Technology Choice and Price Signaling in Markets for Label Credence Goods

by

Martin OBRADOVITS, Markus WALZL

Working Paper No. 2511
August 2025

Johannes Kepler University of Linz
Department of Economics
Altenberger Strasse 69
A-4040 Linz - Auhof, Austria
www.econ.jku.at

martin.obradovits@jku.at

Technology Choice and Price Signaling in Markets for Label Credence Goods*

Martin Obradovits† Markus Walzl‡

August 4, 2025

Abstract

Consumers increasingly value the environmental and social responsibility of the production processes used by firms, yet these processes often remain unobservable, even after consumption. In this paper, we develop a simple model to examine firms' technology choices and subsequent price competition in markets for such *label credence goods* with hidden process attributes. Using a multi-sender signaling framework, we show that in the payoff-dominant equilibrium, firms can partially signal their production choices and avoid Bertrand competition when at least one firm adopts a green technology. Surprisingly, increasing consumers' environmental concern or eliminating the information asymmetry may reduce social welfare by discouraging green production.

Keywords: label credence goods, technology choice, asymmetric information, price competition, signaling, green production

JEL Classification: D82, D83, L13, L15

1 Introduction

In product markets where environmental or social responsibility is an important aspect, sellers often hold an informational advantage that remains unre-

*Financial support by FWF (SFB63) is gratefully acknowledged.

†Department of Economics, Johannes Kepler University Linz, Altenberger Straße 69, 4040 Linz, Austria. Email: martin.obradovits@jku.at

‡Department of Economics, University of Innsbruck, Universitätsstraße 15, 6020 Innsbruck, Austria. Email: markus.walzl@uibk.ac.at

solved even after trade.[1] For instance, consumers cannot easily verify the CO2 emissions of a car, the extent of child labor in the production of a running shoe, or whether a cosmetic product was tested on animals. These goods and services, which we refer to as *label credence goods*, require consumers to trust the claims or labels issued by firms.[2]

There is a profound economic and societal relevance of label credence goods. For example, UNICEF estimates indicate that more than 160 million children between the ages of 5 and 17 were engaged in child labor in 2020, with nearly half involved in hazardous work (UNICEF 2020). Organic food sales reached €136 billion in 2024, with farmland used for organic production increasing by more than 400% over the last 25 years (Willer, Travnicek, and Schlatter 2025). At the same time, some of the most prominent antitrust cases of the last decade have involved label credence goods, such as the adoption of low-emission technologies for trucks, the "AdBlue" emissions scandal at Volkswagen, and the use of bisphenols in food containers (Holmes 2024). Despite their importance, markets for label credence goods remain poorly understood, particularly in terms of how firms can signal their production choices and how these signals shape market outcomes.

This paper addresses this gap by developing a theoretical framework to study technology choice and price signaling in markets for label credence goods. Specifically, we examine how profit-maximizing firms decide between adopting socially responsible "green" technologies and cost-saving "brown" technologies, how they set prices to signal their choices, and how these decisions interact with consumer preferences, which may themselves be influenced by policy in-

1. E.g., Iacovides and Stylianou (2024) discuss the endorsement of sustainability in EU competition law and practice over recent years, and illustrate the relevance of these markets for economic policy.

2. Over the last decades, research on credence goods has focused on settings where consumers do not know what they need and may never learn whether the treatment or service proposed by an expert seller is appropriate (Darby and Karni 1973; Wolinsky 1995; Fong 2005; Dulleck and Kerschbamer 2006; Dulleck, Kerschbamer, and Sutter 2011; Bester and Dahm 2018). In the context of environmental or social responsibility, consumers *do* know what they want but may never find out whether this is indeed what the seller or provider actually supplied (Feddersen and Gilligan 2001; Cason and Gangadharan 2002; Baksi and Bose 2007). The latter type of credence good is commonly referred to as *label credence good* (see, e.g., Balafoutas and Kerschbamer 2020).

terventions. Consumers differ in their distaste for brown products and cannot directly observe firms' technology choices, but they may be able to infer them from prices. The central question is whether prices can serve as credible signals of sustainable production technologies and, if so, how this affects market outcomes and social welfare.

Our model sets up a two-stage game to explore these dynamics. In the first stage, two (initially symmetric) firms simultaneously decide which production technology to adopt: green or brown. The brown technology has a lower marginal cost of production but is overall less efficient because it generates a sufficiently large negative externality that is not present for the green technology. We focus on the case where the brown technology is not socially detrimental *per se* (and thus not subject to outright policy bans) but is still suboptimal from a social perspective, as ideally all production should be green. However, firms' profit-maximizing incentives may not align with this.

In the second stage, the firms learn about each other's technology choices, but—crucially—the consumers do not. Firms are often aware of their competitors' production technologies due to industry-specific knowledge, supply chain transparency, or observable production practices that are not accessible to consumers.[3] The firms then simultaneously set prices, anticipating that consumers may be able to infer information about the underlying production technologies through the multi-dimensional signal given by the realized price vector. Finally, consumers make their consumption decisions, and the game ends.

To analyze this game, we use the concept of Perfect Bayesian Equilibrium (PBE) refined by the *Unprejudiced Beliefs* (UB) criterion as introduced by Bagwell and Ramey (1991). PBE requires that consumers form beliefs that are consistent with firms' equilibrium strategies, while UB further restricts

3. For example, firms may have common suppliers or monitor each other's input sources, production processes, or certifications, which are often shared within the industry but not disclosed to the public. In contrast, consumers face significant informational barriers when it comes to verifying production technologies. For label credence goods, such as eco-friendly cars or socially responsible running shoes, it is often prohibitively costly or even impossible for consumers to directly observe attributes like CO_2 emissions or the use of child labor. As a result, consumers must rely on indirect signals, such as prices, to infer the underlying production technologies.

consumers' off-equilibrium beliefs. In particular, UB demands that consumers rationalize off-equilibrium price vectors as stemming from technology combinations that require a minimum number of deviations to arrive at the observed vector. We moreover restrict attention to symmetric PBEs where the firms engage in pure-strategy pricing in the second stage of the game.

In the benchmark scenario with perfect information, the game can be solved by backward induction. If consumers' average concern for the negative externality of brown consumption is sufficiently low, both firms choose the brown technology in the unique symmetric equilibrium, which is followed by marginal-cost pricing. Differentiating by deviating to the green technology is not beneficial, as this would induce zero demand. By contrast, for a sufficiently large environmental concern of consumers, the firms randomize which production technology to choose in the unique symmetric equilibrium. Then, if the firms happen to select different production technologies (i.e., one brown and one green), the brown firm sets a lower price, consumers distribute themselves across the two firms according to their environmental preferences, and both firms make a positive profit. Overall, firms' equilibrium propensity to choose the green technology strictly increases with consumers' average environmental concern.

For our main specification with asymmetric information, we show that, given UB, only four possible types of equilibria remain. First, it is always an equilibrium that both firms choose the brown technology, leading to marginal-cost pricing in the second stage. Depending on the parameters of the model, three other types of equilibria may be supported: i) the equilibrium under perfect information, where firms randomize over production technologies and prices fully reveal technology choices; ii) firms randomizing over production technologies and fully revealing the underlying technology *combination* through prices (with marginal-cost pricing in case of homogeneous technologies and firms pooling at a common price which strictly exceeds green marginal cost for heterogeneous technologies); iii) firms randomizing over production technologies and *partially* revealing the underlying technology combination through prices (with marginal-cost pricing if both firms choose the brown technology and firms pooling at a common price which strictly exceeds green marginal cost as long as at least one firm produces green).

Depending on the specific parameter combination in place, some or all of these different types of equilibria may coexist. Moreover, the pooling equilibria of type ii) and iii) can typically be supported for a continuum of pooling prices. In order to obtain a clear-cut equilibrium prediction, we focus on the payoff-dominant equilibrium. It turns out that – provided any symmetric equilibrium with positive profits exists – this is always the last type of equilibrium (type iii)) (for an appropriately chosen pooling price). This is because in this equilibrium, the firms manage to credibly signal to consumers when *at least* one of them has chosen the green technology, while avoiding Bertrand competition in the case where both firms have chosen green production. We characterize the payoff-maximizing pooling price for any combination of parameters.

Focusing on the payoff-dominant equilibrium, we are ultimately interested in the efficacy of various policy interventions that may alleviate the inefficiencies caused by market intransparency. First – and in contrast to the benchmark model with perfect information – it is generally not optimal from a social perspective to promote consumers' environmental concerns without limit. Pushing concerns is socially beneficial as long as a larger environmental concern *increases* the payoff-dominant pooling price (by relaxing an incentive constraint) and thereby enhances the equilibrium propensity with which firms choose the green technology. Beyond a certain level of concern, the payoff-dominant pooling price starts to decrease (suppressing green production) and additionally more consumers may inefficiently forego consumption altogether. This adverse welfare result holds regardless of the true negative externality caused by brown consumption. In particular, if this negative externality is relatively large, it may not even be optimal to push consumers' *maximum* internalization of the damage of brown consumption to its true value.

Second, our model enables us to study the impact of eliminating or reducing the asymmetric-information problem faced by consumers, for example, due to better information policies. A surprising finding is that eliminating consumers' information asymmetry leads to *lower* market performance, provided that the marginal-cost difference between green and brown production is not too large.

In a nutshell, for a small marginal-cost difference, the firms predominantly choose the green technology in the payoff-dominant equilibrium, as choosing the brown technology carries the risk of zero profit if the other firm does so as well, while the potential cost savings are minimal. In contrast, with perfect information, the rate of green production is always bounded away from one, as a near deterministic choice of green production would imply near zero profits and would therefore give firms an incentive to differentiate and choose brown production instead.

Third and finally, our model can shed light on government regulations that intend to directly level the playing field between green and brown production technologies, such as (Pigouvian) taxation of brown production or a subsidy of green production. As we show, market efficiency can be increased by bringing together the effective marginal costs of brown and green production *provided that the information asymmetry prevails.*

The remainder of this article is structured as follows. In Subsection 1.1, we discuss the related literature. The model is introduced in Section 2. Section 3 provides the benchmark analysis with perfect information. In Section 4, we turn to the main analysis with asymmetric information. There, we outline our equilibrium concept and refinements, before describing the different types of potential equilibria. We then characterize the payoff-dominant equilibrium for all parameter combinations. In Section 5, we conduct a welfare analysis and discuss the effects of various policy interventions. Concluding remarks are provided in Section 6. In Appendix A, we characterize the other types of (payoff-dominated) equilibria that may exist under asymmetric information. Technical proofs are collected in Appendix B.

1.1 Literature Review

Our paper analyzes prices as signals in markets for label credence goods. This contributes to several strands of research. First, it adds to classical signaling models where a monopolistic firm produces either low or high quality and signals quality to uninformed consumers via prices or costly actions such as advertisement (see, e.g., Milgrom and Roberts 1986; Bagwell and Riordan 1991;

Linnemer 2002; Orzach, Overgaard, and Tauman 2002). While these models typically address experience goods where customers learn the true quality after purchase, the existence of separating equilibria demonstrated in this class of models translates to settings with label credence goods: If higher quality (or greener production) is more costly, high-quality firms prefer higher prices (and lower demand) which establishes a separating equilibrium. However, this equilibrium transmission of quality information breaks down for label credence goods as soon as firms decide upon quality before offering prices to customers: for every candidate separating equilibrium in the pricing stage, it would be optimal for the firm to choose low quality instead (and ask for the high price).

If multiple firms compete, the translation from experience to credence goods no longer works that straightforwardly even if quality is exogenously given. In the classical models of competition with uninformed consumers (see, e.g., Klein and Leffler 1981; Wolinsky 1983; Bester 1998), customers receive (imperfect) quality signals due to experience or pre-purchase inspections. In a market for label credence goods, however, quality remains unobservable even after consumption, such that neither experience nor pre-purchase inspections help to uncover the actual quality. As a consequence, the literature on label credence goods has focused on (self-)labeling and third-party certification to overcome the informational asymmetry between producers and consumers (see, e.g., Baksi and Bose 2007; Harbaugh, Maxwell, and Roussillon 2011; Arguedas and Blanco 2025; Blanco et al. 2025).

An analysis of prices as means of information exchange between competing producers and consumers of label credence goods builds on the literature of multi-sender price-signaling games. A principal theme in this literature is the question of whether prices can truthfully reveal product qualities to consumers, and if so, which price distortions (relative to a complete-information benchmark) arise. In terms of the underlying informational structure, a main dividing line in this literature is whether firms are privately informed about their own product qualities – a situation known as *pure private information* (e.g., Janssen and Roy 2010) – or whether the informational asymmetry only applies to consumers, while firms can observe each other's product qualities

– a situation known as *common private information* (e.g., Hertzendorf and Overgaard 2001a).

In the framework with pure private information, Daughety and Reinganum (2007, 2008) establish the existence of fully revealing equilibria for settings with sufficiently strong horizontal product differentiation, while the model by Janssen and Roy (2010) can generate the same result for – apart from unobserved potential quality differences – homogeneous products, as in our setting. They show that despite their highly competitive (Bertrand-like) market structure, both low- and high-quality firms may enjoy significant market power in the fully revealing equilibrium. In follow-up work where firms can additionally (credibly) disclose private quality information before setting prices, Janssen and Roy (2015) demonstrate that non-disclosure of quality by all firms is often the unique symmetric equilibrium outcome. In this case, the firms still manage to truthfully signal their product qualities via prices.[4] This is contrasted by Sengupta (2024), who demonstrates that quality disclosure is more favorable if firms simultaneously decide upon prices and quality disclosure, i.e., if firms are uncertain about the other firm's technology when choosing a price.

Our model falls squarely within the latter framework of common private information, as explored in Hertzendorf and Overgaard (2001a, 2001b), Fluet and Garella (2002), Yehezkel (2008), Caldieraro, Shin, and Stivers (2011), Bester and Demuth (2015), and Chen, Serfes, and Zacharias (2023), among others. Most closely related in this stream of research is the foundational paper by Hertzendorf and Overgaard (2001b), which features competition between two firms that sell products of either low or high quality, drawn independently by nature (where only the probability distribution is known to consumers, whereas the firms observe each other's product qualities).[5] They apply the

4. See also Janssen and Roy (2022), which analyzes regulation of fraudulent communication of private quality information within the authors' earlier framework.

5. Other papers in this literature simplify the analysis by assuming perfectly negatively correlated product qualities (Hertzendorf and Overgaard 2001a; Yehezkel 2008; Caldieraro, Shin, and Stivers 2011) or by ruling out that both firms have high quality (Fluet and Garella 2002; Bester and Demuth 2015). Moreover, they explore different settings and aspects, such as when dissipative advertising can be used as additional quality signal (Hertzendorf and Overgaard 2001a; Fluet and Garella 2002; Yehezkel 2008), a share of consumers is informed about product qualities (Yehezkel 2008; Bester and Demuth 2015), truthful quality

Unprejudiced Beliefs refinement (Bagwell and Ramey 1991) to show that no fully revealing equilibria (in particular, where it is revealed that one firm has high quality and the other low quality) exist. They also argue that a fully non-revealing pooling equilibrium, where firms price at marginal cost, seems to be a likely outcome.[6]

None of the above papers considers an endogenous choice of product qualities; moreover, potential pooling equilibria remain largely unexplored, and a characterization of the payoff-dominant equilibrium (as well as a welfare analysis thereof) is not attempted. The only papers addressing endogenous technology choice are Dubovik and Janssen (2012) and Sengupta (2015, 2024).

Dubovik and Janssen (2012) studies a simultaneous choice of quality (in a continuous manner, where higher quality is associated with higher unit costs) and price in a duopoly model where a share of consumers is partially informed and can only observe prices (while some consumers are fully informed and some are completely uninformed). The authors show that if there are sufficiently many uninformed consumers, a unique so-called *perfect indicator equilibrium* exists where firms randomize over price-quality pairs, and prices perfectly reveal product qualities. Their contribution differs in various important ways from ours. Most crucially, they consider pure rather than common private information and assume the presence of a share of fully informed consumers. In addition, both partially and uninformed consumers can observe a firm's quality choice after visiting it (i.e., an inspection good is considered). Without these assumptions in place, firms would never have an incentive to raise their quality above the lowest possible level.

Sengupta (2015) analyzes investment incentives into green production technologies in markets with environmentally conscious consumers and demonstrates that incentives are larger for competing firms than for a monopolist (as in, e.g., Sengupta 2012). Within the same setting, Sengupta (2024) shows

disclosure is possible (Caldieraro, Shin, and Stivers 2011), there is entry of a firm whose quality is unknown to some consumers (Bester and Demuth 2015), or consumers can inspect firms' product qualities before purchase at a cost (Chen, Serfes, and Zacharias 2023).

6. This is only possible because the model assumes quality-independent unit costs, different from us and most specifications in the literature. A first analysis of type-dependent marginal costs in the same model context is given in Hertzendorf and Overgaard (2002).

that investments into green production technologies drop if a (costless and trustworthy) eco-label allows firms to disclose product quality. Yet again, Sengupta (2015, 2024) analyze pure rather than common private information and assume that investment choices (but not whether the investment succeeds in producing a green product) are observable for competitors *and* consumers. In contrast, we assume that competitors (but not consumers) know product qualities when deciding upon prices.

By also endogenizing firms' choice of production technologies, we contribute to the small and scattered literature on *endogenous signaling games* (see In and Wright 2018 for an overview). For a multi-sender model of price-quality signaling as in Hertzendorf and Overgaard (2001b), where firms can observe each other's quality choices while consumers remain uninformed, our paper demonstrates that an endogenous quality choice actually facilitates the analysis, while introducing non-trivial effects on the intensity of price competition and market outcomes.

