A model of vertical restraints and labeling: the case of green hydrogen.*

Sai Bravo†1 and Carole Haritchabalet[2,3]

[1]ENAC, Université de Toulouse, 7 Av. Edouard Belin, 31400 Toulouse, France

[2]Université de Pau et des Pays de l'Adour, E2S UPPA, CNRS, TREE, Pau, France

[3] Toulouse School of Economics

Abstract

A label for green gases, such as green hydrogen (H2) and bio-methane, could allow retailers to exploit consumers' willingness to pay for environmental quality and ease their diffusion. The cost gap between green gases and their conventional counterparts raises concerns regarding the effectiveness of a label in markets characterized by a complex value chain such as road transportation. We build a stylized model of an H2-based road transport market to assess whether the market's organization could be as efficient as a label policy in a setup where consumers have no direct information about production. With the label, producers prefer to exploit the double marginalization to the detriment of social welfare. However, this allows the high-quality producer to cover its fixed costs. Without the label, producers can use vertical restraints to convey quality information to consumers. The informational problem creates a trade-off between the intensity of competition (driven by perceived qualities) and cost efficiency. The implementation of an optimal label policy depends on the cost gap between qualities and on consumers' expectations about the share of green H2 available in the market. Under the current cost gap, if consumers were to be informed about the current production landscape, it is possible that their beliefs would lean towards a relatively pessimistic view. In such a case, the label would be socially optimal. Additional policy instruments such as a carbon tax could decrease the cost gap, in such a case society would be better off without the label.

Keywords— Label, Vertical Restraints, Innovation, Hydrogen

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†corresponding author: s.bravo-melgarejo@univ-pau.fr

1 Introduction

Green gases, such as biomethane and green hydrogen, are promising energy vectors to decarbonize hard-to-abate end-sectors with complex value chains, such as transportation, industry, and heating. However, these gases confront a significant entry barrier: they are not cost-efficient (International Energy Agency, 2019).[1] Therefore, their uptake depends on consumers' willingness to pay for environmental quality. The most straightforward way for policymakers to support the uptake of expensive high-quality products is a label policy. Today, a labeling scheme based on guarantees of origin (GoOs) is already in place for biomethane and the European Union (EU) recently adopted a similar system for H2 (Velazquez Abad and Dodds, 2020).[2] Alternatively, a market's organization can also provide quality information. For instance, in the early days of the gasoline market, a fuel station vertically integrated with an oil producer was considered a signal of high-quality fuel (Melaina, 2007; Lewis, 2008). This paper compares a label policy versus market organization as tools to convey quality information to consumers in markets with complex value chains.

Transportation is the highest-emitting end sector. In 2021, it accounted for about 37% of global carbon dioxide (CO2) emissions. Fuel Cell Electric Vehicles (FCEVs) can contribute to reducing emissions, provided that H2 comes from a renewable source. Today, passenger light-duty vehicles account for the largest share of FCEVs (Figure 1). Their number will likely increase following the ambitious deployment targets of some Asian countries and the United States.[3] Industrial players also consider that there is a significant potential for individual hydrogen mobility (ENGIE, 2021). According to Trencher et al. (2020), today, most FCEVs use H2 from the reformation of fossil fuels. This is problematic because CO2 emissions are being transferred from the road to H2 production (Steinhilber et al., 2013). Furthermore, Hardman et al. (2017) and Saritas et al. (2019) find that the lack of green H2 supply limits the adoption and diffusion of FCEVs. Thus, this calls for measures to promote green H2 (Ajanovic and Haas,

