly convex for $\delta > 2$ and strictly concave for $\delta \in \left[\frac{3-t}{2}, 2\right)$.

Proof The first and second derivative of $z(\beta)$ at a generic $t \in (0,1)$ are

$$
\begin{aligned}
z'(\beta) &= \frac{1}{(\delta-1)}\Big\{(2-\delta-t)\left[(\beta+\vartheta)^{\frac{1}{\delta-1}} - (\beta-\vartheta)^{\frac{1}{\delta-1}}\right] + \\
&\quad -(\beta-\vartheta)\left[(\beta+\vartheta)^{\frac{2-\delta}{\delta-1}} - (\beta-\vartheta)^{\frac{2-\delta}{\delta-1}}\right]\Big\}, \\
z''(\beta) &= \frac{1}{(\delta-1)^2}\Big\{(3-2\delta-t)\left[(\beta+\vartheta)^{\frac{2-\delta}{\delta-1}} - (\beta-\vartheta)^{\frac{2-\delta}{\delta-1}}\right] + \\
&\quad -(2-\delta)(\beta-\vartheta)\left[(\beta+\vartheta)^{\frac{3-2\delta}{\delta-1}} - (\beta-\vartheta)^{\frac{3-2\delta}{\delta-1}}\right]\Big\}.
\end{aligned}
$$

For $\delta = 2$, $z''(\beta) = 0$ for any $t \in (0,1)$, so $z(\beta)$ is linear.
For $\delta = \frac{3}{2}$, $z''(\beta) < 0$ for any $t \in (0,1)$, so $z(\beta)$ is concave.
For $\delta \neq 2, \delta \neq \frac{3}{2}$, we can re-write

$$
\begin{aligned}
z''(\beta) &= \frac{(2-\delta)}{(\delta-1)^2}\left[(\beta+\vartheta)^{\frac{3-2\delta}{\delta-1}} - (\beta-\vartheta)^{\frac{3-2\delta}{\delta-1}}\right] \cdot \\
&\quad \cdot \left\{ \frac{(3-2\delta-t)\left[(\beta+\vartheta)^{\frac{2-\delta}{\delta-1}} - (\beta-\vartheta)^{\frac{2-\delta}{\delta-1}}\right]}{(2-\delta)\left[(\beta+\vartheta)^{\frac{3-2\delta}{\delta-1}} - (\beta-\vartheta)^{\frac{3-2\delta}{\delta-1}}\right]} - (\beta-\vartheta) \right\}
\end{aligned}
$$

and study the three sub-cases $\delta > 2$, $\delta \in \left(\frac{3}{2}, 2\right)$, $\delta \in \left(1, \frac{3}{2}\right)$.

For $\delta > 2$, the sign of $z''(\beta)$ is the same as the sign of the term in curly brackets. Let $a_0 = (\beta-\vartheta)^{\frac{3-2\delta}{\delta-1}}$ and $a_1 = (\beta+\vartheta)^{\frac{3-2\delta}{\delta-1}}$, notice that $a_0 > a_1$ and consider the function $g(a) = \left(\frac{3-2\delta}{2-\delta}\right) a^{\frac{2-\delta}{3-2\delta}}$. Since it is concave, we have $\frac{g(a_0)-g(a_1)}{a_0-a_1} > g'(a_0) = (\beta-\vartheta)$. The left hand side in this inequality is the first term in the curly brackets for $t = 0$, so that we have $z''(\beta) > 0$ for $t = 0$. Since $\frac{\partial z''(\beta)}{\partial t} > 0$, we have that for any $t \in (0,1)$, $z''(\beta) > 0$.

For $\delta \in \left(\frac{3}{2}, 2\right)$, the sign of $z''(\beta)$ is opposite to the sign of the term in curly brackets. We have $\frac{2-\delta}{3-2\delta} < 0$, so $g(a)$ is again concave, and again $a_0 > a_1$. So $\frac{g(a_0)-g(a_1)}{a_0-a_1} > g'(a_0) = (\beta-\vartheta)$ and $z''(\beta) < 0$ for $t = 0$. Since $\frac{\partial z''(\beta)}{\partial t} < 0$, we have that for any $t \in (0,1)$, $z''(\beta) < 0$.

For $\delta \in \left(1, \frac{3}{2}\right)$, using the fact that $(\beta+\vartheta)^{\frac{2-\delta}{\delta-1}} = (\beta+\vartheta)(\beta+\vartheta)^{\frac{3-2\delta}{\delta-1}}$ and $(\beta-\vartheta)^{\frac{2-\delta}{\delta-1}} = (\beta-\vartheta)(\beta-\vartheta)^{\frac{3-2\delta}{\delta-1}}$, and rearranging, we can write $z''(\beta) =$

$\frac{1}{(\delta-1)^2}\left[A(\beta-\vartheta)^{\frac{3-2\delta}{\delta-1}} - B(\beta+\vartheta)^{\frac{3-2\delta}{\delta-1}}\right]$, where $A \equiv (\delta + t - 1)(\beta - \vartheta)$ and $B \equiv (\delta+t-1)\beta+(3\delta+t-5)\vartheta = A+2(2\delta+t-3)\vartheta$. Since $\delta \in \left(1, \frac{3}{2}\right)$ implies that $(\beta-\vartheta)^{\frac{3-2\delta}{\delta-1}} < (\beta+\vartheta)^{\frac{3-2\delta}{\delta-1}}$, and $B > A \iff 2\delta + t > 3$, we have that a sufficient condition for $z''(\beta) < 0$ is $\frac{3-t}{2} \leq \delta < \frac{3}{2}$. ■

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