Finally, this paper adds to the recent literature on the impact of competition on moral behavior. In contrast to recent contributions that emphasize the robustness of moral behavior towards the intensity of competition (see, e.g., Dewatripont and Tirole 2024) or a negative impact of an environment's competitiveness either via the so-called *replacement effect* that deteriorates moral concerns (see, e.g., Falk, Neuber, and Szech 2020) or a dampening of individual concerns by market feedback (see, e.g., Kaufmann, Andre, and Kőszegi 2024), our paper highlights that competition – and the need to differentiate from competitors – may enhance social or environmental responsibility by firms even if consumers do not observe a firm's more or less responsible behavior, but can only update their corresponding beliefs based on prices as signals.

2 Model Setup

We consider the following market. There are two profit-maximizing and risk-neutral firms $i = 1, 2$ that engage in a two-stage game of product competition. In the first stage, they simultaneously decide upon their production technologies: brown, $t_i = b$, or green, $t_i = g$. We let $t = \{t_i, t_j\}$ $(j \neq i)$ denote the corresponding *multiset*[7] of chosen production technologies. Firm i's constant marginal costs of production are given by $b \geq 0$ for $t_i = b$ and by $g > b$ for $t_i = g$. We denote the cost difference by $\Delta_g \equiv g - b$. In the second stage, the firms observe each other's production technologies and compete in prices p_i. In the situation where different production technologies have been chosen in the first stage, whenever this is unambiguous, we denote firms' prices by p_b and p_g, respectively.

The green technology is clean / socially responsible and therefore the consumption of *green products* (produced with $t_i = g$) does not cause any societal harm. On the other hand, *brown products* (produced with $t_i = b$) cause a societal harm (imposed on some third party) of $H > 0$ per unit consumed. We will refer to the green technology as efficient if $\Delta_g < H$.

There is a unit mass of consumers with unit demand and an outside option valued at zero. Disregarding environmental concerns, there is no horizontal or vertical product differentiation, so each consumer has the same gross utility $v > g$ for consuming the product of either firm. Consumers cannot directly observe firms' production technologies, but they may be able to infer them from firms' pricing strategies.

Consumers are heterogeneous with respect to their environmental concerns, that is, to their disutility from consuming brown products. In particular, we posit that a consumer of type η values consumption of the brown product at $v - \eta$, where for simplicity and to ensure tractability, we assume that η is uniformly distributed on $[0, h]$, with $h > 0$. We interpret the parameter h as a (potential policy) variable that shifts up the environmental proclivity of consumers.[8]

In sum, absent asymmetric information, a consumer of type η has a net valuation for a green product of $u_g = v - p_g$ and a net valuation for a brown

7. A multiset is a set that allows for duplicate elements, but where the order of the elements is irrelevant.

8. More generally, we could assume that η follows some sufficiently well-behaved cumulative distribution function $F(\eta|h)$ with support $[0, \overline{\eta}(h)]$, where an increase in h shifts up F in the sense of first-order stochastic dominance. To induce closed-form solutions, we set $F(\eta|h) = \frac{\eta}{h}$ for $0 \leq \eta \leq \overline{\eta}(h) \equiv h$.

product of $u_b = v - \eta - p_b$. If a consumer of type η *believes* that a product priced at p was produced with $t_i = g$ with probability μ, her valuation for it is given by $v - (1-\mu)\eta - p$.

We will first analyze the benchmark setting with perfect information. We will then proceed with the main analysis with asymmetric information.

3 Perfect Information Benchmark

Under perfect information, consumers observe firms' production technologies, such that we can solve the game by backward induction.

Suppose first that both firms have chosen the same production technology in the first stage. Then the ensuing Bertrand competition leads to marginal-cost pricing in the respective (unique) subgame equilibrium: we have that $p_1^* = p_2^* = b$ for $t = \{b, b\}$ and $p_1^* = p_2^* = g$ for $t = \{g, g\}$. Firms make zero profit in this case. Note moreover that for $t = \{b, b\}$, the market will not be covered if $v - b - h < 0$.

Suppose now that the firms have chosen different production technologies, $t = \{b, g\}$. Given prices $p_b \leq p_g \leq v$, the indifferent consumer $\tilde{\eta}$ is defined by $v - \tilde{\eta} - p_b = v - p_g$, hence

$$\tilde{\eta}(p_b, p_g) = p_g - p_b. \tag{1}$$

As consumers' environmental types are assumed to be uniformly distributed on $[0, h]$, firm b's and g's demands (for $\tilde{\eta}(p_b, p_g) \in [0, h]$) are given by

$$D_b(p_b, p_g) = \frac{p_g - p_b}{h}$$

and

$$D_g(p_b, p_g) = 1 - \frac{p_g - p_b}{h}.$$

A standard analysis of firms' corresponding best-response functions gives us the following lemma.

Lemma 1. *Under perfect information, there is a unique pricing equilibrium in undominated strategies in the subgame with heterogeneous technologies, as summarized in Table 1 below:*

for h	p_b^*	p_g^*	π_b^*	π_g^*
$\leq \Delta_g/2$	$g-h$	g	$\Delta_g - h$	0
$\in (\Delta_g/2, \frac{3}{2}(v-b)-\Delta_g)$	$b+\frac{h+\Delta_g}{3}$	$g+\frac{2h-\Delta_g}{3}$	$\frac{(h+\Delta_g)^2}{9h}$	$\frac{(2h-\Delta_g)^2}{9h}$
$\geq \frac{3}{2}(v-b)-\Delta_g$	$b+\frac{v-b}{2}$	v	$\frac{(v-b)^2}{4h}$	$(v-g)\left(1-\frac{v-b}{2h}\right)$

Table 1: Firms' equilibrium prices p_b^* and p_g^* and equilibrium profits π_b^* and π_g^* in the subgame with heterogeneous technology choices under perfect information.

Proof. See Appendix B. □

The intermediate case (for $h \in (\Delta_g/2, \frac{3}{2}(v-b)-\Delta_g)$) corresponds to the (strictly) interior solution where both firms are active in equilibrium and the green firm prices strictly below consumers' gross consumption utility v. For a very low average environmental concern of consumers[9], $h \leq \Delta_g/2$, the green firm cannot profitably conduct business, as even when pricing at marginal cost, the brown firm finds it optimal to undercut it so that it serves the whole market. Finally, for a sufficiently large environmental concern of consumers, $h \geq \frac{3}{2}(v-b)-\Delta_g$, the green firm finds it optimal to price at v (offering its customers a net surplus of zero), while the brown firm best-responds to that by choosing its monopoly price.

Turning to the first stage of the game, from firms' profits in the first row of Table 1, it is clear that for $h \leq \Delta_g/2$, it is no equilibrium that both firms choose $t_i = g$ (where both firms make zero profit), as each firm would have an incentive to deviate to $t_i = b$ and make a positive profit. In this case, there are two asymmetric pure-strategy equilibria, $(t_1, t_2) = (b, g)$ and $(t_1, t_2) = (g, b)$, where only the firm with the brown technology makes a positive profit. Moreover, in the unique symmetric equilibrium, $(t_1, t_2) = (b, b)$, and the firms price at marginal cost and make zero profit.

9. Here and in what follows, we loosely refer to h as the "average environmental concern" of consumers (or just their "environmental concern"), even though their mean concern is $h/2$ following our model specification.

In contrast, for $h > \frac{\Delta_g}{2}$, the second and third rows of Table 1 reveal that it cannot be an equilibrium that both firms choose the same production technology (where they make zero profit), as deviating to the other technology would then generate a strictly positive instead of zero profit. In this case, we still have the two asymmetric pure-strategy equilibria from before, $(t_1, t_2) = (b, g)$ and $(t_1, t_2) = (g, b)$, where now both firms make a positive profit. Moreover, the unique symmetric equilibrium is in mixed strategies, where the firms choose the green production technology with probability

$$\alpha^{perf} = \frac{\pi_g^*}{\pi_b^* + \pi_g^*} \in (0, 1). \tag{2}$$

Note that, as might be expected, α^{perf} strictly *increases* in h.[10]

The corresponding equilibrium profit in the mixed-strategy equilibrium is given by $\Pi_i^{perf} = \alpha^{perf}\pi_b^* = (1 - \alpha^{perf})\pi_g^*$, hence

$$\Pi_i^{perf} = \frac{\pi_b^*\pi_g^*}{\pi_b^* + \pi_g^*}. \tag{3}$$

Focusing on the unique symmetric equilibrium for each of the cases outlined above and inserting the appropriate expressions into Equation (2), the following proposition summarizes our findings.

Proposition 1. *Suppose that the consumers can observe firms' technology choices (perfect information). Then the unique symmetric equilibrium of the game is characterized as follows:*

- *If $h \leq \Delta_g/2$, the firms choose $t_i = b$ with probability 1, price at marginal cost, and make zero profit. The market is covered.*

- *If $h \in (\Delta_g/2, \frac{3}{2}(v - b) - \Delta_g)$, the firms choose $t_i = g$ with probability*

$$\alpha_1^{perf} = \frac{(2h - \Delta_g)^2}{(h + \Delta_g)^2 + (2h - \Delta_g)^2} \in (0, 1)$$

10. To prove this, it suffices to show that π_b^*/π_g^* strictly decreases in h for both relevant cases, which is straightforward.

and $t_i = b$ with the remaining probability.

In case they choose the same production technology in the first stage, they price at marginal cost, while with different production technologies, the brown (green) firm sets p_b^* (p_g^*) as given in the second row of Table 1. If both firms choose $t_i = b$, the market is covered if and only if $h \leq v - b$.

- *If $h \geq \frac{3}{2}(v-b) - \Delta_g$, the firms choose $t_i = g$ with probability*

$$\alpha_2^{perf} = \frac{2(v-g)[2h-(v-b)]}{(v-b)^2 + 2(v-g)[2h-(v-b)]} \in (0,1)$$

and $t_i = b$ with the remaining probability.

In case they choose the same production technology in the first stage, they price at marginal cost, while with different production technologies, the brown (green) firm sets p_b^* (p_g^*) as given in the third row of Table 1. If both firms choose $t_i = b$, the market is covered if and only if $h \leq v - b$.

4 Main Model with Asymmetric Information

Roadmap. We first describe our equilibrium concept, including the applied equilibrium refinement. We proceed to characterize the set of equilibria with a deterministic technology choice (Proposition 2). We then enumerate the potential types of symmetric equilibria with a stochastic technology choice, before characterizing the (what turns out to be) payoff-dominant type of equilibrium: a partially technology-revealing pooling equilibrium (Proposition 3). We finally determine the payoff-dominant pooling price for this type of equilibrium across the parameter space (Proposition 4).

Equilibrium Concept. We restrict attention to symmetric Perfect Bayesian Equilibria (PBE) in which the firms engage in pure-strategy pricing in the second stage of the game. This means that we are interested in the set of equilibria in which (a) both firms choose $t_i = g$ with probability $\alpha \in [0,1]$ and $t_i = b$ with the remaining probability in the first stage; (b) given that the firms have chosen the same technology in the first stage, they set the same deterministic price $p^*(t)$ in the second stage, where $p^*(t) \geq t$ $(t = b, g)$; (c) given that the firms have chosen different technologies $(t = \{b, g\})$ in the first stage, they either choose different prices, $p_b^* \geq b$ and $p_g^* \geq g$ (where $p_g^* \neq p_b^*$), or they choose the same price $p^* \geq g$.

Throughout, we impose the *Unprejudiced Beliefs* (UB) equilibrium refinement (Bagwell and Ramey 1991). UB asserts that when observing a deviant price vector, consumers rationalize this as coming from only those equilibrium price vectors that require the fewest number of deviations. To illustrate this concept, we present an example based on our model.

Consider a hypothetical equilibrium with a mixed-strategy technology choice, such that in equilibrium, all technology combinations $t = \{b, b\}$, $t = \{b, g\}$, and $t = \{g, g\}$ arise with positive probability. Suppose that this equilibrium prescribes firms to choose the completely distinct prices $p^*(b)$ in case of $t = \{b, b\}$, $p^*(g)$ in case of $t = \{g, g\}$, and the pair (p_b^*, p_g^*) in case of $t = \{b, g\}$, with $p^*(b) \neq p^*(g) \neq p_b^* \neq p_g^*$. Note that these four different equilibrium prices correspond to the maximum number of equilibrium prices in a symmetric equilibrium with mixed-strategy technology choice and pure-strategy pricing on the equilibrium path.

UB now restricts consumers' beliefs when facing an off-equilibrium price vector (where at least one price differs from $p^*(b)$, $p^*(g)$, p_b^*, and p_g^*; or two of these equilibrium prices appear together that should not do so in equilibrium). Specifically, it asserts that when an equilibrium price appears alongside an off-equilibrium price, the consumers must put probability one on that the deviation has originated from the technology combination that features the remaining equilibrium price. For example, when consumers observe the price vector $(p, p^*(g))$, where $p \neq \{p^*(b), p^*(g), p_b^*, p_g^*\}$, they must believe that the deviation has originated from $t = \{g, g\}$ (the only technology combination where just a single deviation from the prescribed equilibrium strategies is needed to end up with the given price vector) with probability one.

Similarly, when two equilibrium prices appear alongside each other that should not be observed together in any technology combination, UB requires that the consumers put probability one on that the deviation has originated from one of the two technology combinations that feature these equilibrium prices. For example, when consumers observe the price vector $(p^*(b), p^*(g))$, they must put probability one on that the deviation has originated from either $t = \{b, b\}$ (i.e., one of two brown firms has deviated from $p^*(b)$ to $p^*(g)$) or from $t = \{g, g\}$ (i.e., one of two green firm has deviated from $p^*(g)$ to $p^*(b)$). However, in such situations, UB does not restrict consumers' beliefs regarding the distribution of probabilities across the two considered technology combinations.

Equilibria with Deterministic Technology Choice. First, it is easy to see that an efficient equilibrium where both firms choose the green technology in the first stage (i.e., where $\alpha = 1$) cannot exist. In such an equilibrium, marginal-cost pricing would ensue in the second stage, implying zero profits. However, by deviating to the brown technology and setting (e.g.) $p_i = \frac{b+g}{2} \in (b, g)$, a firm could secure a strictly positive profit, upsetting this candidate equilibrium.

On the other hand, it is straightforward that deterministic brown production by both firms (i.e., $\alpha = 0$) is always an equilibrium, given consumers' inability to observe firms' technology choices, and the strictly lower marginal cost of brown production. Clearly, in such an equilibrium, there must be marginal-cost pricing in the second stage, so that the firms make zero profit. A minor technical complication is that we have to specify firms' pricing in the off-equilibrium event where one firm deviates to green production in the first stage. Equilibrium existence requires that such a deviation also leads to zero profit for the deviator, and that the specified off-equilibrium prices are sequentially rational (i.e., would not invite further deviations). In the proof of the following proposition, we construct such prices: In the off-equilibrium event where one firm deviates to $t_i = g$ in the first stage, the green firm sets $p_g = g$, while the brown firm either best-responds to that with a strictly lower price, outing itself as brown, or sets $p_b = g$ as well.

Proposition 2. *Suppose that the consumers cannot observe firms' technology choices (asymmetric information). Then:*

- *There does not exist an equilibrium where both firms choose $t_i = g$ with probability one.*
- *It is always an equilibrium that both firms choose $t_i = b$ with probability one and set $p_i^* = b$ in the second stage.*

Proof. See Appendix B. □

Equilibria with Stochastic Technology Choice. We now turn to symmetric candidate equilibria in which firms' technology choice is not deterministic. This means that in the first stage, the firms randomize whether to choose the green technology (with probability $\alpha \in (0, 1)$) or the brown technology (with probability $(1 - \alpha)$). Since in such candidate equilibria, all technology combinations arise with positive probability on the equilibrium path, we can now categorize potential equilibria with respect to the inferences consumers can draw from firms' (pure-strategy) equilibrium prices about the underlying technology state.

Technology-revealing equilibria. Suppose first that on the equilibrium path, consumers are able to perfectly distinguish between the technology combinations $t = \{b, b\}$, $t = \{g, g\}$, and $t = \{b, g\}$. This means that these technology combinations are associated with distinct prices $p^*(b) \geq b$ for $t = \{b, b\}$ and $p^*(g) \geq g$ for $t = \{g, g\}$, and, for $t = \{b, g\}$, either different prices (p_b^*, p_g^*) (with $p_b^* \geq b$, $p_g^* \geq g$, and $p_b^* \neq p_g^*$), or the same pooling price $p^* \geq g$, where $p^*(b) \neq p^*(g) \neq p^*$. Using UB, it is then necessary that $p^*(b) = b$ and $p^*(g) = g$, as otherwise, for $t = \{b, b\}$ and $t = \{g, g\}$, the firms would have an incentive to marginally deviate downward and discretely increase their demand by attracting all of the rival's consumers. If prices are distinct for $t = \{b, g\}$, with prices (p_b^*, p_g^*), applying UB implies that p_b^* and p_g^* must be mutual best responses, as otherwise, at least one of the firms could profitably deviate.[11] Hence, the candidate equilibrium with distinct prices for $t = \{b, g\}$ coincides with the perfect-information benchmark equilibrium. If equilibrium prices are instead the same for $t = \{b, g\}$, $p_b = p_g = p^*$, it must

11. This is also the case when $p_b^* = p^*(b) = b$, or $p_g^* = p^*(g) = g$, or both.

hold that $p^* > g$, as $p^* = g$ would not allow consumers to distinguish between the technology combinations $t = \{b, g\}$ and $t = \{g, g\}$.

It turns out that both types of these technology-revealing equilibria (either with distinct prices (p_b^*, p_g^*), or the same pooling price $p^* > g$ for $t = \{b, g\}$) can be supported for parts of the parameter space. However, we can also show that whenever these equilibria exist, they are payoff-dominated by a concurrent equilibrium that only partially reveals the underlying technology combination (see below). Because of this, we relegate a further characterization of these equilibria to Appendix A.