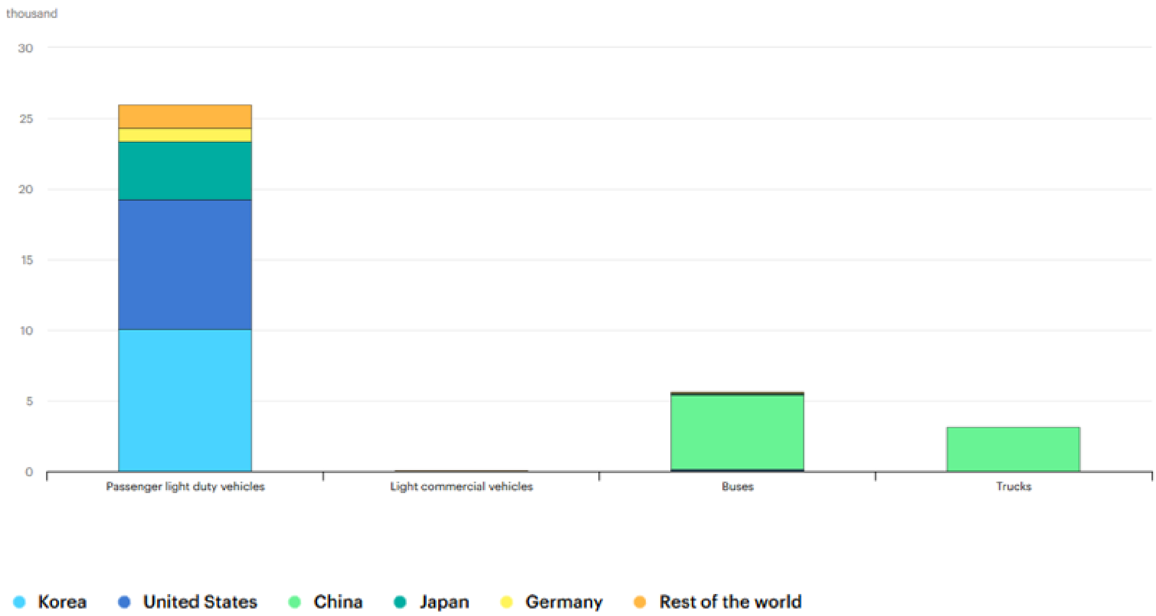
[1] Fossil-fuel-based H2 has a unit production cost of 1.5€/kg, while production from renewable sources is around 2.5–5.5€/kg. Fossil production can be coupled with Carbon Capture and Storage techniques (CCS) to reduce emissions by 60% for an extra 0.5€/kg.

[2] The European Commission (2020) labeling system differentiates between three H2: Gray H2 produced using fossil-fuel-based technologies; Green and Blue H2 with 60% fewer emissions compared to Gray H2 and produced with renewable and non-renewable energy, respectively (HyLaw, 2019).

[3] By 2030, Japan aims to deploy 800000 new FCEVs and 900 fuel stations, while China and the state of California aim to have 1 million FCEVs in operation (International Renewable Energy Agency, 2022).

2019). FCEVs offer multiple advantages, compared to other zero-emission vehicles, like their driving range and refueling time similar to the one of Internal Combustion Engines Vehicles (Hardman et al., 2016, 2017). Also, unlike Battery Electric Vehicles (BEVs), they are exempt from concerns regarding battery deterioration and supply chain risks for cobalt, lithium, and nickel (International Energy Agency, 2019). Today, BEVs dominate the zero-emissions vehicles market. Andreassen and Rosendahl (2022) show that this situation could only be a result of BEVs' early entry, even though it could be optimal to have both BEVs and FCEVs.[4]

Figure 1: FCEV stock by region and type as 2020 (thousands)



Source: International Energy Agency (2020)

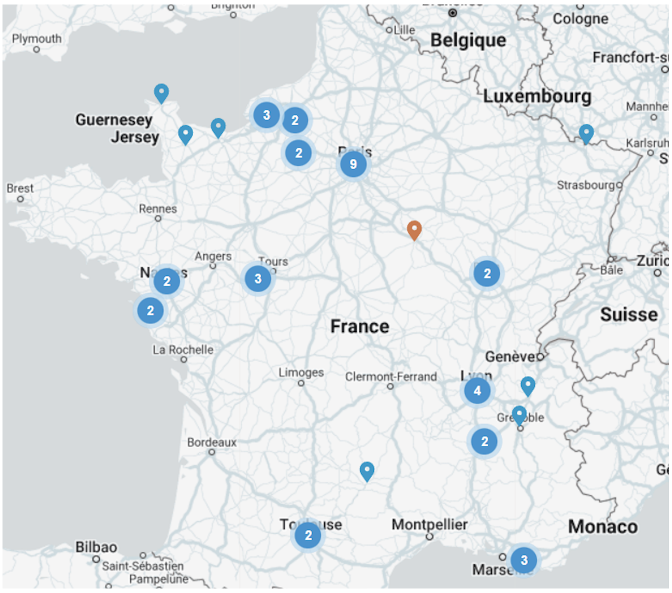
The road transport market has a complex value chain with fuel producers upstream and stations downstream. As previously mentioned, an interesting feature of this market is the value chain organization's ability to reveal information about fuel quality. Despite consumers' purchases being mainly driven by prices (NACS, 2020), their preference for a store or brand also influences their choices.[5] A brand might signal higher quality, but the opposite effect is also possible. Following the 2010 BP oil spill, BP stations' margins declined by 2.9 cents per gallon, and sales volume decreased by 4.2% (Barrage et al., 2014). Thus, to some degree, company-owned stations, compared to independent ones, do provide a quality signal.