Pure pooling equilibrium. The other informational extreme would be an equilibrium where the consumers cannot distinguish at all between the different technology combinations. Clearly, this would require that the firms always choose the same pooling price $p^* \geq g$, irrespective of the realized technology combination. However, it is easy to see that this cannot be part of an equilibrium with a mixed-strategy technology choice, as then choosing the brown production technology, with its strictly lower marginal cost, would yield a strictly higher profit.

Partially technology-revealing equilibria. Finally, we need to consider the case that firms' equilibrium pricing allows to distinguish one technology combination from the other possible combinations, but that the latter cannot be distinguished from each other.

Case (i): Suppose first that $t = \{b, b\}$ and $t = \{g, g\}$ cannot be distinguished, where the firms set the same pooling price $p^{**} \geq g$ (in case the equilibrium prescribes firms to also choose a pooling price $p^* \geq g$ for $t = \{b, g\}$, it has to hold that $p^{**} \neq p^*$). But then, due to UB, the firms could profitably undercut in these technology configurations unless $t = \{g, g\}$ and $p^{**} = g$. But even with $p^{**} = g$, undercutting in the state $t = \{b, b\}$ would still be profitable, ruling out this candidate equilibrium.

Case (ii): Suppose second that $t = \{b, b\}$ and $t = \{b, g\}$ cannot be distinguished, where the firms again set the same price $p^* \geq g$. Then, for $t = \{g, g\}$, the firms would have to set a different price $p^*(g) \neq p^*$, which would fully reveal this technology combination. But from UB, this would mean that the firms would have an incentive to marginally undercut in $t = \{g, g\}$ unless $p^*(g) = g$ – which, in turn, implies $p^* > g$. As a result, choosing $t_i = g$ would generate a strictly lower profit than choosing $t_i = b$, as $t_i = g$ comes with a higher marginal cost and would lead to zero profit if the rival firm also happens to choose the green technology. This is incompatible with the assumed mixed-strategy technology choice.

Case (iii): The only candidate equilibrium that remains is such that $t = \{g, g\}$ and $t = \{b, g\}$ cannot be distinguished, where the firms set the same price $p^* \geq g$. Instead, for $t = \{b, b\}$, the firms price at marginal cost, which fully reveals this technology combination (similar to case (ii) above, due to UB it cannot be the case that $p^*(b) > b$ for $t = \{b, b\}$, as this would invite undercutting by either firm). For this case, $p^* = g$ can moreover be ruled out. This is because for $p^* = g$, choosing the brown technology would generate a strictly higher profit, given that the other firm randomizes which technology to choose, upsetting the candidate equilibrium.

As it turns out, an equilibrium as in Case (iii) with a suitably chosen $p^* > g$ will always be the payoff-dominant equilibrium (if any of the other equilibria with positive profits exists). Due to this, we will subsequently restrict attention to this type of equilibrium. In the remainder of this section, we will give a full characterization of this payoff-dominant equilibrium.

Partially Technology-Revealing Pooling Equilibrium – Characterization. From the above discussion, we look for existence of the following candidate equilibrium:

- In the first stage, the firms choose $t_i = g$ with probability $\alpha^* \in (0, 1)$ and $t_i = b$ with probability $1 - \alpha^*$.
- In the second stage, after observing each other's technologies:
  - If $t = \{b, b\}$, both firms set $p_i = b$.
  - If $t = \{g, g\}$ or $t = \{b, g\}$, both firms set $p_i = p^* \in (g, v]$.

- From firms' pricing decisions, consumers perfectly infer whether both firms have chosen the brown technology or not. However, when observing the price vector (p^*, p^*), they do not know whether just one or both firms have chosen the green technology.

Note that in this candidate equilibrium, the market may or may not be covered in the profit-generating technology combinations $t = \{g, g\}$ and $t = \{b, g\}$. Let $\hat{\eta}$ denote the type of the consumer who is indifferent between buying and not buying when facing p^* on the equilibrium path (where we set $\hat{\eta} = h$ if the market is covered). Then a brown firm's candidate equilibrium profit is given by $\pi_b = (p^* - b)\frac{\hat{\eta}}{2h}$ in the technology state $t = \{b, g\}$, while it is zero in the state $t = \{b, b\}$. On the other hand, a green firm's candidate equilibrium profit is given by $\pi_g = (p^* - g)\frac{\hat{\eta}}{2h}$ in every possible state.

In order for the firms to be indifferent between technologies in the first stage, we therefore need that

$$\underbrace{(1-\alpha^*)\cdot 0 + \alpha^*\pi_b}_{\pi_i(t_i=b|\alpha^*)} \quad = \quad \underbrace{\pi_g}_{\pi_i(t_i=g|\alpha^*)}$$

which implies that

$$\alpha^* = \frac{\pi_g}{\pi_b} = 1 - \frac{\Delta_g}{p^* - b} \in (0, 1), \tag{4}$$

irrespective of $\hat{\eta}$.

It follows that on the equilibrium path, the *conditional probability* of exactly one firm being brown (recall that both firms being brown would be revealed by firms' marginal-cost pricing) when consumers observe the price vector (p^*, p^*) is given by $\frac{2\alpha^*(1-\alpha^*)}{1-(1-\alpha^*)^2} = \frac{2(1-\alpha^*)}{2-\alpha^*}$. Hence, the expected disutility for a consumer of type η when buying from one of the firms at random is given by

$$X(p^*) = \frac{\eta}{2} \cdot \frac{2(1-\alpha^*)}{2-\alpha^*} = \frac{\eta\Delta_g}{p^* - b + \Delta_g}.$$

Since the consumer who is indifferent between buying and not buying satisfies $v - p^* - X(p^*) = 0$, it directly follows that

$$\hat{\eta}(p^*) \equiv \frac{(v - p^*)(p^* - b + \Delta_g)}{\Delta_g}. \tag{5}$$

Building on these results, our next proposition delineates the set of equilibria following the above structure.

Proposition 3. *There exists a partially technology-revealing pooling equilibrium with stochastic technology choice where the firms set $p_i = b$ for $t = \{b, b\}$ and $p_i = p^* > g$ for $t = \{b, g\}$ and $t = \{g, g\}$, with $\alpha^* = 1 - \frac{\Delta_g}{p^* - b}$, whenever*

$$\Delta_g < \min\left\{2h, \frac{4}{5}(v - b)\right\}.$$

The set of feasible equilibrium prices p^* for $t = \{b, g\}$ and $t = \{g, g\}$ is given by

$$p^* \in \begin{cases} (g, b + 2h] & \text{if} \quad h \leq \tilde{h}_1 \\ (g, \overline{p}^*] & \text{if} \quad h > \tilde{h}_1, \end{cases}$$

where[12]

$$\overline{p}^* \equiv b + \frac{v - b - \frac{3}{2}\Delta_g}{2} + \sqrt{\left(\frac{v - b - \frac{3}{2}\Delta_g}{2}\right)^2 + (v - b)\Delta_g} \in (v - \frac{\Delta_g}{2}, v), \tag{6}$$

$$\tilde{h}_1 \equiv \frac{\overline{p}^* - b}{2} = \frac{v - b - \frac{3}{2}\Delta_g}{4} + \frac{1}{2}\sqrt{\left(\frac{v - b - \frac{3}{2}\Delta_g}{2}\right)^2 + (v - b)\Delta_g}. \tag{7}$$

Proof. See Appendix B. □

The characterized equilibrium is stabilized by the off-equilibrium belief that a downward deviation from the pooling price $p^* > g$ must come from

12. To see that $\overline{p}^* > v - \frac{\Delta_g}{2}$, note that the expression under the root in (6) can be rewritten as

$$\frac{(v - b)^2 + (v - b)\Delta_g + \frac{9}{4}\Delta_g^2}{4} > \left(\frac{v - b + \frac{\Delta_g}{2}}{2}\right)^2.$$

the brown firm in $t = \{b, g\}$.[13] Of course, for a large candidate equilibrium price p^* and a relatively small average environmental concern h, firms may still find it profitable to undercut p^*. As we show in the proof of Proposition 3, the highest deviation profit of a brown firm (with its higher incentive to deviate downward) for some fixed $p^* > g$ is given by $\frac{(p^*-b)^2}{4h}$, which may not exceed the candidate equilibrium profit to support the equilibrium. For small h, the highest p^* which satisfies this is $b + 2h$, while for large h, it is $\overline{p}^*$. If $\Delta_g \geq \min\{2h, \frac{4}{5}(v-b)\}$, the range of feasible pooling prices $(g, \min\{b+2h, \overline{p}^*\}]$ collapses, and the considered equilibrium cannot be supported anymore.

Equilibrium Selection. Since the model typically gives rise to a multiplicity of equilibria, with up to four different types of equilibria coexisting (two of which exhibit a continuum of possible pooling prices themselves), in order to proceed with the analysis we need to engage in equilibrium selection. In the present context with ex-ante symmetric firms and a continuum of atomistic consumers, we find it natural to select equilibria according to payoff dominance.

Building on the set of partially technology-revealing pooling equilibria characterized in Proposition 3 above, the following proposition identifies the – from an ex-ante perspective – payoff-dominant equilibrium for each parameter combination.

Proposition 4. *Whenever the partially technology-revealing pooling equilibrium of Proposition 3 exists – i.e., for* $\Delta_g < \min\left\{2h, \frac{4}{5}(v-b)\right\}$ *– it is the payoff-dominant symmetric equilibrium with pure-strategy pricing in the second stage, for an appropriate choice of* p^**. If this equilibrium does not exist, the unique symmetric equilibrium involves both firms choosing* $t_i = b$ *and earning zero profit.*

13. To rule out profitable *upward* deviations, it suffices to assume that consumers do not believe that the deviating firm is more likely to have adopted the green technology than its non-deviating rival. After identifying the payoff-dominant pooling price within this class of equilibria under this assumption, we will briefly discuss the reasonableness of such off-equilibrium beliefs. Specifically, we will apply a version of the Intuitive Criterion (Cho and Kreps 1987), suitably adapted to a multi-sender context.

Specifically, let

$$\hat{p} \equiv b + \frac{v-b-\Delta_g}{2} + \sqrt{\left(\frac{v-b+\Delta_g}{2}\right)^2 - h\Delta_g}, \tag{8}$$

$$\check{p} \equiv b + \frac{v-b}{3} + \frac{\sqrt{(v-b)^2+3\Delta_g^2}}{3}, \tag{9}$$

$$\tilde{h}_2 \equiv \frac{1}{\Delta_g}\left[\left(\frac{v-b+\Delta_g}{2}\right)^2 - \left(\frac{\sqrt{(v-b)^2+3\Delta_g^2}}{3} - \frac{v-b-3\Delta_g}{6}\right)^2\right]. \tag{10}$$

Then:

- *For $h < \tilde{h}_1$, the payoff-dominant pooling price is $p^* = b + 2h < \hat{p}$, with corresponding equilibrium profit $\Pi^0_{max} = \frac{2h-\Delta_g}{2}$.*
- *For $h \in [\tilde{h}_1, \tilde{h}_2]$, the payoff-dominant pooling price is $p^* = \hat{p}$, with corresponding equilibrium profit $\Pi^1_{max} = \frac{\hat{p}-g}{2}$.*
- *For $h > \max\{\tilde{h}_1, \tilde{h}_2\}$, the payoff-dominant pooling price is $p^* = \check{p}$, with corresponding equilibrium profit $\Pi^2_{max} = (\check{p} - g)\frac{\hat{\eta}(\check{p})}{2h}$.*

Proof. See Appendix B. □

What constitutes the payoff-dominant pooling price for the partially technology-revealing pooling equilibrium depends on consumers' average environmental concern h. For a fairly low h, $h < \tilde{h}_1$, downward deviations from p^* are so tempting that the highest feasible pooling price is $b + 2h$, which still lies in the upward-sloping segment of the equilibrium profit schedule $\Pi_i(p^*) = (p^* - g)\frac{\hat{\eta}(p^*)}{2h}$. But once h gets sufficiently large, $h > \tilde{h}_1$, the highest feasible pooling price becomes $\overline{p}^*$, which always lies in the downward-sloping segment of the equilibrium-profit schedule. In this case, for a not too large h, $h \leq \tilde{h}_2$, the optimal pooling price is $\hat{p}$ ($< \overline{p}^*$), which is the largest pooling price where the market is still covered when both firms set p^*. But when h exceeds $\tilde{h}_2$, consumers' maximum environmental concern is so large that a covered market at p^* would require a pooling price that lies very close above g, or is not feasible at all for any $p^* > g$. In this case, the optimal pooling price is $\check{p}$ ($\in (\hat{p}, \overline{p}^*)$), which induces an uncovered market.

Robustness to the Intuitive Criterion. As outlined above (see Footnote 13), the class of partially technology-revealing pooling equilibria (for arbitrary equilibrium pooling prices p^*) is shielded from profitable upward deviations by assuming that consumers do not update their beliefs about a firm's technology type in the favor of green production (relative to the other firm). Based on a suitably adapted variant of the Intuitive Criterion (Cho and Kreps 1987; IC in what follows) we now want to discuss how reasonable such off-equilibrium beliefs are.

Assume that an upward deviation from some equilibrium pooling price p^* to some $p' > p^*$ could only conceivably be profitable (by endowing consumers with sufficiently optimistic off-equilibrium beliefs about the deviating firm's technology relative to the non-deviating one's) for a firm with the green technology, but never for a firm with the brown technology. As demand is (potentially) elastic in our model and the brown firm has lower unit costs, such a situation may indeed arise, in particular for a small environmental concern h in the population.[14] If this is the case, our equilibrium fails IC.

However, it is straightforward to prove that even when consumers have only moderately favorable off-equilibrium beliefs regarding the deviating firm's technology position – namely, that it has the green technology for sure, whereas its rival has the brown technology with the posterior probability that $t = \{b, g\}$, given the observed price vector (p^*, p') and UB – the *payoff-dominant* partially technology-revealing pooling equilibrium is robust to IC whenever $h \geq \tilde{h}_1$.[15]

14. Suppose that $p^* + h \leq v$ for some equilibrium pooling price p^*. In this case, following a deviation from p^* to $p' = p^* + h$, even the most optimistic off-equilibrium beliefs about the deviating firm's technology (i.e., that it has the green technology for sure) induce zero demand for the deviator (irrespective of the beliefs about the non-deviating firm's type). However, with such optimistic off-equilibrium beliefs, due to the higher unit cost of green firms, there *will* be a range of deviation prices $P^{dev} \subset (p^*, p^* + h)$ to which only green firms find it profitable to deviate. In turn, this rationalizes consumers' optimistic off-equilibrium beliefs and makes such deviations profitable indeed. Hence, whenever $p^* + h \leq v$, a respective partially technology-revealing pooling equilibrium does not survive IC.

15. Given any fixed beliefs about the non-deviating firm's type (including the described moderately optimistic off-equilibrium beliefs from the perspective of the deviator), for IC

For $h < \tilde{h}_1$, where the payoff-dominant pooling price is $b + 2h$, the condition for an equilibrium robust to IC is

$$\Delta_g \geq \Delta_g^{IC} \equiv \frac{2h(v-b)(v-b-2h)}{2h(v-b-h)-(v-b)(v-b-2h)}.$$[16]

Region Plot. Figure 1 illustrates the parameter region in (h, Δ_g)-space where the partially technology-revealing pooling equilibrium exists (strictly below the solid purple line given by $\min\{2h, 4/5(v-b)\}$). It also showcases the bounds $\tilde{h}_1$ and $\tilde{h}_2$ that determine the payoff-dominant pooling price p^*.

to hold it is necessary and sufficient that an upward deviation to v *is* profitable for a brown firm. If this is the case, consumers can never rule out that upward deviations came from a brown firm, such that IC has no bite. Now, a firm (say, firm i) deviating to $p_i = v$ that is considered to have $t_i = g$ with probability one delivers a perceived net utility of $u_i = 0$ to all consumers, while its rival (say, firm $j \neq i$) pricing at $p_j = p^*$ delivers a perceived net utility of $u_j = v - p^* - \eta \cdot \mathbb{P}\{t_j = b|(p^*, v), UB, t_i = g\} = v - p^* - \eta \cdot \frac{2(1-\alpha^*)}{2-\alpha^*}$ for a consumer of type η. Comparing these utilities, all consumers with $\eta > \frac{\hat{\eta}(p^*)}{2}$ will buy from the deviating firm i, for a demand of $\max\{1 - \frac{\hat{\eta}(p^*)}{2h}, 0\}$, as compared to a demand of $\min\{\frac{\hat{\eta}(p^*)}{2h}, \frac{1}{2}\}$ if firm i had stuck to the equilibrium price p^*. Clearly, this renders the considered deviation profitable (due to a higher price and weakly higher demand) for $p^* = \hat{p}$ (where $\hat{\eta}(p^*) = h$) and $p^* = \check{p}$ (where $\hat{\eta}(p^*) < h$). That is, the deviation to v is profitable in the payoff-dominant equilibrium whenever $h \geq \tilde{h}_1$.

16. The relevant condition is $(v-b)\left(1 - \frac{\hat{\eta}(b+2h)}{2h}\right) \geq h$, which easily reduces to the given inequality.