[4]The Nissan Leaf was the first commercially produced BEV in 2010, whereas the first FCEV was the Hyundai ix35 in 2013.

[5]The NACS (2020) survey finds that compared to 2015, consumers in 2020 are not as driven by prices (58%) as they were five years ago (71%). In NACS (2020) study, almost two out of three consumers (62%) stated a preference for a specific store or chain, while in 2002, only 36% of consumers preferred one brand of gasoline (Blumberg, G. P., 2002).

We build on the literature about labels in vertically related markets (Fulton and Giannakas, 2004; Lapan and Moschini, 2007; Bonroy and Lemarié, 2012) and propose a stylized model of an H2-based road transport market. We aim to assess whether market organization could be as efficient as a labeling policy for green H2 in terms of information and social welfare. We consider two producers: a low-quality one with fossil-fuel-based H2 production and a high-quality producer with renewable-based technology.[6] Producers serve fuel stations that perfectly observe the fuel's quality, but this information may be difficult to pass on to consumers. According to Zhao et al. (2022), today, the few operating H2 stations are located far away from each other in H2 industrial clusters (Figure 2).[7] Investing in new fuel stations is costly, about 0.6–2 million USD per station according to the International Energy Agency (2019). This market concentration raises concerns regarding possible anti-competitive behavior and the effectiveness of policy instruments.[8] We account for this and consider that only two stations serve the market.

Figure 2: H2 fuel stations (open to the public) in France



Source: https://www.h2-mobile.fr/stations-hydrogene/

We depart from previous contributions and focus on how labels affect the downstream market's organization. A label increases the costs of high-quality H2 but allows to exploit consumers' willingness to pay for environmental quality.In a similar setup, Bonroy and Lemarié

[6]Notice that infrastructure-intensive industries initially tend to rely on state-owned monopolies, but in the case of H2 there exist already well-established players along the supply chain.

[7]H2 clusters are geographic areas with H2 ecosystems whose objective is to secure demand and benefit from synergies between actors in the supply chain (e.g., the Zero-Emissions Valley in Auvergne Rhône-Alpes, France).

[8]Notice that a slow uptake of FCEVs may aggravate this situation; indeed, FCEVs suffer from the chicken-and-egg dilemma: large-scale diffusion is only possible through a simultaneous ramp-up of vehicles and fuel stations.

(2012) consider retailers which always buy from both producers and they show that a label would increase the high-quality quantity sold in the market.[9] We depart from their paper and consider that producers can specialize and exclusively supply one station at a time. In our paper, we show that at equilibrium, producers always specialize but society would be better off if they served all stations. Thus, our paper highlights that the low uptake of FCEV can allow producers and stations to exert market power. We then consider a *laissez-faire* scenario (without the label policy). In such as case, the producers' qualities are perceived as homogeneous, and the low-quality producer can set a wholesale price such that the high-quality producer makes negative profits. Therefore, in the absence of a labeling system, the high-quality producer may look for strategies to provide quality information at the level of stations. The market's organization can reveal information about the final product in road transportation. We assume that the high-quality producer merges with one of the fuel stations and that vertically integrated stations sell only one quality. Thus, this strategy increases the perceived quality of the merged station. An independent station may or may not buy from a vertical structure making its quality uncertain. Consumers today are confronted with contradictory information. Today, most of the promoted H2-based mobility solutions supposedly rely exclusively on green H2, but still, approximately 95% of production comes from fossil fuel sources. This context makes it difficult to assess to what extent consumers expect to have access to high-quality H2 when they buy from an independent station. We assume that when producers do not inform consumers about quality, the latter anticipate an average quality level that is influenced by their perceived share of high-quality H2 in the market. One may wonder about the merged entity's incentives to serve the independent station. We find that, at equilibrium, the high-quality producer prefers not to serve the independent station. This is in line with Nocke and Rey (2018). Our paper departs from Nocke and Rey (2018) by introducing an information problem downstream and considering price competition. In Nocke and Rey (2018), a merger between a non-integrated producer and a retailer always increases their joint profits. In our setup, the informational problem creates a trade-off between the intensity of competition (driven by perceived qualities) and cost efficiency. Their result holds when the cost difference between qualities is small. Furthermore, we show that the more consumers are optimistic about the share of high-quality

[9] They consider interlocking relationships (Rey and Vergé, 2008): upstream competitors engage with the same competing downstream retailers.

H2 in the market, the smaller the threshold value of the cost difference between qualities below which the low-quality producer does not exploit the informational problem. Overall, we show that the merger is socially optimal for large values of the cost difference between qualities. The merger reduces the low-quality producer's high price for its lower-than-anticipated quality. Finally, we analyze whether producers would have the incentive to merge under a label policy. This strategy is never profitable. We find that compared to the case without government intervention, a label would ease the diffusion of green H2. Indeed, the latter would allow the high-quality producer to make high profits. This policy can also be welfare-enhancing provided of having a free label. Specifically, when the cost difference between qualities is such that the low-quality producer prefers to exploit the informational problem, provided of having very pessimistic or optimistic consumers. Today green gases are not cost-efficient, and our findings indicate that the implementation of an optimal label policy highly depends on consumers' perceptions. In addition to the label policy, governments could work on information campaigns to eliminate these noisy perceptions regarding the share of green H2 that is available in the market. Today, low-quality H2 production benefits from freely allocated emission permits to limit the risk of carbon leakage, i.e., the relocation of industrial activities outside the EU (RTE, 2020). If consumers are not very pessimistic or optimistic about the share of high-quality H2 available in the market, when combined with a carbon tax, then a label policy may no longer be welfare-enhancing. Instead, if consumers are very pessimistic or optimistic, a carbon tax could allow a cost difference between qualities such that the label policy provides the largest welfare. If consumers were to be informed about the current production landscape, it is possible that their beliefs would lean towards a relatively pessimistic view regarding the share of high-quality hydrogen within the market. In such a case, the label would be socially optimal.

The remainder of this paper is organized as follows. Section 2 describes the H2 market value chain. Section 3 presents the equilibrium outcome with a label policy. Section 4 presents the equilibrium outcome when producers use vertical restraints. Section 5 discusses and compares the two outcomes. Section 6 concludes.

2 Theoretical Framework

In this section, we describe the organization of the H2-based transport market value chain.

2.1 Supply-side

We consider a vertically related market with producers upstream and fuel stations downstream. It is possible to produce H2 using several technologies that differ in terms of costs and negative externalities (CO2 emissions). We consider two types of H2: a low-quality one f with positive CO2 emissions, and a high-quality one g with zero emissions. Producers choose the wholesale linear price w. Fuel stations distribute H2 to FCEV owners at retail price p.

Upstream market (H2 Producers) We consider that there is a fossil producer (f) offering a low environmental quality H2 produced at a marginal cost c_f. There is also a green producer (g) selling high environmental quality H2. The latter incurs a fixed investment cost of E and has a marginal production cost of c_g. The low-quality producer has an absolute cost advantage with its low-quality H2 ($c_g > c_f$).

Downstream market (Fuel Stations) Today, this market is highly concentrated, only a few stations operate in distant H2 clusters (Figure 2). Thus, we consider that only two fuel stations 1 and 2 operate in this market at a unit cost $d+w$, with d the station's operational costs (e.g., maintenance cost, employees' salaries, etc.) and w the H2 wholesale price. We assume that stations perfectly observe the producer's quality, but this information is not passed on to consumers.

2.2 Demand-side

We consider a continuum of consumers each owning a FCEV. Thus, we abstract from the decision regarding which type of vehicle to purchase (e.g., ICEV, BEV, etc.) and rather focus on the decision regarding the type of H2. Our consumers have a reservation price of v for H2 fuel, large enough to have a covered market. In our framework, consumers are FCEV owners; thus, there is no outside option regarding the type of fuel (H2). We also assume that consumers have a willingness to pay for high environmental quality (θ), where the taste parameter θ is uniformly distributed on the unit interval. The environmental quality index of a product is denoted s_j, it follows that $s_g > s_f$. We assume that when producers do not inform consumers about quality, the latter anticipate an average quality level that is influenced by their perceived share of high-quality H2 in the market $\alpha \in]0;1[$. The indirect utility of a non informed θ-type consumer buying H2 at price p is then:

$$\mathrm{U} = v + \theta(\alpha s_g + (1-\alpha)s_f) - p \tag{1}$$

Otherwise, when consumers can perfectly observe the product quality at the level of fuel stations, then, denoting respectively p_f and p_g the price of the low and high quality, the indirect utility of a θ-type consumer is:

$$\mathrm{U} = \begin{cases} v + \theta s_g - p_g & \text{if} \quad j = g \\ v + \theta s_f - p_f & \text{if} \quad j = f \end{cases} \tag{2}$$

To make the model tractable we assume that the true quality of low-carbon H2 is equal to $s_g = 1$, while the true quality of gray H2 is $s_f = 0$.