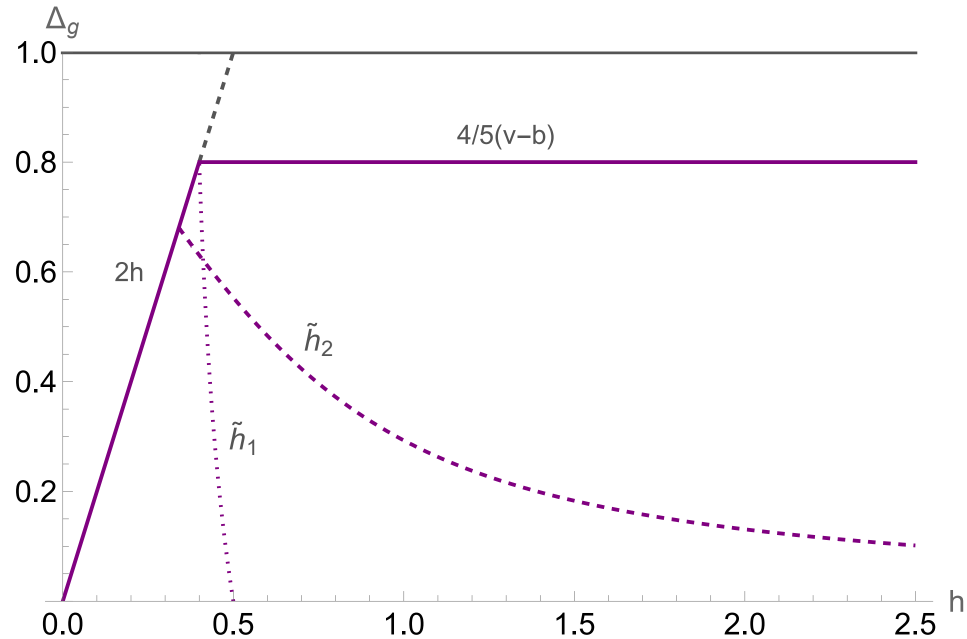

Figure 1: Partially technology-revealing pooling equilibrium (for $v - b = 1$): it exists below the solid purple line. The bounds $\tilde{h}_1$ and $\tilde{h}_2$ determine the payoff-dominant pooling price. It is given by $2h + b < \hat{p}$ to the left of the dotted purple line, by $\hat{p}$ to the right of the dotted and to the left of the dashed purple line, and by $\check{p}$ to the right of both the dotted and the dashed purple line.

5 Welfare

In this section, we analyze the welfare properties of the model. In order to avoid a double-counting of the societal harm created by the consumption of brown products, we adopt the following convention: If a brown product (creating a true negative externality of size $H > 0$ per unit) is consumed, the net surplus (or loss) created is simply given by $v - b - H$, irrespective of the perceived consumption disutility of consumers. Likewise, the consumption of green products (which do not create any negative externality) generates a surplus of $v - g > 0$, again irrespective of the perceived consumption disutility.

We first characterize welfare in the benchmark model with perfect information, before turning to a welfare analysis of the payoff-dominant equilibrium of the main model with asymmetric information. We also compare welfare across these two settings. We focus on the most interesting situation where green production is socially more efficient than brown production, yet consumption of the brown product is not socially harmful: $H \in (\Delta_g, v - b)$. In particular, while our model can also provide policy recommendations for the socially detrimental case where $H \geq v - b$, in such instances an outright ban of brown production appears to be the best solution.

5.1 Welfare in the Perfect Information Benchmark

If $\Delta_g \geq 2h$, only brown production takes place in equilibrium, even under perfect information. The resulting welfare in the market is given by[17]

$$W^{brown} \equiv (v - b - H) \min\left\{\frac{v - b}{h}, 1\right\}. \tag{11}$$

If instead $\Delta_g < 2h$, there are two types of equilibria: either an asymmetric equilibrium where $(t_i, t_j) = (b, g)$, or a symmetric mixed-strategy equilibrium where each firm chooses $t_i = g$ with probability $\alpha^{perf} \in (0, 1)$ as defined in Equation (2).

In the asymmetric equilibrium, the market is covered (as the green firm creates no negative externality and never prices above v), with a total welfare of

$$\begin{aligned} W^{perf}_{asym} &= \frac{\tilde{\eta}(p^*_b, p^*_g)}{h}(v - b - H) + \left[1 - \frac{\tilde{\eta}(p^*_b, p^*_g)}{h}\right](v - g) \\ &= v - g - (H - \Delta_g)\frac{\tilde{\eta}(p^*_b, p^*_g)}{h}. \end{aligned}$$

Using the appropriate expressions from Section 3, it follows that

$$W^{perf}_{asym} \equiv \begin{cases} v - g - (H - \Delta_g)\frac{\Delta_g + h}{3h} & \text{if} \quad h \leq \frac{3}{2}(v - b) - \Delta_g \\ v - g - (H - \Delta_g)\frac{v - b}{2h} & \text{if} \quad h > \frac{3}{2}(v - b) - \Delta_g. \end{cases} \tag{12}$$

17. Since both firms choose $t_i = b$, there is marginal-cost pricing in the second stage, and the consumer who is indifferent between buying and not buying (if any) satisfies $v - b - \eta = 0$. Hence, all consumers for which $\eta \leq v - b$ buy, for a total demand of $\min\{(v - b)/h, 1\}$.

As $H > \Delta_g$, it can clearly be seen that W^{perf}_{asym} strictly increases in consumers' environmental concern h.

In the symmetric mixed-strategy equilibrium, all technology combinations occur with positive probability, and the market will not be covered if both firms choose $t_i = b$ and $h > v - b$. The expected social welfare is then given by

$$W^{perf}_{sym} \equiv (\alpha^{perf})^2(v-g) + 2\alpha^{perf}(1-\alpha^{perf})W^{perf}_{asym} + (1-\alpha^{perf})^2 W^{brown}. \quad (13)$$

Note that whenever the market is (strictly) covered even when both firms choose $t_i = b$ (i.e., when $h < v-b$), a small increase of consumers' environmental concern h unambiguously increases W^{perf}_{sym}, as firms' equilibrium product choice is shifted in favor of choosing the more efficient green technology.[18] However, when $h \geq v - b$ but (as assumed) $H < v - b$ such that brown consumption is still socially beneficial (albeit less so than green consumption), an increase in h decreases W^{brown}, the welfare generated when both firms choose the brown technology. This is because more consumers drop out of the market, which leads to a larger deadweight loss. Given that a choice of the brown technology is still fairly prevalent in this case, which is true when the cost difference Δ_g is relatively large, a local increase in h may actually decrease the expected social welfare in the market. Nevertheless, in the limit as h grows without bound, W^{perf}_{sym} tends to the first-best, as firms' equilibrium propensity to choose the green technology tends to one.[19]

Using the normalization $v = 1$ and $b = 0$ and setting $H = 0.6$, Figure 2 shows a contour plot of the expected total welfare in (h, g)-space in the symmetric equilibrium of the perfect-information benchmark. We restrict our attention to the region where green production is more efficient ($\Delta_g = g < H$). In the area to the left of the left dashed line (where $h = \Delta_g/2$), only brown production occurs in equilibrium, whereas in the area to its right, the firms choose the green technology with positive probability. The right dashed line (where $h = \frac{3}{2}(v-b) - \Delta_g$) separates the parameter space into the region where

18. Recall from Section 3 that α^{perf} is strictly increasing in h.

19. See the limit behavior of α^{perf}_2 in Proposition 1.

the pricing equilibrium is interior in subgames with heterogeneous production technologies (left) and where it is not (right). The dotted vertical line (at $h = v - b$) separates the parameter space into the region where the market is covered if both firms choose the brown technology (left) and where it is not (right).

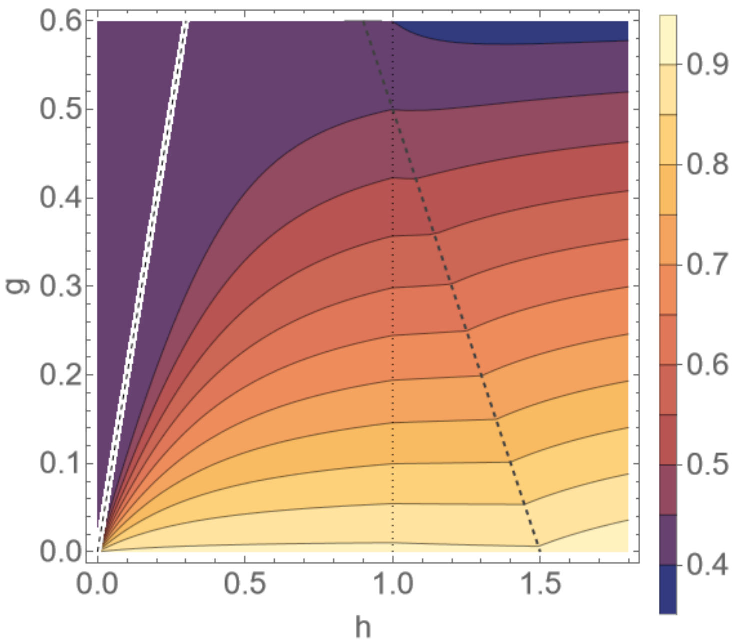

Figure 2: Contour plot of the expected total welfare in the symmetric mixed-strategy equilibrium of the perfect-information case ($v = 1$, $b = 0$, $H = 0.6$).

5.2 Welfare under Asymmetric Information

We now compute the expected total social welfare in the main model with asymmetric information, where we select the payoff-dominant equilibrium as delineated in Proposition 4. For $\Delta_g < \min\{2h, \frac{4}{5}(v - b)\}$, firms randomize which technology to choose in the first stage. Then, if the firms have chosen different production technologies, or if they have both chosen the green technology, they set the same (payoff-maximizing) pooling price $p^* > g$ in the second stage. On the other hand, if both firms have chosen the brown technology, marginal-cost pricing ensues.

Letting $\alpha^* = 1 - \frac{\Delta_g}{p^*-b} \in (0,1)$ denote the probability with which the firms choose the green technology in the first stage (cf. Section 4), the expected total welfare is now given by[20]

$$\begin{aligned} W^{pool} &= (\alpha^*)^2(v-g)\min\{\hat{\eta}(p^*)/h, 1\} \\ &+ 2\alpha^*(1-\alpha^*)\left[(v-g)\frac{\min\{\hat{\eta}(p^*)/h,1\}}{2} + (v-b-H)\frac{\min\{\hat{\eta}(p^*)/h,1\}}{2}\right] \\ &\qquad + (1-\alpha^*)^2 W^{brown}. \quad (14) \end{aligned}$$

As $\alpha^* = 1 - \frac{\Delta_g}{p^*-b}$ only depends indirectly on h via its influence on the payoff-dominant pooling price p^*, the dependency of W^{pool} on consumers' environmental-concern parameter h is surprisingly straightforward.

In particular, note from Proposition 4 that for $h \in (\Delta_g/2, \tilde{h}_1)$, the payoff-dominant pooling price is given by $p^* = b + 2h$, which induces a covered market ($\hat{\eta}(b+2h) \geq h$). Moreover, for $h < \tilde{h}_1$, the market is also covered when both firms choose the brown technology.[21] Together, this implies that for $h \in (\Delta_g/2, \tilde{h}_1)$, W^{pool} unambiguously increases in h, as (i) α^* increases, leading to a more efficient product supply and consumption in equilibrium, and (ii) the market remains covered for each technology combination.

For the case $h \in [\tilde{h}_1, \tilde{h}_2]$, the payoff-dominant pooling price is $p^* = \hat{p}$, which also induces a covered market. However, p^* now strictly decreases in h, which implies that α^* strictly decreases in it as well. An increase in h therefore leads to a less efficient product supply; in addition, it may also increase the deadweight loss in the case where both firms choose the brown technology (this is the case whenever $h \geq v - b$). Overall, an increase in h therefore unambiguously reduces W^{pool} in the range $[\tilde{h}_1, \tilde{h}_2)$.

Finally, for the case $h > \max\{\tilde{h}_1, \tilde{h}_2\}$, the payoff-dominant pooling price is $p^* = \check{p}$, which induces an uncovered market. Note that $\check{p}$ is independent of h,

20. Due to the various case distinctions that need to be made to pin down the payoff-maximizing p^* (with corresponding α^* and $\hat{\eta}$) and the complex expressions involved, we omit an explicit representation of W^{pool}. However, for each parameter combination, W^{pool} can easily be computed using Equation (14) and the characterization of the payoff-dominant equilibrium in Proposition 4.

21. This is because $\tilde{h}_1 = \frac{\overline{p}^*-b}{2} < \frac{v-b}{2}$, such that clearly $\frac{v-b}{h} > 1$ for $h < \tilde{h}_1$.

hence the equilibrium propensity of green production α^* is also not affected by it in the considered range. While $\hat{\eta}$ is also not affected by h, firms' demands $\frac{\hat{\eta}/h}{2}$ are clearly decreasing in it. Moreover, an increase in h will once again increase the deadweight loss in the case where both firms choose the brown technology, provided that $h \geq v - b$. In sum, W^{pool} therefore also strictly decreases in h for $h \geq \max\{\tilde{h}_1, \tilde{h}_2\}$. We summarize these findings in the following proposition.

Proposition 5. *Suppose that $\Delta_g < \frac{4}{5}(v - b)$. Then in the payoff-dominant equilibrium, welfare is non-monotonic in consumers' average environmental concern h:*

- *For $h \leq \Delta_g/2$, there is only brown production in equilibrium and welfare is independent of h.*
- *For $h \in [\Delta_g/2, \tilde{h}_1)$, welfare strictly increases in h.*
- *For $h \geq \tilde{h}_1$, welfare strictly decreases in h.*

Using again the normalization $v = 1$ and $b = 0$ and setting $H = 0.6$, Figure 3 shows a contour plot of the expected total welfare in (h, g)-space in the payoff-dominant equilibrium of the main game with asymmetric information.[22] We once more restrict attention to the region where $\Delta_g = g < H$. As in Figure 2, the dotted vertical line (at $h = v - b$) separates the parameter space into the region where the market is covered if both firms choose the brown technology (left) and where it is not (right).

The contour plot clearly showcases our analytical result that welfare strictly decreases in h starting from $h = \tilde{h}_1$. Note that this implies that, if the true negative externality from brown consumption H exceeds $\tilde{h}_1$ for some given set of parameters (v, g, b), then from a societal perspective, it is not even optimal that the *maximum* perceived harm h (let alone the median) from brown consumption in the population reflects the full negative externality H induced by it. In this case, provided that already $h \geq \tilde{h}_1$, naively sensitizing consumers further regarding the adverse effects of brown consumption

22. Note that for $\Delta_g = g \geq 2h$, both firms choose $t_i = b$ in the unique equilibrium, and welfare is given by W^{brown}.

backfires. Since $\tilde{h}_1$ is bounded above by $(v-b)/2$ (for $\Delta_g \to 0$), this is always the case when $H \geq (v-b)/2$, as is featured in the given plot (where $H = 0.6 > 0.5 = (v-b)/2$).

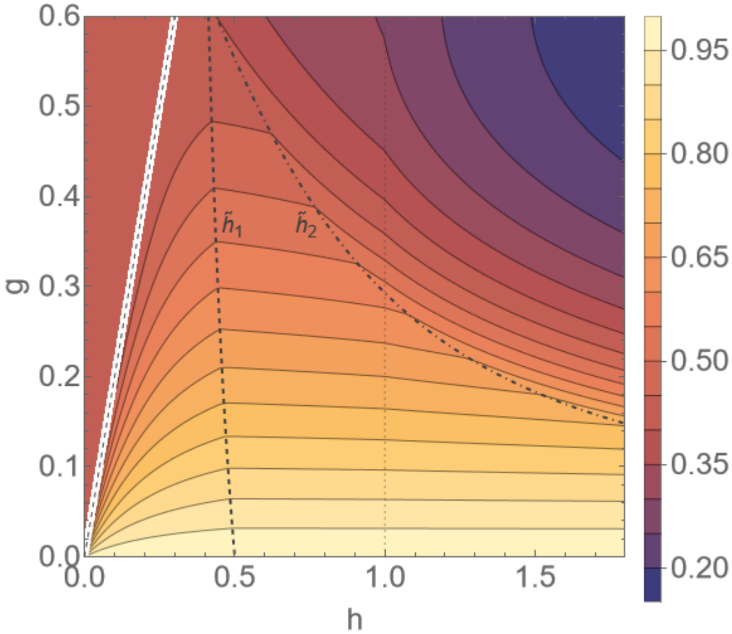

Figure 3: Contour plot of the expected total welfare in the payoff-dominant pooling equilibrium under asymmetric information ($v = 1$, $b = 0$, $H = 0.6$).

Figure 4 finally shows a contour plot of the *difference* between the expected total welfare in the symmetric mixed-strategy equilibrium of the perfect-information benchmark and the expected total welfare in the payoff-dominant equilibrium under asymmetric information. Interestingly, it can be seen that for a sufficiently small marginal-cost difference Δ_g, total welfare is *higher* under asymmetric information.

This property holds in general, as the following proposition establishes formally:

Proposition 6. *For any $h > 0$, the payoff-dominant partially technology-revealing pooling equilibrium achieves a higher social welfare than the symmetric perfect-information equilibrium, provided that Δ_g is sufficiently close to zero.*

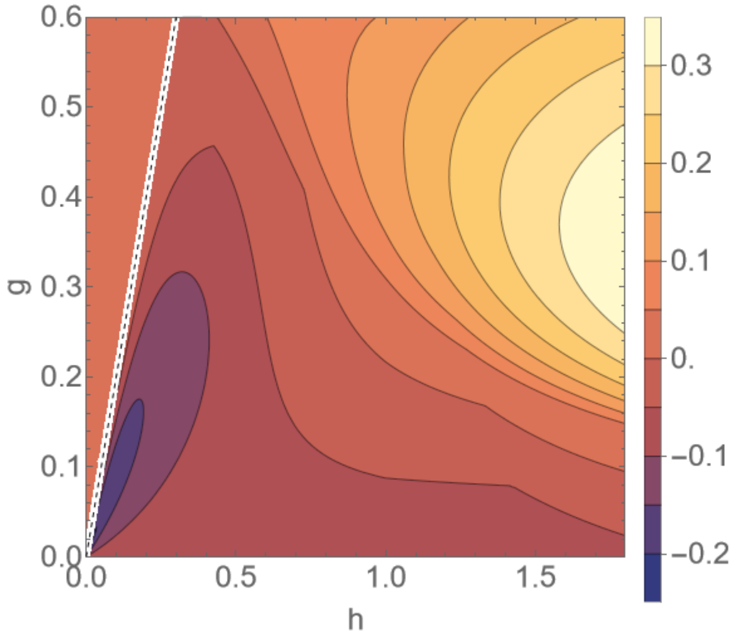

Figure 4: Contour plot of the difference in expected total welfare between the symmetric perfect-information equilibrium and the payoff-dominant symmetric equilibrium under asymmetric information ($v = 1$, $b = 0$, $H = 0.6$).