2.3 Timing

The timing of the game is as follows:

- T=1: Producers choose their wholesale prices and how many stations they serve.
- T=2: Fuel stations compete in prices to supply consumers.

H2 has many applications across sectors (e.g., transportation, energy, industry, etc.); thus, producers can always have an outside option. We consider that producers only sell H2 in the transport market when they make positive profits. Thus, we have a short-run price competition game. Our equilibrium concept is sub-game perfect equilibrium.

3 Label for green hydrogen

The European Commission (2020) labeling system for H2 is based on the industry initiative *Certifhy* (HyLaw, 2019). The latter differentiates between three types of H2: gray, blue, and green. This system is relevant in the case of transportation since it prevents infrastructure duplication while making quality differentiation possible. Labeling systems (e.g., GoOs for green electricity) allow retailers to exploit consumers' willingness to pay for green quality compared to undisclosed quality (Mulder and Zomer, 2016). For simplicity, we consider that the label informs consumers only about two types of H2: low-quality and high-quality. We study the equilibrium when the high-quality producer can use a label at a cost $l \in [0;1]$.

Assumption 1. $c_g + l - c_f < 1$ *the label cost is such that the low-quality producer's demand is never negative.*

Denoting p_g (resp. p_f) the retail price of high (low) H2 quality, the demands are:

$$D_g(p_g, p_f) = 1 - p_g + p_j \quad \text{and} \quad D_f(p_g, p_f) = p_g - p_f \tag{3}$$

In Bonroy and Lemarié (2012) retailers always buy from both producers. Namely, they consider interlocking relationships (Rey and Vergé, 2008): upstream competitors engage with the same competing downstream retailers. We depart from their paper and consider that producers can specialize and exclusively supply one particular station at a time. Specifically, the high-quality producer may choose to sell only to station 1, while the low-quality producer may exclusively serve station 2.

In stage 2, fuel stations compete à la Bertrand. High-quality (respectively low-quality) H2 unit cost is $d + w_g$ (respectively $d + w_f$), with w_g the high-quality (low-quality) producer's wholesale price. The game between stations depends on the producers' choices. When producers specialize in stage 1, the stations' programs are:

$$\max_{p_1} \quad \pi_1(p_1, p_2) = D_g^1(p_1, p_2)(p_1 - w_g - d) \tag{4}$$

$$\max_{p_2} \quad \pi_2(p_1, p_2) = D_f^2(p_1, p_2)(p_2 - w_f - d) \tag{5}$$

Else, when in stage 1 a producer chooses to serve more than one station at a time, at equilibrium its quality's retail price equals the marginal cost. In such a case, the stations' margins are null.

In stage 1, producers choose the wholesale prices for their respective qualities and whether they specialize or not. The producer's programs are:

$$\max_{w_g} \quad \pi_g(p_1(w_g, w_f), p_2(w_g, w_f)) = D_g(p_1(w_g, w_f), p_2(w_g, w_f))(w_g - c_g - l) - E \tag{6}$$

$$\max_{w_f} \quad \pi_f(p_1(w_g, w_f), p_2(w_g, w_f)) = D_f(p_1(w_g, w_f), p_2(w_g, w_f))(w_f - c_f) \tag{7}$$

The following table presents the producers' payoffs under the different cases.

Table 1: Producer's Payoff Matrix

G \ F	Specialize (S)	Do Not Specialize (NS)
Specialize (S)	$(\frac{(5+c_f-c_g-l)^2}{27} - E, \frac{(4-c_f+c_g+l)^2}{27})$	$(\frac{(3+c_f-c_g-l)^2}{18} - E, \frac{(3-c_f+c_g+l)^2}{18})$
Do Not Specialize (NS)	$(\frac{(4+c_f-c_g-l)^2}{18} - E, \frac{(2-c_f+c_g+l)^2}{18})$	$(\frac{(2+c_f-c_g-l)^2}{9} - E, \frac{(1-c_f+c_g+l)^2}{9})$

As long as assumption 1 holds, we have one Nash Equilibrium in pure strategies: (S, S).

Proposition 1. *With a label policy, at equilibrium, producers always specialize.*

Social welfare in this market writes:

$$SW = v + \int_{D_f(p_g,p_f)}^{1} \theta d\theta - D_g(p_g, p_f)(c_g + d + l) - D_f(p_g, p_f)(c_f + d) - E$$

Proposition 2. *Private incentives are never aligned with society, producers prefer to specialize which is detrimental to social welfare.*

Proof. See Appendix A.1. □

Here, the equilibrium outcome does not provide the highest social welfare. Indeed, society would be better off if producers did not specialize. Regardless of the market configuration, social welfare decreases with the label's cost. With a downstream market highly concentrated, producers always prefer to specialize, creating two successive quasi-monopolists for each quality. In Bonroy and Lemarié (2012), retailers' heterogeneity compared to consumers' determines who bears the burden of the label. Instead, we consider retailers with identical operational costs. As a result, when producers serve all stations, the label puts an economic burden on the high-quality producer. Otherwise, when producers specialize, the high-quality producer and its served station share the economic burden of the label.

4 Vertical Restraints

With a label, at equilibrium, producers prefer to specialize, which is detrimental to society. One may wonder about the equilibrium outcome without a labeling system. Without any action taken by the high-quality producer, in stage 2, stations will compete à la Bertrand with homogeneous products. In stage 1, the low-quality producer can set a wholesale price $w_f = c_g > c_f$ such that the high-quality producer makes negative profits: $\pi_g = -E < 0$. Therefore, in the absence of a labeling system, the high-quality producer may look for strategies to provide quality information at the level of stations. The market's organization can reveal information about the final product in road transportation. For instance, in the early days of the gasoline market, being vertically integrated with an oil station was considered a signal of high-quality fuel (Melaina, 2007; Lewis, 2008). We consider that the high-quality producer merges with station 1 and that this strategy provides environmental quality information.[10] We assume that stations sell only one quality (single-fuel stations) when part of a vertical structure, whereas an independent station may or may not buy from a vertical structure. Thus, the H2 quality remains uncertain when consumers buy from station 2. This context creates two different qualities on the market: a high quality sold by the vertically integrated station 1, and a lower "uncertain" quality sold by the independent station 2. In such a case, the indirect utility of a θ-type consumer is:

$$\mathrm{U} = \begin{cases} v + \theta s_g - p_1 & \text{if it buys from station 1} \\ v + \theta(\alpha s_g + (1-\alpha)s_f) - p_2 & \text{if it buys from station 2} \end{cases} \tag{8}$$

We first consider the case of single vertical integration between the high-quality producer and station 1 and analyze the integrated structure's incentives to supply the independent station. Then, we study the low-quality producer's incentives to merge with the independent station 2. Finally, we compare the different regimes in terms of private incentives and welfare implications.

4.1 Single Vertical Integration (SVI)

First, we consider that the high-quality producer sells exclusively through station 1. The independent station can only buy from the low-quality producer but consumers do not observe this. We denote p_1 (resp. p_2) the price at the high-quality producer's (independent) station, the demand for each station is:

[10] This could be the case if the high-quality producer equipped stations with an on-site combined solar photovoltaic panel and electrolyzer system.

$$D^1(p_1,p_2) = \frac{1-\alpha-p_1+p_2}{1-\alpha} \quad \text{and} \quad D^2(p_1,p_2) = \frac{p_1-p_2}{1-\alpha} \tag{9}$$

In stage 2, the independent station competes with the high-quality producer's station. The stations' programs are:

$$\max_{p_1} \quad \pi_1(p_1,p_2) = D^1(p_1,p_2)(p_1 - c_g - d) - E \tag{10}$$

$$\max_{p_2} \quad \pi_2(p_1,p_2) = D^2(p_1,p_2)(p_2 - w_f - d) \tag{11}$$

In stage 1, the low-quality producer chooses its wholesale price w_f:

$$\max_{w_f} \quad \pi_f(w_f) = D^2(p_1(w_f), p_2(w_f))(w_f - c_f) \tag{12}$$

which gives the equilibrium wholesale price:

$$w_f^* = \frac{1-\alpha+c_g+c_f}{2} \tag{13}$$

Second, we consider that the high-quality producer does not distribute exclusively through its retailer. In stage 1, producers choose their wholesale prices and which stations they serve.