Proof. See Appendix B. □

The intuition is that in the perfect-information benchmark, firms make zero profit in case they choose the same technology in the first stage. Hence, their equilibrium propensity to choose the green technology stays bounded away from one even as Δ_g tends to zero (e.g., α_1^{perf} caps out at 4/5 as Δ_g goes to zero). By contrast, for any permissible pooling price $p^* > g$ – including the (endogenous) payoff-dominant one – firms' equilibrium propensity to choose the green technology approaches one as the cost difference becomes negligible (cf. Equation (4)). This corresponds to the first-best outcome.

A simple corollary to the fact that the market outcome tends to full efficiency as the difference in marginal costs between green and brown production vanishes is that policy interventions such as taxation of brown production or subsidies to green production may help to improve market outcomes. However, this clearly requires that the policy-maker is able to observe firms' production technologies, which may be infeasible – or at least quite costly – given the credence-goods nature of the considered products. Moreover, it is vital that the consumers remain uninformed about firms' production technologies, as otherwise, the efficient outcome is not attained for $\Delta_g \to 0$.

6 Conclusion

A growing interest into the environmental and social responsibility of production processes and services asks for the analysis of market models in which quality differences (regarding a product's ecological or social footprint) are per-se unobservable to consumers even after purchase and consumption. For exogenously given technologies (e.g., either high marginal costs for high/green quality or low marginal costs for low/brown quality) or observable investment choices with unobservable stochastic outcome, the literature has delineated conditions under which technologies may be revealed in a separating equilibrium. In these cases, prices serve as signals of technology or quality, and consumers can choose products according to their (environmental or quality-related) preferences.

However, when production technologies can be chosen strategically but are unobservable to customers, it is a priori unclear whether a decision in favor of (more costly) higher quality or green production can be sustained in equilibrium. This is particularly true in markets for label credence goods, where consumers do not even learn the relevant product characteristics after consumption (so that repeated purchases or information spillovers from other consumers play no role). If firms' strategic incentives do not permit a choice of high-quality/green production that can at least to some extent be signaled to consumers, the only way to promote green production and consumption is by establishing institutions that enhance the intrinsic or extrinsic motives of firms (such as easier credit access, monitoring, third-party certification, or reputation building, as in Blanco et al. 2025).

As we demonstrate in this paper, an intrinsic "green" motivation of firms or the existence of institutions that hold firms accountable for their production decisions are not necessary prerequisites for the emergence of green production in a label-credence good model with competition and an endogenous technology choice. Whenever firms observe each other's production technologies but consumers do not, firms can randomize over technology choices and pool price offers when at least one firm produces in a green way. This boosts firm profits and provides incentives to "go green" for firms. As a result, this type of equilibrium is payoff-dominant for firms and may even be welfare-superior to the perfect-information benchmark. In particular, it is welfare-superior to the case where only the firm itself is informed about its production technology (i.e., the case of pure private information): If technologies are unobservable to competitors, green production is never in the best interest of a profit-maximizing firm. That is, prices can be a signal of green production by competing providers of label credence goods, but only if firms can choose how responsible their technology actually is *and* if competitors do learn about it.

We argue that both of these assumptions are realistic in many real-life markets for label credence goods. While an environmental or social footprint of a production process will only be observed by customers via reliable monitoring institutions (e.g., certifiers, NGOs, media, etc.), supply chains offer opportunities for competitors to learn about each other's technology choices. For example, supply chains of competing firms may overlap when different producers of hydrogen use the same electricity provider for more or less climate-neutral electricity as an input to their electrolysis processes. Or, garment producers having the same set of suppliers in developing countries may know more about working conditions and the use of child labor. At the same time, these examples illustrate the relevance of endogenous technology choices, as switching back and forth between green and brown production technologies is rather straightforward in these cases.

References

Arguedas, Carmen, and Esther Blanco. 2025. "On fraud and certification of green production." *Journal of Economics & Management Strategy* 34 (2): 501–524. https://doi.org/https://doi.org/10.1111/jems.12609.

Bagwell, Kyle, and Garey Ramey. 1991. "Oligopoly limit pricing." *The RAND Journal of Economics* 22 (2): 155–172. https://www.jstor.org/stable/2601015.

Bagwell, Kyle, and Michael H. Riordan. 1991. "High and Declining Prices Signal Product Quality." *American Economic Review* 81 (1): 224–239. https://www.jstor.org/stable/2006797.

Baksi, Soham, and Pinaki Bose. 2007. "Credence Goods, Efficient Labelling Policies, and Regulatory Enforcement." *Environmental & Resource Economics* 37 (2): 411–430. https://doi.org/10.1007/s10640-006-9032-0.

Balafoutas, Loukas, and Rudolf Kerschbamer. 2020. "Credence goods in the literature: What the past fifteen years have taught us about fraud, incentives, and the role of institutions." *Journal of Behavioral and Experimental Finance* 26:100285. https://doi.org/10.1016/j.jbef.2020.100285.

Bester, Helmut. 1998. "Quality uncertainty mitigates product differentiation." *The RAND Journal of Economics* 29 (4): 828–844. https://www.jstor.org/stable/2556096.

Bester, Helmut, and Matthias Dahm. 2018. "Credence Goods, Costly Diagnosis and Subjective Evaluation." *The Economic Journal* 128 (611): 1367–1394. https://doi.org/10.1111/ecoj.12472.

Bester, Helmut, and Juri Demuth. 2015. "Signalling Rivalry and Quality Uncertainty in a Duopoly." *Journal of Industry, Competition and Trade* 15 (2): 135–154. https://doi.org/10.1007/s10842-014-0178-0.

Blanco, Esther, Felix Holzmeister, Rudolf Kerschbamer, and Markus Walzl. 2025. "The Economics of Label Credence Goods." *mimeo.*

Caldieraro, Fabio, Dongsoo Shin, and Andrew Stivers. 2011. "Voluntary Quality Disclosure under Price-Signaling Competition." *Managerial and Decision Economics* 32 (8): 493–504. https://doi.org/10.1002/mde.1550.

Cason, Timothy N., and Lata Gangadharan. 2002. "Environmental Labeling and Incomplete Consumer Information in Laboratory Markets." *Journal of Environmental Economics and Management* 43 (1): 113–134. https://doi.org/10.1006/jeem.2000.1170.

Chen, Minghua, Konstantinos Serfes, and Eleftherios Zacharias. 2023. "Prices as signals of product quality in a duopoly." *International Journal of Game Theory* 52 (1): 1–31. https://doi.org/10.1007/s00182-022-00808-1.

Cho, In-Koo, and David M. Kreps. 1987. "Signaling Games and Stable Equilibria." *The Quarterly Journal of Economics* 102 (2): 179–221. https://doi.org/10.2307/1885060.

Darby, Michael R., and Edi Karni. 1973. "Free Competition and the Optimal Amount of Fraud." *The Journal of Law & Economics* 16 (1): 67–88. https://doi.org/10.1086/466756.

Daughety, Andrew F., and Jennifer F. Reinganum. 2007. "Competition and confidentiality: Signaling quality in a duopoly when there is universal private information." *Games and Economic Behavior* 58 (1): 94–120. https://doi.org/10.1016/j.geb.2006.03.001.

———. 2008. "Imperfect competition and quality signalling." *The RAND Journal of Economics* 39 (1): 163–183. https://doi.org/10.1111/j.1756-2171.2008.00008.x.

Dewatripont, Mathias, and Jean Tirole. 2024. "The Morality of Markets." *Journal of Political Economy* 132 (2): 2655–2694. https://doi.org/10.1086/729445.

Dubovik, Andrei, and Maarten C.W. Janssen. 2012. "Oligopolistic competition in price and quality." *Games and Economic Behavior* 75 (1): 120–138. https://doi.org/10.1016/j.geb.2011.09.005.

Dulleck, Uwe, and Rudolf Kerschbamer. 2006. "On Doctors, Mechanics, and Computer Specialists: The Economics of Credence Goods." *Journal of Economic Literature* 44 (1): 5–42. https://doi.org/10.1257/002205106776162717.

Dulleck, Uwe, Rudolf Kerschbamer, and Matthias Sutter. 2011. "The Economics of Credence Goods: An Experiment on the Role of Liability, Verifiability, Reputation, and Competition." *American Economic Review* 101 (2): 526–555. https://doi.org/10.1257/aer.101.2.526.

Falk, Armin, Thomas Neuber, and Nora Szech. 2020. "Diffusion of Being Pivotal and Immoral Outcomes." *The Review of Economic Studies* 87 (5): 2205–2229. https://doi.org/10.1093/restud/rdz064.

Feddersen, Timothy J., and Thomas W. Gilligan. 2001. "Saints and Markets: Activists and the Supply of Credence Goods." *Journal of Economics & Management Strategy* 10 (1): 149–171. https://doi.org/10.1111/j.1430-9134.2001.00149.x.

Fluet, Claude, and Paolo G. Garella. 2002. "Advertising and prices as signals of quality in a regime of price rivalry." *International Journal of Industrial Organization* 20 (7): 907–930. https://doi.org/10.1016/S0167-7187(01)00075-3.

Fong, Yuk-fai. 2005. "When do experts cheat and whom do they target?" *The RAND Journal of Economics* 36 (1): 113–130. https://www.jstor.org/stable/1593757.

Harbaugh, Rick, John W. Maxwell, and Beatrice Roussillon. 2011. "Label Confusion: The Groucho Effect of Uncertain Standards." *Management Science* 57 (9): 1512–1527. https://doi.org/10.1287/mnsc.1110.1412.

Hertzendorf, Mark N., and Per Baltzer Overgaard. 2001a. "Price Competition and Advertising Signals: Signaling by Competing Senders." *Journal of Economics & Management Strategy* 10 (4): 621–662. https://doi.org/10.1111/j.1430-9134.2001.00621.x.

———. 2001b. "Prices as Signals of Quality in Duopoly." *mimeo,* accessed March 20, 2025. https://drive.google.com/file/d/1mcZl0s45sajp2VufyaQGCNoOO2ubNylh/view?usp=sharing.

———. 2002. "Prices as Signals of Quality in Duopoly: Type-Dependent Unit Costs." *mimeo,* accessed March 20, 2025. https://drive.google.com/file/d/16wNlUtmwAfGTZDcn8egclE_F9WHCkthQ/view?usp=sharing.

Holmes, Simon. 2024. "Sustainability and competition policy in Europe: recent developments." *Journal of European Competition Law & Practice* 15 (8): 562–570. https://doi.org/10.1093/jeclap/lpae063.

Iacovides, Marios C., and Konstantinos Stylianou. 2024. "The new goals of EU competition law: sustainability, labour rights, and privacy." *European Law Open* 3 (3): 587–616. https://doi.org/10.1017/elo.2024.31.

In, Younghwan, and Julian Wright. 2018. "Signaling Private Choices." *The Review of Economic Studies* 85 (1): 558–580. https://doi.org/10.1093/restud/rdx012.

Janssen, Maarten C.W., and Santanu Roy. 2010. "Signaling quality through prices in an oligopoly." *Games and Economic Behavior* 68 (1): 192–207. https://doi.org/10.1016/j.geb.2009.06.001.

———. 2015. "Competition, Disclosure and Signalling." *The Economic Journal* 125 (582): 86–114. https://doi.org/10.1111/ecoj.12110.

———. 2022. "Regulating Product Communication." *American Economic Journal: Microeconomics* 14 (1): 245–283. https://doi.org/10.1257/mic.20190187.

Kaufmann, Marc, Peter Andre, and Botond Kőszegi. 2024. "Understanding Markets with Socially Responsible Consumers." *The Quarterly Journal of Economics* 139 (3): 1989–2035. https://doi.org/10.1093/qje/qjae009.

Klein, Benjamin, and Keith B. Leffler. 1981. "The Role of Market Forces in Assuring Contractual Performance." *Journal of Political Economy* 89 (4): 615–641. https://doi.org/10.1086/260996.

Linnemer, Laurent. 2002. "Price and advertising as signals of quality when some consumers are informed." *International Journal of Industrial Organization* 20 (7): 931–947. https://doi.org/10.1016/S0167-7187(01)00081-9.

Milgrom, Paul, and John Roberts. 1986. "Price and Advertising Signals of Product Quality." *Journal of Political Economy* 94 (4): 796–821. https://doi.org/10.1086/261408.

Orzach, Ram, Per Baltzer Overgaard, and Yair Tauman. 2002. "Modest advertising signals strength." *The RAND Journal of Economics* 33 (2): 340–358. https://www.jstor.org/stable/3087437.

Sengupta, Aditi. 2012. "Investment in cleaner technology and signaling distortions in a market with green consumers." 2010 Monte Verita Conference on Sustainable Resource Use and Economic Dynamics(SURED), *Journal* *of Environmental Economics and Management* 64 (3): 468–480. https://doi.org/https://doi.org/10.1016/j.jeem.2012.04.001.

Sengupta, Aditi. 2015. "Competitive investment in clean technology and uninformed green consumers." *Journal of Environmental Economics and Management* 71:125–141. https://doi.org/https://doi.org/10.1016/j.jeem.2015.03.001.

———. 2024. "Communicating clean technology: Green premium, competition, and ecolabels." *Journal of Economics & Management Strategy* 33 (3): 605–629. https://doi.org/https://doi.org/10.1111/jems.12587.

UNICEF. 2020. *Child Labour: Global estimates 2020, trends and the road forward.* New York: UNICEF. https://www.ilo.org/publications/major-publications/child-labour-global-estimates-2020-trends-and-road-forward.

Willer, Helga, Jan Travnicek, and Berhard Schlatter. 2025. *The World of Organic Agriculture. Statistics and Emerging Trends 2025.* Bonn: Research Institute for Organic Agriculture. https://www.organic-world.net/yearbook/yearbook-2025.html.

Wolinsky, Asher. 1983. "Prices as Signals of Product Quality." *The Review of Economic Studies* 50 (4): 647–658. https://doi.org/10.2307/2297767.

———. 1995. "Competition in Markets for Credence Goods." *Journal of Institutional and Theoretical Economics* 151 (1): 117–131. https://www.jstor.org/stable/40751782.

Yehezkel, Yaron. 2008. "Signaling quality in an oligopoly when some consumers are informed." *Journal of Economics & Management Strategy* 17 (4): 937–972. https://doi.org/10.1111/j.1530-9134.2008.00201.x.

Appendix A: Other Equilibria under Asymmetric Information

In this appendix, we characterize the two other equilibria that may exist under asymmetric information, as previewed in Section 4. First, in Appendix A.1, we delineate the conditions under which the benchmark equilibrium under perfect information also exists under asymmetric information. Second, in Appendix A.2, we prove existence of a pooling equilibrium in which firms' pricing perfectly reveals the underlying technology combination, but where, in case of heterogeneous technologies, consumers cannot infer which firm has which production technology. We call this the *technology-revealing pooling equilibrium.*

A.1 Perfect Information Equilibrium

Here, we ask whether and under which circumstances the symmetric perfect-information equilibrium with stochastic choice of production technologies as characterized in Section 3 can be sustained under asymmetric information (i.e., when consumers cannot observe firms' production technologies). We thus suppose that $h > \frac{\Delta_g}{2}$ (otherwise, green production is never chosen even when firms' production technologies are perfectly observable) and look for existence of the following candidate equilibrium:

- In the first stage, the firms choose $t_i = g$ with probability $\alpha^{perf} \in (0, 1)$ and $t_i = b$ with probability $1 - \alpha^{perf}$, where α^{perf} is given in (2).
- In the second stage, after observing each other's technologies:
  - If $t = \{b, b\}$, both firms set $p_i = b$.
  - If $t = \{g, g\}$, both firms set $p_i = g$.
  - If $t = \{b, g\}$, the firms set $p_b = p_b^*$ and $p_g = p_g^*$.
- From firms' pricing decisions, consumers perfectly infer firms' technology choices, and buy according to their preferences.

Using UB, it is then immediately clear that deviations to any off-equilibrium price $p \neq \{b, g, p_b^*, p_g^*\}$ cannot pay under any technology combination. This is the case because consumers could then still perfectly infer firms' technologies, and the specified candidate equilibrium prices already constitute best responses to each other.

Next, it is obvious that a unilateral deviation to $p_i = b$, or to $p_g = g$ by the green firm in $t = \{b, g\}$, cannot be profitable. Moreover, with reasonable off-equilibrium beliefs, any unilateral deviation coming from $t = \{b, b\}$ (with $p_i = b$ in the candidate equilibrium) to another equilibrium price $p_i \in \{g, p_b^*, p_g^*\}$ should be identified as such, and hence is not profitable. This is because a green firm clearly has no reason to deviate to a price below its marginal cost (ruling out that such a deviation came from $t = \{g, g\}$ or from the green firm in $t = \{b, g\}$), while the brown firm in $t = \{b, g\}$ would make a positive profit in the candidate equilibrium and thus clearly also has no reason to deviate downward to its marginal cost.

It thus remains to rule out unilateral deviations from $t = \{g, g\}$ (with $p_i = g$ in the candidate equilibrium) to $p_i \in \{p_b^*, p_g^*\}$ and from $t = \{b, g\}$ (with $p_b = p_b^*$ and $p_g = p_g^*$ in the candidate equilibrium) to $p_b \in \{g, p_g^*\}$ and to $p_g = p_b^*$.

Deviations from $t = \{g, g\}$: In the candidate equilibrium, the firms price at marginal cost, $p_i = g$. Consider first a unilateral deviation to $p_i = p_b^*$, for a deviant price vector of (g, p_b^*). In this case, from UB, the consumers cannot assess whether the deviation has originated from $t = \{g, g\}$ or from $t = \{b, g\}$. However, the latter deviation would mean that the green firm in $t = \{b, g\}$ has deviated downward from p_g^* to its marginal cost g. Since this strictly reduces the deviating firm's profit compared to the equilibrium play, reasonable off-equilibrium beliefs should assign probability 1 on that the deviation has originated from $t = \{g, g\}$. Hence, the considered deviation implies zero demand, and is therefore not profitable.

Consider next a unilateral deviation to $p_i = p_g^*$, for a deviant price vector of (g, p_g^*). If this generates any demand, the deviation is profitable, upsetting the candidate equilibrium. Let consumers' beliefs that a price vector (g, p_g^*) (symmetrically, (p_g^*, g)) has originated from $t = \{g, g\}$ be given by μ_{gg}. By UB, consumers must then put probability $1 - \mu_{gg}$ on that the deviation has originated from the brown firm in $t = \{b, g\}$. Hence, buying from the firm with price p_g^* (who is believed to be a green firm for sure) gives consumers a utility of $v - p_g^*$, while buying from the firm with price g gives an expected utility, for a consumer of type η, of $v - (1 - \mu_{gg})\eta - g$. The deviation is thus not profitable if and only if $v - (1 - \mu_{gg})\eta - g \geq v - p_g^*$ for all $\eta \in [0, h]$ (i.e., even the most environmentally conscious type $\eta = h$ must prefer to buy from the firm with $p_i = g$, given their beliefs). Rearranging for μ_{gg}, equilibrium existence thus requires that

$$\mu_{gg} \equiv \mu\{t = \{g, g\} \mid p = (g, p_g^*) \vee p = (p_g^*, g)\} \geq \underline{\mu} \equiv 1 - \frac{p_g^* - g}{h}. \tag{15}$$

Deviations from $\boldsymbol{t = \{b, g\}}$: In the candidate equilibrium, the firms set prices $p_b = p_b^*$ and $p_g = p_g^*$. Consider first a deviation by the green firm to $p_g = p_b^*$. In this case, UB implies that the consumers know that the deviation has originated from $t = \{b, g\}$, but they cannot infer which firm has which technology, such that they must put probability 1/2 on either firm having the green technology. However, it is easy to see that the considered deviation cannot be profitable: Instead of deviating to p_b^*, the green firm could also deviate to $p_g = p_b^* + \epsilon$ for a sufficiently small $\epsilon > 0$, which would imply a higher demand (as by UB, the consumers would understand that the deviation has originated from the green firm in $t = \{b, g\}$) and therefore profit than the original deviation. But we already know from above that deviations to any off-equilibrium price $p_i \notin \{b, g, p_b^*, p_g^*\}$ cannot be profitable (in fact, the best response of the green firm to $p_b = p_b^*$ is $p_g = p_g^*$). Hence, the green firm has no profitable deviation.

Consider next a deviation by the brown firm to $p_b = g$. By the argument from the case $t = \{g, g\}$ above that an observed price vector (g, p_g^*) must not generate any demand for the firm with price p_g^* (caused by the belief $\mu_{gg} \geq \underline{\mu}$ derived there), the considered deviation must capture the whole market, for a deviation profit of Δ_g. Depending on whether the perfect-information equilibrium is interior or not, equilibrium existence thus requires that $\Delta_g \leq$

$\frac{(h+\Delta_g)^2}{9h}$ (for $h < \frac{3}{2}(v-b) - \Delta_g$) or $\Delta_g \leq \frac{(v-b)^2}{4h}$ (for $h \geq \frac{3}{2}(v-b) - \Delta_g$) – cf. Table 1. It can be shown that the former condition is equivalent to[23]

$$\Delta_g \leq \overline{\Delta}_g^{(1)} \equiv \left(\frac{7-3\sqrt{5}}{2}\right)h, \tag{16}$$

while the latter condition is directly given by

$$\Delta_g \leq \overline{\Delta}_g^{(2)} \equiv \frac{(v-b)^2}{4h}. \tag{17}$$

Consider finally a deviation by the brown firm to $p_b = p_g^*$. By UB, the consumers will then know that the deviation has originated from $t = \{b, g\}$, but they are unable to ascertain which firm has which technology. Thus, they believe that each firm has the green technology with probability 1/2, for an expected utility (for a consumer of type η) of $v - \eta/2 - p_g^*$. If $h \geq \frac{3}{2}(v-b) - \Delta_g$ and therefore $p_g^* = v$, no consumer would buy after this deviation, such that it is clearly not profitable. Suppose hence that $h \in (\Delta_g/2, \frac{3}{2}(v-b) - \Delta_g)$, such that $p_g^* = g + \frac{2h-\Delta_g}{3}$ and $\pi_b^* = \frac{(h+\Delta_g)^2}{9h}$. In this case, if $v - h/2 - p_g^* \geq 0$, all consumers buy (from either firm at random) following the deviation, for a deviation profit of the brown firm of $\frac{p_g^*-b}{2} = \frac{h+\Delta_g}{3} > \pi_b^*$. Hence, the candidate equilibrium cannot be supported in this case. If instead $v - h/2 - p_g^* < 0$, the market will not be covered after the deviation, with the marginal consumer $\tilde{\eta}$ satisfying $v - \tilde{\eta}/2 - p_g^* = 0$. From this, it follows that $\tilde{\eta} = 2(v - p_g^*)$, for a demand of $\frac{v-p_g^*}{h}$ for each firm. In the considered case, equilibrium existence thus requires that

$$(p_g^* - b)\left(\frac{v - p_g^*}{h}\right) \leq \pi_b^*,$$

23. This condition is equivalent to

$$f(\Delta_g) \equiv \Delta_g^2 - 7h\Delta_g + h^2 \geq 0.$$

As $f(\Delta_g)$ is a strictly convex function that satisfies $f(0) > 0$, all values of Δ_g up to the lower root of $f(\Delta_g)$, $\overline{\Delta}_g^{(1)}$, clearly satisfy this inequality. The larger root of $f(\Delta_g)$,

$$\left(\frac{7+3\sqrt{5}}{2}\right)h,$$

exceeds the permissible range for g, as by assumption $\Delta_g < 2h$.

which can be simplified to

$$h \geq \underline{h} \equiv \frac{6}{5}(v-b) - \Delta_g. \tag{18}$$

Note that for $h \geq \frac{3}{2}(v-b) - \Delta_g$, condition (18) is automatically satisfied.

Moreover, for future reference, observe that conditions (16) and (18) can only hold jointly if

$$h \geq h_{min}^{perf} \equiv \frac{4}{5(3-\sqrt{5})}(v-b) \approx 1.047(v-b). \tag{19}$$

Similarly, conditions (16) and (17) are both least stringent for $h = \frac{3}{2}(v-b)-\Delta_g$, in which case they reduce to

$$\Delta_g \leq (\Delta_g)_{max}^{perf} \equiv \frac{7-3\sqrt{5}}{6-2\sqrt{5}}(v-b) \approx 0.191(v-b). \tag{20}$$

Hence, a necessary condition for the perfect-information equilibrium to exist under asymmetric information is that both $h \geq h_{min}^{perf}$ and $g \leq (\Delta_g)_{max}^{perf}$.

Figure 5 illustrates the relevant parameter bounds for existence of the perfect-information equilibrium under asymmetric information in (h, Δ_g)-space.

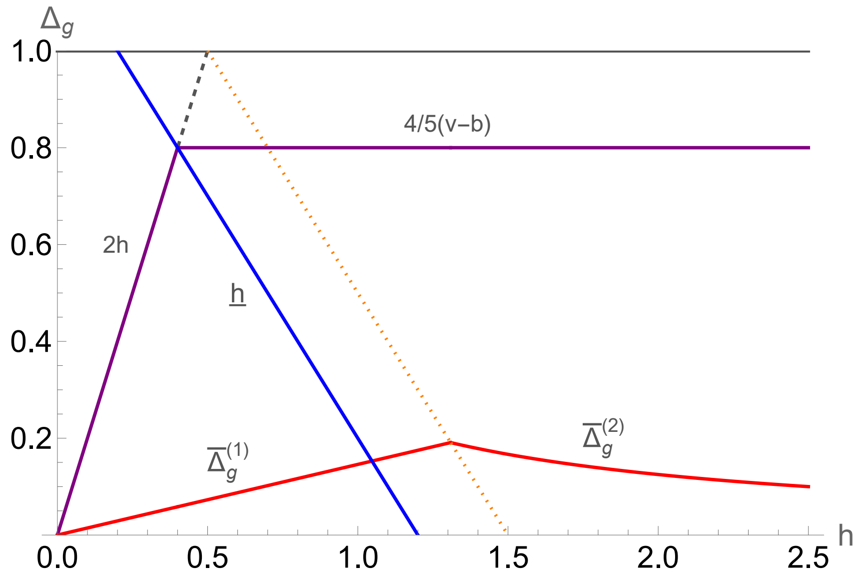

Figure 5: Perfect-information equilibrium under asymmetric information (for $v - b = 1$): the equilibrium exists in the region to the right of the blue line and below the red line. The dashed orange line separates the region where $p_g^* = p_{g,1}^* < v$ (for h small) from that where $p_g^* = v$ (for h large). The partially technology-revealing pooling equilibrium exists below the purple line.

A.2 Technology Revealing Pooling Equilibrium

In this candidate equilibrium, the firms set the same pooling price $p^* > g$ in case they have chosen different production technologies in the first stage. If, however, they have chosen the same technology, $t = \{b, b\}$ or $t = \{g, g\}$, this is revealed by their (marginal-cost) pricing. Precisely, we now look for existence of the following candidate equilibrium:

- In the first stage, the firms choose $t_i = g$ with probability $\alpha^* \in (0, 1)$ and $t_i = b$ with probability $1 - \alpha^*$.
- In the second stage, after observing each other's technologies:
  - If $t = \{b, b\}$, both firms set $p_i = b$.
  - If $t = \{g, g\}$, both firms set $p_i = g$.
  - If $t = \{b, g\}$, both firms set $p_i = p^* \in (g, v]$.

- From firms' pricing decisions, consumers perfectly infer the prevalence of the brown and green product in the market, however, when observing the price vector (p^*, p^*), they do not know which firm has which production technology.

Note that in this candidate equilibrium, the firms only make a positive profit when they happen to choose different production technologies in the first stage. In this case, their profits depend on whether the market is covered or not. Since the expected disutility when buying from a random firm (which has the brown technology with probability 1/2) is $\eta/2$ for a consumer of type η, the market is covered if and only if $v - \frac{h}{2} - p^* \geq 0$, that is, if and only if $p^* \leq v - \frac{h}{2}$. Otherwise, for $p^* > v - \frac{h}{2}$, the marginal consumer who is indifferent between buying and not buying is of type η such that $v - \frac{\eta}{2} - p^* = 0$, which implies that $\tilde{\eta} = 2(v - p^*)$ and hence a demand per firm of $\frac{v-p^*}{h}$. Overall, this gives rise to the following profits for the asymmetric technology combination $t = \{b, g\}$ in this candidate equilibrium:[24]

$$\pi_b = \begin{cases} \frac{p^*-b}{2} & \text{if } \; p^* \leq v - \frac{h}{2} \\ \frac{(p^*-b)(v-p^*)}{h} & \text{if } \; p^* \in (v - \frac{h}{2}, v] \end{cases} \tag{21}$$

$$\pi_g = \begin{cases} \frac{p^*-g}{2} & \text{if } \; p^* \leq v - \frac{h}{2} \\ \frac{(p^*-g)(v-p^*)}{h} & \text{if } \; p^* \in (v - \frac{h}{2}, v]. \end{cases} \tag{22}$$

The candidate equilibrium propensity α^* to choose the green technology and the overall equilibrium profit Π^* are then given by (2) and (3), with the profits taken from (21) and (22).[25] We now check under which conditions the specified candidate equilibrium can be supported.

From UB, it is clear that in the homogeneous technology states $t = \{b, b\}$ and $t = \{g, g\}$, a unilateral deviation to any off-equilibrium price ($p_i \notin \{g, p^*\}$ for $t = \{b, b\}$ and $p_i \notin \{b, p^*\}$ for $t = \{g, g\}$) cannot pay, as this would be identified as such by consumers and would hence induce zero demand for

24. Note that since necessarily $p^* > g$, the respective first case is obsolete when $h \geq 2(v-g)$.

25. Note that the highest equilibrium profit of the brown firm is given by $\pi_b^* = \frac{v-\frac{h}{2}-b}{2}$ (with $p^* = v - \frac{h}{2}$) for $h \leq v - b$ and by $\pi_b^* = \frac{(v-b)^2}{4h}$ (with $p^* = b + \frac{v-b}{2}$) for $h > v$. Similarly, the green firm's highest equilibrium profit is given by $\pi_g^* = \frac{v-\frac{h}{2}-g}{2}$ (with $p^* = v - \frac{h}{2}$) for $h \leq v - g$ and by $\pi_g^* = \frac{(v-g)^2}{4h}$ (with $p^* = g + \frac{v-g}{2}$) for $h > v - g$. This implies that for $h > v - g$, the firms will disagree about which equilibrium price to coordinate on once the asymmetric technology combination has arisen.

prices above the corresponding marginal cost. It is moreover obvious that a deviation to $p_i = b$ can never pay from any technology combination, even though this is an equilibrium price. This implies that when consumers observe one of the deviant price vectors $p = (b, g)$, $p = (g, b)$, $p = (b, p^*)$, or $p = (p^*, b)$, with reasonable off-equilibrium beliefs they should infer that the deviation must have come from $t = \{b, b\}$ and not from $t = \{g, g\}$ (in case $p = (b, g)$ or $p = (g, b)$) or from $t = \{b, g\}$ (in case $p = (b, p^*)$ or $p = (p^*, b)$).

It thus remains to rule out three types of potentially profitable deviations. First, for $t = \{g, g\}$ (where in the candidate equilibrium $p = (g, g)$), the firms should not want to deviate to $p^* > g$. Second, for $t = \{b, g\}$ (where in the candidate equilibrium $p = (p^*, p^*)$), the *brown* firm should not want to deviate to $p_b = g$ (clearly, the green firm will never have an incentive to deviate downward to its marginal cost). Third, also for $t = \{b, g\}$, neither the brown firm nor the green firm should have an incentive to deviate to any off-equilibrium price $p_i \notin \{p^*, g\}$.

We start with the first deviation. Observing a deviant price vector (g, p^*) (or symmetrically, (p^*, g)), consumers do not know whether this deviation stems from $t = \{g, g\}$ (i.e., one firm has deviated up to p^*) or from $t = \{b, g\}$ (i.e., either the brown firm or the green firm has deviated down from p^* to g). However, since the green firm in $t = \{b, g\}$ would make a strictly positive profit on the equilibrium path setting $p_g = p^* > g$, with reasonable off-equilibrium beliefs the consumers will rule out the last deviation. Hence, they should believe that the firm charging p^* must definitely have the green technology, while they may believe that the firm charging g has the green technology (i.e., that the deviation has originated from $t = \{g, g\}$ and not from $t = \{b, g\}$) with some probability $\mu_{gg} \in [0, 1]$. Now clearly, equilibrium existence requires that μ_{gg} is so large that no consumer will buy from the firm charging p^*: Otherwise, the upward deviation from $t = \{g, g\}$ to $p_i = p^*$ would pay, upsetting the candidate equilibrium.

In turn, this implies that the second type of deviation outlined above – the brown firm deviating downward from p^* to g in $t = \{b, g\}$ – must capture the whole market (recall that consumers believe that the firm setting p^* in this case must have the green technology for sure, so that the market must be covered due to $p^* \leq v$), for a corresponding deviation profit of Δ_g. Hence, equilibrium existence further requires that $\pi_b \geq \Delta_g$, where π_b is given in (21). For the considered equilibrium to exist, it is thus necessary that

$$\begin{aligned} \frac{p^* - b}{2} &\geq \Delta_g && \text{if } \ p^* \leq v - \frac{h}{2} \\ \frac{(p^* - b)(v - p^*)}{h} &\geq \Delta_g && \text{if } \ p^* \in (v - \frac{h}{2}, v], \end{aligned}$$

which is equivalent to

$$\begin{aligned} &p^* \geq b + 2\Delta_g && \text{if } \ p^* \leq v - \frac{h}{2} \\ &p^* \in [p^*_{min}, p^*_{max}] && \text{if } \ p^* \in (v - \frac{h}{2}, v], \end{aligned}$$

where

$$p^*_{min} \equiv b + \frac{v-b}{2} - \sqrt{\left(\frac{v-b}{2}\right)^2 - h\Delta_g} > b \tag{23}$$

and

$$p^*_{max} \equiv b + \frac{v-b}{2} + \sqrt{\left(\frac{v-b}{2}\right)^2 - h\Delta_g} < v. \tag{24}$$

We now consider the final type of deviation from $t = \{b, g\}$ to some off-equilibrium price. When consumers observe a deviant price pair (p_i, p^*), with $p_i \notin \{b, g\}$, UB asserts that consumers must believe that this deviation has come from $t = \{b, g\}$, but it does not restrict their beliefs about the probabilities as to which firm has which technology. In order to derive a necessary condition for equilibrium existence, in what follows we assume that consumers' off-equilibrium beliefs are most punitive in the sense that they believe that the deviating firm has $t_i = b$ with probability 1 (and thus, that its rival charging the equilibrium price p^* has $t_j = g$ with probability 1).