Lemma 1. *There exists a unique Nash Equilibrium where the low-quality producer serves the independent station with w_f^*.*

Proof. See Appendix A.2. □

The high-quality producer has no incentive to serve the independent station. At the equilibrium, the low-quality producer always serves the independent station at its profit-maximizing wholesale price (w_f^*). Consumers buying from the independent station get a lower quality than anticipated. This is in line with Nocke and Rey (2018), who show that when there is a vertical merger between a producer and a retailer, an equilibrium where the vertically integrated firm "forecloses" the downstream rival exists.

4.2 Pairwise Vertical Integration (PVI)

Nocke and Rey (2018) show that when facing an integrated structure, an independent producer and a retailer can increase their joint profits by merging. We study whether this result holds when there is an information problem at the level of retailers. We consider that the low-quality producer merges with station 2, such that we have two competing vertically integrated supply chains. We denote p_1 (resp. p_2) the price of the high-quality producer's (independent) station, the demand for each station is:

$$D^1(p_1, p_2) = 1 - p_1 + p_2 \quad \text{and} \quad D^2(p_1, p_2) = p_1 - p_2 \tag{14}$$

The high-quality and low-quality producer's station's programs are:

$$\max_{p_1} \quad \pi_1 = D^1(p_1, p_2)(p_1 - c_g - d) - E \tag{15}$$

$$\max_{p_2} \quad \pi_2 = D^2(p_1, p_2)(p_2 - c_f - d) \tag{16}$$

Proposition 3. *The equilibrium depends on the cost difference between qualities $c_g - c_f$:*

- *if $c_g - c_f > c^p$ the low-quality producer and independent station do not merge.*
- *if $c_g - c_f \leq c^p$ the low-quality producer and independent station merge.*

Proof. See Appendix A.3. □

When the cost difference between qualities is large, the low-quality producer prefers not to merge with station 2 and exploit the informational problem. Otherwise, it prefers to differentiate itself from the high-quality producer to reduce the intensity of competition. There is a trade-off between the intensity of competition (driven by the perceived qualities) and cost efficiency. The threshold value of the cost difference, at which the low-quality producer chooses to merge with an independent station, decreases as consumers' beliefs about the market's share of high-quality H2 become more optimistic. Consequently, the more consumers are optimistic about the share of high-quality H2 in the market, the smaller the threshold value of the cost difference between qualities below which the low-quality producer does not exploit the informational problem. In this scenario, unless high-quality H2 becomes very cost-competitive, the low-quality producer opts to exploit the informational problem. Consequently, consumers who purchase from the independent station receive a lower quality product than they initially anticipated.

Proposition 4. *The merger between the low-quality producer and station 2 is socially optimal when $\hat{c^w} \leq c_g - c_f \leq c^p$ for $\alpha \in [\frac{3}{4}; 1[$, and when $\bar{c^w} \leq c_g - c_f \leq c^p$ for $\alpha \in]0; \frac{3}{4}[$.*