From Equation (1), the deviating firm's demand is then given by $D_i(p_i, p^*) = \frac{p^* - p_i}{h}$, for $p_i < p^*$. It is now easy to check that the maximal deviation profit of the brown firm equals $\pi_{b,dev} = \frac{(p^*-b)^2}{4h}$, while that of the green firm equals $\pi_{g,dev} = \frac{(p^*-g)^2}{4h}$. Equilibrium existence clearly requires that both $\pi_b \geq \pi_{b,dev}$ and $\pi_g \geq \pi_{g,dev}$. A simple calculation reveals that the former condition is always the binding one.

It is now useful to note that the brown firm's candidate equilibrium profit π_b as specified in (21) is linearly increasing in p^* up to $v - \frac{h}{2}$ (provided that

$h < 2v$; otherwise, the linear part does not exist) and is then strictly concave up to v. For $h \leq v - b$, the function is strictly decreasing for all $p^* > v - \frac{h}{2}$, while for $h > v - b$, the function is first strictly increasing up to $p^* = b + \frac{v-b}{2}$ and then strictly decreasing.

Suppose first that $h \leq v - b$. Then, the brown firm's candidate equilibrium profit π_b is maximal for $p^* = v - \frac{h}{2}$, such that $\pi_b \leq \pi_b(p^* = v - \frac{h}{2}) = \frac{v-b}{2} - \frac{h}{4}$. As equilibrium existence requires that $\pi_b \geq \Delta_g$ (see above), a necessary condition for equilibrium existence is hence that $\Delta_g \leq \frac{v-b}{2} - \frac{h}{4}$. Suppose that this is the case. Then the condition $\pi_b(p^*) \geq \Delta_g$ is equivalent to $p^* \in [b + 2\Delta_g, p^*_{max}]$.

In addition, the brown firm's (strictly increasing and convex) maximal deviation profit $\pi_{b,dev}$ uniquely crosses π_b in its linear segment at $p^* = b + 2h$ if $b + 2h \leq v - \frac{h}{2}$, that is, if $h \leq \frac{2}{5}(v - b)$. Otherwise, if $h \in (\frac{2}{5}(v-b), v-b]$, $\pi_{b,dev}$ uniquely crosses π_b in its downward-sloping segment at $p^* = b + \frac{4}{5}(v - b)$. We can thus conclude that for $h \leq \frac{2}{5}(v - b)$, equilibrium existence also requires that $p^* \leq b + 2h$, while for $h \in (\frac{2}{5}(v - b), v - b]$, equilibrium existence also requires that $p^* \leq b + \frac{4}{5}(v - b)$.

Combining results, for the case $h \leq \frac{2}{5}(v - b)$, equilibrium existence thus requires that $p^* \in [b + 2\Delta_g, b + 2h]$,[26] which is only possible if $\Delta_g \leq h$. For the case $h \in (\frac{2}{5}(v - b), v - b]$, equilibrium existence instead requires that $\Delta_g \leq \frac{v-b}{2} - \frac{h}{4}$ and $p^* \in [b + 2\Delta_g, \min\{p^*_{max}, b + \frac{4}{5}(v - b)\}]$. Note moreover that $p^*_{max} \lesseqqgtr b + \frac{4}{5}(v - b) \Leftrightarrow \Delta_g \gtreqqless \left(\frac{2}{5}(v - b)\right)^2 / h$.

Suppose now that $h > v - b$. In this case, the brown firm's candidate equilibrium profit π_b is maximal for $p^* = b + \frac{v-b}{2}$, such that $\pi_b \leq \pi_b(p^* = b + \frac{v-b}{2}) = \frac{(v-b)^2}{4h}$. Again, as equilibrium existence requires that $\pi_b(p^*) \geq \Delta_g$, a necessary condition for equilibrium existence is that $\Delta_g \leq \frac{(v-b)^2}{4h}$. If this is the case, $\pi_b \geq \Delta_g$ is equivalent to $p^* \in [p^*_{min}, p^*_{max}]$ for $\Delta_g \in (\frac{v-b}{2} - \frac{h}{4}, \frac{(v-b)^2}{4h}]$, and to $p^* \in [b + 2\Delta_g, p^*_{max}]$ for $\Delta_g \leq \frac{v-b}{2} - \frac{h}{4}$ (as in the case $h \leq v - b$ before).

In addition, the brown firm's maximal deviation profit $\pi_{b,dev}$ uniquely crosses π_b in its downward-sloping segment at $p^* = b + \frac{4}{5}(v - b)$, same as for $h \in (\frac{2}{5}(v - b), v - b]$.

Combining results, for the case $h > v - b$, equilibrium existence thus requires that either $\Delta_g \leq \frac{v-b}{2} - \frac{h}{4}$ and $p^* \in [b + 2\Delta_g, \min\{p^*_{max}, b + \frac{4}{5}(v - b)\}]$, or that $\Delta_g \in (\frac{v-b}{2} - \frac{h}{4}, \frac{(v-b)^2}{4h}]$ and $p^* \in [p^*_{min}, \min\{p^*_{max}, b + \frac{4}{5}(v - b)\}]$. Again, note that $p^*_{max} \lesseqqgtr b + \frac{4}{5}(v - b) \Leftrightarrow \Delta_g \gtreqqless \left(\frac{2}{5}(v - b)\right)^2 / h$.

26. Note that $b + 2h \leq p^*_{max}$ in this case.

The dashed green line in Figure 6 superimposes the upper bounds on Δ_g for existence of the candidate pooling equilibrium ($\Delta_g = h$ for $h \leq \frac{2}{5}(v-b)$; $\Delta_g = \frac{v-b}{2} - \frac{h}{4}$ for $h \in (\frac{2}{5}(v-b), v-b]$; $\Delta_g = \frac{(v-b)^2}{4h}$ for $h > v-b$) on the (relevant) bounds derived for existence of the perfect-information equilibrium as shown in Figure 5. The different cases for the range of the equilibrium p^*'s outlined above are separated by the dashed-dotted green lines ($h = \frac{2}{5}(v-b)$ and $h = v-b$, respectively) and the dotted green lines ($\Delta_g = \left(\frac{2}{5}(v-b)\right)^2/h$ for the non-linear one and $\Delta_g = \frac{v-b}{2} - \frac{h}{4}$ for the linear one).

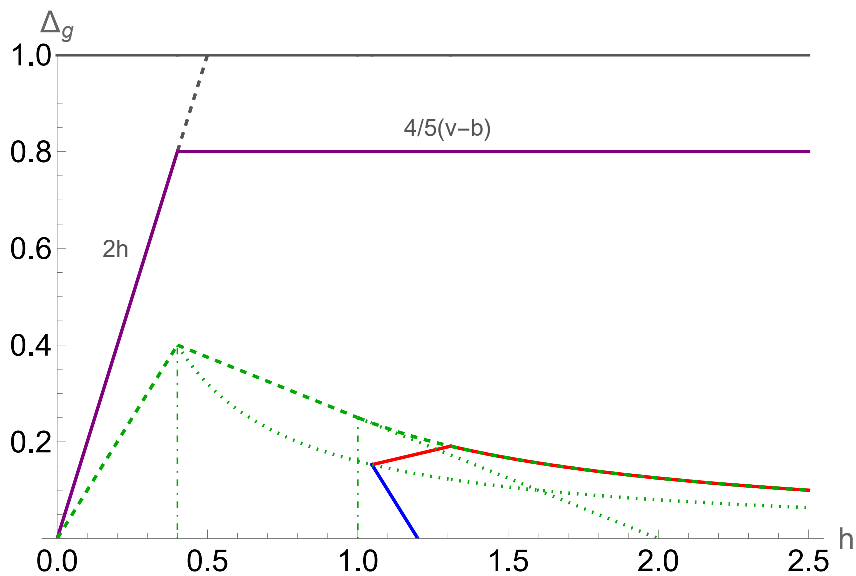

Figure 6: Technology-revealing pooling equilibrium (for $v - b = 1$): it exists below the dashed green line. The partially technology-revealing pooling equilibrium exists below the purple line. The perfect-information equilibrium exists in the region to the right of the blue and below the red solid line.

Appendix B: Proofs Omitted from the Main Text

Proof of Lemma 1. The demand functions in the main text give rise to the best-response functions

$$p_b^*(p_g) = \frac{p_g + b}{2}$$

and

$$p_g^*(p_b) = \frac{p_b + h + g}{2}.$$

These uniquely intersect at $\hat{p}_b \equiv b + \frac{h+\Delta_g}{3}$ and $\hat{p}_g \equiv g + \frac{2h-\Delta_g}{3}$, as given in the second row of Table 1. Note now that $\hat{p}_g > g$ if and only if $h > \Delta_g/2$. For $h \leq \Delta_g/2$, it is instead straightforward to see that the pair $\tilde{p}_g \equiv g$ and $\tilde{p}_b \equiv g - h$, as given in the first row of Table 1, constitutes the unique equilibrium in undominated strategies (where no firm prices below its marginal cost). To see this, note in particular from the above best-response functions that $p_b^*(g) = \frac{g+b}{2} < g - h$ for $h < \Delta_g/2$, so that in this case, firm b's best response to $p_g = g$ is indeed to price at $g - h$ (the highest price where it still captures the whole market) and not at $\frac{g+b}{2}$. Note finally that $\hat{p}_g < v$ if and only if $h < \frac{3}{2}(v - b) - \Delta_g$. Since pricing above v would automatically result in zero demand due to consumers' outside option, the green firm's best response to $\check{p}_b \equiv \frac{v+b}{2}$ is $\check{p}_g \equiv v$ for $h \geq \frac{3}{2}(v - b) - \Delta_g$, and vice versa. These are indeed found in the third row of Table 1. □

Proof of Proposition 2. Since the firms make zero profit in the pure brown candidate equilibrium (as there is marginal-cost pricing in the second stage), we restrict our attention to such equilibria where, given a first-stage deviation to $t_i = g$ by one of the firms, the then green firm still optimally prices at marginal cost, $p_g = g$, in the second stage (given the specified off-equilibrium pricing behavior of its rival). We thus look for off-equilibrium price profiles $(p_b, p_g = g)$ in the off-equilibrium technology combination $t = \{b, g\}$ where neither the green firm has an incentive to deviate upward, nor the brown firm wishes to set a different price than p_b. For completeness, we specify that both firms price at marginal cost g in the off-equilibrium technology combination $t = \{g, g\}$.

Now clearly, for $p_b = g - h$ – which is a best response to $p_g = g$ whenever $h \leq \Delta_g/2$ and both firms' technologies are correctly identified, see Lemma 1 and its proof – the green firm cannot profitably deviate upward from g, as this would induce zero demand. On the other hand, a deviation to $p_b = g$ by the brown firm would at best capture half of the market, for a deviation profit (from the supposed off-path play) of at most $\Delta_g/2$, as compared to $\Delta_g - h$ when following the specified off-path behavior. Provided that $h \leq \Delta_g/2$, deviating upward to $p_b = g$ hence does not pay for the brown firm. Given that a deviation from $(p_b = g - h, p_g = g)$ by the brown firm to a price that strictly exceeds g leads to zero demand (as would naturally follow from many consumer off-equilibrium beliefs), the pure brown equilibrium thus exists.

Suppose next that $h > \Delta_g/2$ and consider pure brown candidate equilibria with the off-equilibrium price pair $(p_b = \frac{g+b}{2}, p_g = g)$. As can be seen in the proof of Lemma 1, the price $p_b = \frac{g+b}{2} > g - h$ is then indeed a best response to $p_g = g$, given that the firms' technologies are identified correctly by consumers, as would be the case from UB. In this off-equilibrium scenario, the brown firm makes a profit of $\pi_b(\frac{g+b}{2}) = \frac{\Delta_g^2}{4h}$. Note moreover that, in contrast to the situation with perfect information, an upward deviation by the green firm may not be profitable. This is because an observed price vector $(p_b = \frac{g+b}{2}, p_g > g)$ corresponds to an at least dual deviation from the prescribed equilibrium play, such that the consumers might attribute this deviation as coming from $t = \{b, b\}$ with arbitrarily high probability. Consequently, an upward deviation by the green firm will result in zero demand for appropriately specified off-equilibrium beliefs (that do not contradict UB). However, it remains to rule out a deviation to $p_b = g$ by the brown firm.[27] In this case, the price vector (g, g) (which, in the eyes of consumers, results from at least a dual deviation) is at best – to support the equilibrium – interpreted to come from $t = \{b, b\}$ with certainty.[28] Given this, it is easy to check that the market will not be covered for $\Delta_g > v - b - h$, with a corresponding demand of $\frac{v-b-\Delta_g}{2h}$ per firm. The brown firm then makes a profit of $\pi_b(g) = \Delta_g \left(\frac{v-b-\Delta_g}{2h}\right)$, which does not exceed its profit when sticking to the specified off-equilibrium play, $\pi_b(\frac{g+b}{2}) = \frac{\Delta_g^2}{4h}$, provided that $\Delta_g \geq \frac{2}{3}(v - b)$.[29] Note that $\Delta_g \geq \frac{2}{3}(v - b)$ and $h > \Delta_g/2$ jointly imply that $\Delta_g > v - b - h$, so that the market will indeed be uncovered if these two conditions holds. Hence, for $h > \Delta_g/2$ and $\Delta_g \geq \frac{2}{3}(v - b)$, the pure brown equilibrium exists.

Finally, consider brown candidate equilibria with the off-equilibrium price pair $p_b = p_g = g$ in $t = \{b, g\}$. Since then the only unilateral deviation that induces this price pair is a first-stage deviation to $t_i = g$ by either firm (as compared to a dual technology deviation in the first stage, or a dual price

27. Deviations to $p_b > g$ will induce zero demand for many reasonable off-equilibrium beliefs.

28. A very similar argument works when consumers interpret the deviation to come from $t = \{b, g\}$ with certainty. In this case, the lower bound on Δ_g for equilibrium existence to be derived below increases to $\frac{4}{5}(v - b)$.

29. If the market is covered for the price vector (g, g), the off-path deviation from $p_b = \frac{g+b}{2}$ to $p_b = g$ pays for the brown firm (given that $h > \Delta_g/2$, as assumed), eliminating the candidate equilibrium.

deviation in the second stage), from UB the consumers will correctly infer that $t = \{b, g\}$. The prescribed off-path profit of the brown firm thus either equals $\Delta_g/2$ (if the market is covered given consumers' beliefs, $v - g - h/2 \geq 0$) or $\Delta_g \left(\frac{v-g}{h}\right)$ (if the market is not covered given consumers' beliefs, $v - g - h/2 < 0$, such that the marginal consumer satisfies $v - g - \eta/2 = 0$).

We now need to check under which circumstances the brown firm has no profitable downward deviation from the price vector (g, g) in $t = \{b, g\}$.[30] Suppose that the consumers observe some price vector (p, g), where $p \in (b, g)$. In order to maximally support the prescribed off-path behavior in the considered candidate equilibrium, the consumers should believe that this (at least) dual deviation comes from $t = \{b, g\}$ with certainty (where the price p is attributed to the brown firm). Given $h \geq \Delta_g/2$, the brown firm's optimal deviation price then equals $\frac{g+b}{2}$, for a maximal deviation profit of $\frac{\Delta_g^2}{4h}$.[31]

If the market is covered for the price vector (g, g), which is the case when $\Delta_g \leq v - b - \frac{h}{2}$, existence of the considered equilibrium thus requires that $\frac{\Delta_g}{2} \geq \frac{\Delta_g^2}{4h}$, which is equivalent to $h \geq \Delta_g/2$ (i.e., $\Delta_g \leq 2h$). If instead the market is not covered for the price vector (g, g), $\Delta_g > v - b - \frac{h}{2}$, equilibrium existence requires that $\Delta_g \left(\frac{v-g}{h}\right) \geq \frac{\Delta_g^2}{4h}$, which is equivalent to $\Delta_g \leq \frac{4}{5}(v - b)$. Hence, irrespective of whether $\Delta_g \leq v - b - \frac{h}{2}$ or $\Delta_g > v - b - \frac{h}{2}$, the equilibrium can be supported if $\Delta_g \leq \min\{2h, \frac{4}{5}(v - b)\}$.

Overall, at least one of the above three candidate equilibria with deterministic brown production thus always exists (for appropriately specified off-equilibrium prices), which completes the proof.

□

Proof of Proposition 3. We first show that the considered partially technology-revealing pooling equilibrium can be supported for some permissible pooling prices $p^* \in (g, v]$ if and only if $\Delta_g < \min\left\{2h, \frac{4}{5}(v - b)\right\}$. We then characterize the set of pooling prices p^* that are indeed supportable in equilibrium.

Equilibrium Existence. Note first that deviating upward in the state $t = \{b, b\}$ to some $p_i > b$ cannot pay. This is because for $p_i \neq p^*$, due to UB,

30. Upward deviations from either firm induce zero demand for many reasonable off-equilibrium beliefs.

31. If $h < \Delta_g/2$, the brown firm's optimal deviation price is $g - h$, for a deviation profit of $\Delta_g - h$. This necessarily exceeds the profit when sticking to $p_b = g$, which is bounded above by $\Delta_g/2$. Hence, for $h < \Delta_g/2$, the considered equilibrium does not exist.

consumers would still (correctly) believe that the deviating firm has the brown technology, such that it would receive zero demand. If a firm instead deviates to the equilibrium price p^*, it is sensible to assume that consumers will still believe that this deviation stems from the state $t = \{b, b\}$ and not from any of the other technology combinations. This is because deviating downward from p^* to $p_i = b$ in the states $t = \{g, g\}$ and $t = \{b, g\}$ would strictly reduce a firm's profit, compared to the equilibrium play. Thus, also an upward deviation to p^* should induce zero demand.

Now, in order to derive a necessary equilibrium condition, we suppose that downward deviations from p^* are believed to come from a brown firm with probability one (i.e., consumers put probability one on that such a deviation has originated from the brown firm in the state $t = \{b, g\}$).[32] From Equation (1), the deviating firm's demand is then given by $D_i(p_i, p^*) = \frac{p^* - p_i}{h}$ for $p_i < p^*$. It is now easy to check that the maximal deviation profit of the brown firm equals $\pi_{b,dev} = \frac{(p^*-b)^2}{4h}$, while that of the green firm equals $\pi_{g,dev} = \frac{(p^*-g)^2}{4h}$.

Equilibrium existence for any given candidate $p^* > g$ now clearly requires that both $\pi_b(p^*) \geq \pi_{b,dev}(p^*)$ and $\pi_g(p^*) \geq \pi_{g,dev}(p^*)$, where $\pi_b(p^*)$ ($\pi_g(p^*)$) denotes a brown (green) firm's candidate equilibrium profit when the equilibrium pooling price is given by p^*. A straightforward calculation reveals that the former condition is always the binding one. The set of equilibria of the considered type is thus characterized by the set of candidate equilibrium prices $p^* \in (g, v]$ for which

$$\pi_b(p^*) = (p^* - b)\left(\frac{\min\{\hat{\eta}(p^*)/h, 1\}}{2}\right) \geq \frac{(p^* - b)^2}{4h},$$

or, equivalently, for which

$$\min\{\hat{\eta}(p^*)/h, 1\} \geq \frac{p^* - b}{2h},$$

32. In order to rule out profitable upward deviations, it is sufficient that consumers do not put *more* probability than on the equilibrium path that the deviating firm has chosen the green technology.

where $\hat{\eta}(p^*)$ is given in (5). For equilibrium existence, it is thus required that both

$$\frac{\hat{\eta}(p^*)}{h} \geq \frac{p^* - b}{2h}, \tag{25}$$

$$1 \geq \frac{p^* - b}{2h}. \tag{26}$$

Note first that condition (25) can be reduced to[33]

$$f(p^*) \equiv \frac{v - p^*}{\Delta_g} + \frac{v - p^*}{p^* - b} - 1/2 \geq 0.$$

As $f(p^*)$ is strictly decreasing in p^*, with $\lim_{p^* \downarrow b} f(p^*) = +\infty$ and $f(v) < 0$, it follows that there is always an interior upper bound $\overline{p}^* \in (b, v)$ on the admissible equilibrium prices p^* that is defined by the unique solution $p^* \in (b, v)$ to $f(p^*) = 0$. Recall moreover that $p^* > g$ must hold in the candidate equilibrium. Now $f(g) = \frac{2(v-g)}{\Delta_g} - \frac{1}{2} > 0$ if and only if

$$\Delta_g < \frac{4}{5}(v - b).$$

Hence, the candidate equilibrium may only exist if the above inequality holds. Suppose in what follows that this is the case. Now $f(p^*)$ is equivalent to the quadratic inequality

$$z(p^*) \equiv (p^* - b)^2 - (p^* - b)\Big(v - b - \frac{3}{2}\Delta_g\Big) - (v - b)\Delta_g \leq 0,$$

where $z(p^*)$ is strictly convex, with $z(b) < 0$ and $z(v) > 0$. Hence, the upper bound on p^*, $\overline{p}^*$, is defined by the larger root of $z(p^*)$, which is given in (6).

Observe next that condition (26) is equivalent to $p^* \leq b + 2h$, which is only compatible with the condition $p^* > g$ if $\Delta_g < 2h$ – equivalently, $h > \Delta_g/2$;

33. The condition is equivalent to

$$\begin{aligned} &\frac{(v - p^*)(p^* + \Delta_g - b)}{h\Delta_g} \geq \frac{p^* - b}{2h} \\ \Leftrightarrow\ &\frac{(v - p^*)[(p^* - b) + \Delta_g]}{\Delta_g} \geq \frac{p^* - b}{2} \\ \Leftrightarrow\ &\frac{v - p^*}{\Delta_g} + \frac{v - p^*}{p^* - b} \geq \frac{1}{2}. \end{aligned}$$

recall that this condition needs to hold in order to give rise to green production in the perfect-information benchmark. Overall, equilibrium existence therefore requires that $\Delta_g < \min\{2h, \frac{4}{5}(v-b)\}$ and that $p^* \leq \min\{\overline{p}^*, b+2h\}$.

Feasible Pooling Prices. Suppose in what follows that $\Delta_g < \min\{2h, \frac{4}{5}(v-b)\}$. As the upper bound on the equilibrium price, $\overline{p}^*$, does not depend on h, we may finally delineate the set of feasible p^*'s by the size of h:

- For $b+2h \leq \overline{p}^*$, i.e., $h \leq \tilde{h}_1 = \frac{\overline{p}^*-b}{2}$, the set of feasible equilibrium prices is $(g, b+2h]$.
- For $h > \tilde{h}_1$, the set of feasible equilibrium prices is $(g, \overline{p}^*]$.

Note finally that for $p^* = b+2h$, the market is covered if and only if $h \leq \tilde{h}_1$.[34] □

Proof of Proposition 4. We proceed in three steps. First, we argue that the technology-revealing pooling equilibrium (TECH in what follows) as characterized in Appendix A.2 is, whenever it exists, always payoff-dominated by a coexisting, partially technology-revealing pooling equilibrium (PART in what follows) as characterized in Section 4 *with the same pooling price*. Second, we prove that whenever the perfect-information equilibrium (PERF in what follows) exists under asymmetric information – the exact conditions are delineated in Appendix A.1 – it is also payoff-dominated by a coexisting PART. Third, for the class of PART, we determine the payoff-dominant equilibrium for each parameter combination.

1. Payoff Dominance of PART over TECH. Suppose that TECH as described in Appendix A.2 exists for some pooling price $p^* > g$ (which, on the equilibrium path, is chosen by both firms if $t = \{b, g\}$). Then it first follows that a corresponding PART of Proposition 3 with the same pooling price p^* (which, on the equilibrium path, is chosen by both firms if $t = \{b, g\}$ or $t = \{g, g\}$) exists as well, for the following two reasons.

34. A covered market at $p^* = b + 2h$ (i.e, $\hat{\eta}(b + 2g) \geq h$) is equivalent to the quadratic inequality

$$\zeta(h) \equiv 4h^2 - 2h\Big(v - b - \frac{3}{2}\Delta_g\Big) - (v-b)\Delta_g \leq 0.$$

As $\zeta(h)$ is strictly convex in h and $\zeta(0) < 0$, this is satisfied for positive h if and only if h does not exceed the larger root of $\zeta(h)$, which is given by $\tilde{h}_1$.

The first is that PART has fewer deviations to be concerned about. Precisely, since g is not an equilibrium price in PART, deviations from p^* to g in $t = \{b, g\}$ do not impose constraints for equilibrium existence, unlike it is the case for TECH.[35] Moreover, a potential deviation from g to p^* in $t = \{g, g\}$ does not need to be considered in PART.[36] The second reason is that for any given candidate equilibrium price p^* for both types of equilibria, a candidate PART gives rise to a weakly higher per-firm demand, $D_i^{PART}(p^*) \geq D_i^{TECH}(p^*)$, as the expected harm from buying is strictly lower (in TECH, when both firms price at p^*, exactly one of them is expected to have $t_i = b$, while in PART, *at most* one firm is expected to have $t_i = b$). This implies that the on-path profit for $t = \{b, g\}$ in a candidate TECH with pooling price p^* is weakly lower for both the brown and green firm, as compared to PART. As deviations to off-equilibrium prices $p_i < p^*$ give the same deviation profit in both types of equilibria for both types of firms, this shows that whenever there is no profitable deviation in TECH, there is also none in PART.

Consider now some specific PART with pooling price p^* and suppose that a firm chooses $t_i = g$ in the first stage of the game. In this case, it makes a deterministic profit of $\pi_g^{PART}(p^*) = (p^* - g)D_i^{PART}(p^*)$, which (due to indifference in the first stage) corresponds to the overall equilibrium profit $\Pi_i^{PART}(p^*)$. Instead, if a firm chooses $t_i = g$ in the first stage of TECH with the same pooling price p^*, it makes an expected profit of $\mathbb{E}\pi_g^{TECH}(p^*) = (1 - \alpha^{TECH})(p^* - g)D_i^{TECH}(p^*) < \pi_g^{PART}(p^*)$, where the inequality follows from $\alpha^{TECH} > 0$ and $D_i^{TECH}(p^*) \leq D_i^{PART}(p^*)$. As $\mathbb{E}\pi_g^{TECH}(p^*)$ again corresponds to the overall equilibrium profit $\Pi_i^{TECH}(p^*)$ due to indifference in the first stage, we indeed have that $\Pi_i^{PART}(p^*) > \Pi_i^{TECH}(p^*)$ for all pooling prices p^* where TECH – and therefore, also PART – exists.

2. Payoff Dominance of PART over PERF. We will next show that whenever PERF exists, there also exists a (continuum of) PART with a strictly higher equilibrium payoff.

Consider the pooling price $p^* = v - \Delta_g < \overline{p}^*$ in a candidate PART (cf. Equation (6) and Footnote 12). Whenever PERF exists, this price is per-

35. Deviations from $t = \{b, b\}$ are never an issue for both types of equilibria with reasonable off-equilibrium beliefs.

36. As brown firms have a larger incentive to deviate downward, whenever there is no profitable deviation from $t = \{b, g\}$ in PART, there is also none from $t = \{g, g\}$.

missible as equilibrium pooling price in PART, as existence of PERF requires that $h \geq h^{perf}_{min} > v - b$ (cf. condition (19) in Appendix A.1), which trivially implies that $p^* = v - \Delta_g \leq b + 2h$. This – next to $p^* \leq \overline{p}^*$ – is required for existence of PART with pooling price p^*. Moreover, it holds that $p^* > g$ (equivalently, $v - b > 2\Delta_g$), as existence of PERF further requires that $\Delta_g \leq (\Delta_g)^{perf}_{max} < (v-b)/5$ (cf. condition (20) in Appendix A.1).

Using Equation (5), the corresponding marginal consumer for $p^* = v - \Delta_g$ is given by

$$\hat{\eta}(v - \Delta_g) = v - b,$$

for a per-firm demand of $D_i(p^*) = \frac{v-b}{2h} < \frac{1}{2}$ (as $h > v - b$ whenever PERF exists). Thus,

$$\Pi_i(p^*) = (p^* - g)\frac{v-b}{2h} = (v - b - 2\Delta_g)\frac{v-b}{2h}.$$

Now, as $\Delta_g \leq (\Delta_g)^{perf}_{max} < (v-b)/5$, it follows that

$$\Pi_i(p^*) \geq \frac{3(v-b)^2}{10h},$$

which strictly exceeds the profit π^*_b of the brown firm when $t = \{b, g\}$ in PERF (indeed, this profit is bounded above by the brown firm's monopoly profit, $\pi^m_b = \frac{(v-b)^2}{4h}$). As the overall equilibrium profit in PERF is even lower (since $\Pi^{PERF}_i = \alpha^{PERF}\pi^*_b$), we have established that $p^* = v - \Delta_g$ can be supported in PART and achieves a strictly higher profit than PERF whenever the latter exists. Therefore, by continuity, there is also a range of equilibrium pooling prices p^* around $p^* = v - \Delta_g$ which lead to a higher equilibrium profit than PERF.

3. Payoff-Dominant PART. We will finally characterize the payoff-dominant equilibrium of the game, which, from the above results, is given by the highest-profit PART.

If PART exists for some $p^* > g$, the overall equilibrium profit is given by

$$\Pi(p^*) = \pi_g(p^*) = (p^* - g)\left(\frac{\min\{\hat{\eta}(p^*)/h, 1\}}{2}\right), \tag{27}$$

where $\hat{\eta}(p^*)$ is given in (5). Note that $\hat{\eta}(p^*)$ is strictly concave in p^* and attains its maximum at

$$p^*_{\hat{\eta}_{max}} \equiv b + \frac{v-g}{2} \in (b, v).$$

Moreover, it holds that $\hat{\eta}(p^*) > 0$ for all $p^* \in [g, v)$, with $\hat{\eta}(v) = 0$. This implies that the auxiliary profit function

$$\widetilde{\Pi}(p^*) \equiv (p^* - g)\frac{\hat{\eta}(p^*)}{2h},$$

while not necessarily concave,[37] has a unique maximizer in the range $(\max\{p^*_{\hat{\eta}_{max}}, g\}, v)$.[38] It is easy to verify that this maximizer is given by $\check{p}$ as reported in Proposition 4.

If the corresponding demand $\hat{\eta}(\check{p})/h$ does not exceed 1, $\check{p}$ is indeed the maximizer of the equilibrium profit function (27). Otherwise, the maximizer of (27) is given by the largest $p^* > \check{p}$ where still $\hat{\eta}(p^*) \geq h$. In general, the largest p^* for which still $\hat{\eta}(p^*) = h$, if such a p^* exists,[39] can easily be computed to be $\hat{p}$, as reported in Proposition 4.

To find the profit-maximizing p^*, it thus suffices to compare $\check{p}$ with $\hat{p}$. Isolating h in the respective inequality, it can be seen that for h sufficiently small, $h \leq \tilde{h}_2$ (as reported in Proposition 4), it holds that $\hat{p} \geq \check{p}$, such that the equilibrium profit $\Pi(p^*)$ is maximized for $p^* = \hat{p}$. Otherwise, for $h > \tilde{h}_2$, it is maximized for $p^* = \check{p}$.

However, it is established in Proposition 3 and its proof that an upper bound for an equilibrium pooling price p^* is $b + 2h$. For $h < \tilde{h}_1$, this upper

37. This is due to the fact that $\hat{\eta}(p^*)$ may be locally increasing in p^* in the relevant range.

38. The corresponding first-order condition is $\frac{1}{2h}\left[\hat{\eta}(p^*) + (p^* - g)\hat{\eta}'(p^*)\right] = 0$. In the relevant range where $p^* \in (g, v)$, the first term in squared brackets is strictly positive. The second term in squared brackets is strictly negative only if $\hat{\eta}'(p^*) < 0$, which, by strict concavity of $\hat{\eta}$, requires that $p^* > p^*_{\hat{\eta}_{max}}$. Moreover, for $p^* > p^*_{\hat{\eta}_{max}}$, both the first and the second term in squared brackets are strictly decreasing in p^*. Hence, as $\hat{\eta}(v) = 0$, there must be a unique $p^* \in (p^*_{\hat{\eta}_{max}}, v)$ where the first-order condition is satisfied.

39. As $\hat{\eta}(p^*)$ is strictly concave in p^* and attains its maximum at $p^* = b + \frac{v-g}{2} \in (b, v)$, this is the case if and only if (i) $\Delta_g < \frac{v-g}{2}$ and $\hat{\eta}(b + \frac{v-g}{2}) \geq h$, or (ii) $\Delta_g \geq \frac{v-g}{2}$ and $\hat{\eta}(g) > h$. Now $\hat{\eta}(b + \frac{v-g}{2}) \geq h$ is equivalent to $h \leq \frac{(v-b+\Delta_g)^2}{4\Delta_g}$, while $\hat{\eta}(g) > h$ is equivalent to $h < 2(v - g)$.

bound is binding. Overall, we thus have the following payoff-dominant pooling price p^*_{opt}:

$$p^*_{opt} = \begin{cases} b + 2h & \text{if } h < \tilde{h}_1 \\ \hat{p} & \text{if } h \in [\tilde{h}_1, \tilde{h}_2] \\ \check{p} & \text{if } h > \max\{\tilde{h}_1, \tilde{h}_2\}. \end{cases}$$

In the first two cases, the market is covered when $p_i = p^*$ (for a demand of $1/2$ per firm), while in the last case, each firm's demand is given by $\frac{\hat{\eta}(p^*)}{2h} < 1/2$. The corresponding overall equilibrium profit is given by $(p^*_{opt} - g)D_i(p^*_{opt})$. □

Proof of Proposition 6. Consider the payoff-dominant pooling price p^*_{opt} as Δ_g tends to zero. As

$$\lim_{\Delta_g \to 0} \tilde{h}_2 \to +\infty,$$

the condition $h < \tilde{h}_2$ is always satisfied for Δ_g approaching zero, such that the payoff-dominant pooling price is either given by $p^*_{opt} = b + 2h$ or by $p^*_{opt} = \hat{p}$ (cf. Proposition 4), and the market is always covered at that price. Note moreover that

$$\lim_{\Delta_g \to 0} \hat{p} = v.$$

Hence, in either case, the payoff-dominant pooling price p^*_{opt} strictly exceeds b as $\Delta_g \to 0$. For firms' equilibrium propensity to choose the green technology, $\alpha^*(p^*_{opt})$, it therefore follows that

$$\lim_{\Delta_g \to 0} \alpha^*(p^*_{opt}) = \lim_{\Delta_g \to 0} \left(1 - \frac{\Delta_g}{p^*_{opt} - b}\right) = 1.$$

Social welfare thus tends to the first-best as $\Delta_g \to 0$ in the payoff-dominant pooling equilibrium. This is because firms' equilibrium propensity to choose the efficient green technology goes to one, and the market remains covered.

In contrast, using Proposition 1, it is easy to check that firms' equilibrium propensity to choose the green technology under perfect information stays bounded away from one as $\Delta_g \to 0$, failing to achieve the first-best. Hence, by continuity, for Δ_g sufficiently close to zero, social welfare must necessarily be higher in the payoff-dominant pooling equilibrium. □