Proof. See Appendix A.4. □

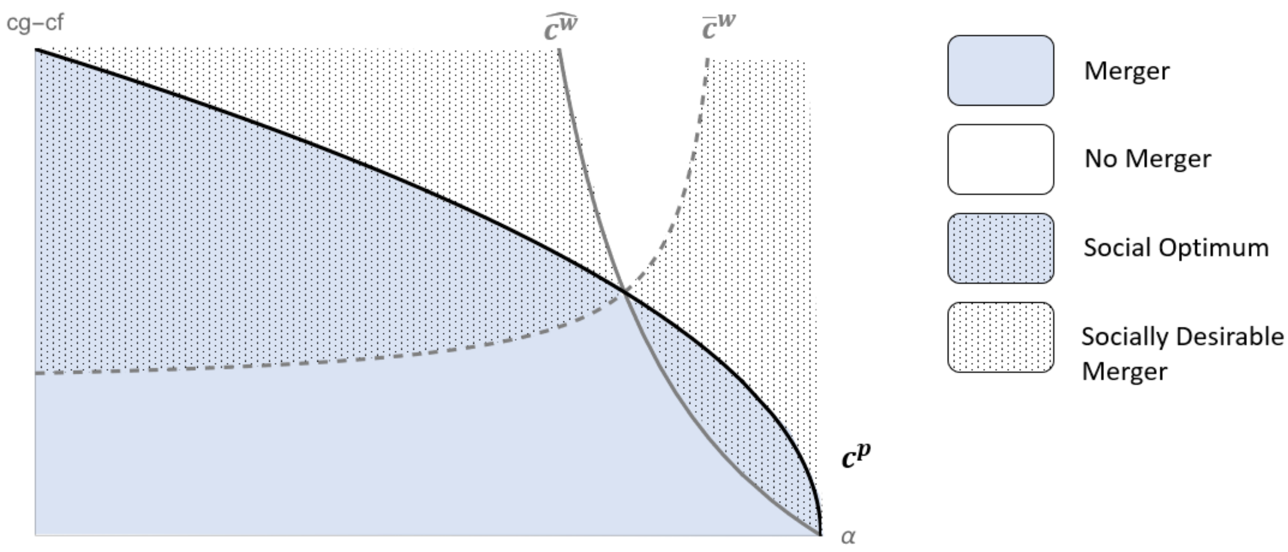


Figure 3: Laissez-faire outcome

The merger between the low-quality producer and the independent station is not socially optimal when the cost difference between qualities is very low, i.e., when $c_g - c_f < \bar{c^w}$ (respectively $c_g - c_f < \hat{c^w}$) for $\alpha \in]0; \frac{3}{4}[$ (respectively $\alpha \in [\frac{3}{4}; 1[$) as depicted in Figure 3. In that scenario, without the merger, high-cost efficiency combined with increased downstream competition (resulting from the close perceived qualities) would lead to low prices. The merger relaxes competition and increases prices to the detriment of consumers. Conversely, a merger would be socially optimal when the cost difference between qualities is very high, i.e., when $c^p < c_g - c_f$ (respectively $c^p < c_g - c_f < \bar{c^w}$) for $\alpha \in]0; \frac{2}{3}[$ (respectively $\alpha \in [\frac{3}{4}; 1[$). Indeed, in that scenario, a merger would reduce the low-quality producer's price for its lower-than-anticipated quality.

5 Discussion and Policy implications

When a label for high-quality H2 is available in the market, producers always prefer to specialize, but society would be better off if they did not.

5.1 Merging incentives with a label

One may wonder about the merging incentives of the high-quality producer and station 1 when a label is available in the market. On the one hand, a label would increase the merged high-quality producer and station 1's costs. On the other hand, consumers would perfectly observe quality. In our framework, vertical integration also conveys quality information. If the merged high-quality producer and station 1 were to utilize a label, the low-quality producer and station 2 joint profits would be equivalent regardless of whether they choose to merge or not:

$$\pi_F^{SVI}(l) + \pi_2^{SVI}(l) = \pi_F^{PVI}(l) = \frac{(1 - c_f + c_g + l)^2}{9}$$

and consequently, the high-quality producer and station 1's profits would also be the same regardless of the low-quality producer and station 2's strategy:

$$\pi_G^{SVI}(l) = \pi_G^{PVI}(l) = \frac{(2 + c_f - c_g - l)^2}{9} - E$$

Notice that, producers would retrieve the same joint profits as when they serve all stations:

$$\pi_G^{NS} + \pi_1^{NS} = \frac{(2 + c_f - c_g - l)^2}{9} - E$$

and

$$\pi_F^{NS} + \pi_2^{NS} = \frac{(1 - c_f + c_g + l)^2}{9}$$

and from section 3, we know that producers are better off when they specialize. Then, merging with station 1 is never a profitable strategy for the high-quality producer when a label is available in the market. We conclude that with a label policy, the high-quality producer never has the incentive to merge with station 1.

5.2 Accelerating the energy transition

The role of labels is to ease the diffusion of high-quality products by exploiting consumers' willingness to pay for quality. Labels are relevant in the case of green gases because they are not cost-competitive. In our model, under a label policy, producers specialize. We have two successive monopolies for each quality which leads to relatively high retail prices:

$$p_g^{SS} - p_g^{SVI} = \frac{5(5 + 3\alpha + c_f - c_g + 2l)}{18} > 0$$

and

$$p_g^{SS} - p_g^{PVI} = \frac{14 + c_f - c_g + 5l}{9} > 0$$

given that $1 > c_g + l - c_f$ and $l \in [0; 1]$. Nevertheless, the specialization allows the high-quality producer to make positive profits even for high values of the fixed cost E, thus easing the diffusion of green H2 in the transport market. Given the high costs associated with green gases, a labeling system would be a good policy instrument to support them from a market penetration perspective.

In the context of the energy transition, a regulator may instead be more concerned about whether the label enables to have a greater quantity of green H2 in the market than a laissez-faire scenario. Indeed, green gases are crucial vectors for the decarbonization of various end sectors. With the label, the equilibrium quantity of green H2 in the market decreases with the latter's cost. Thus, to guarantee a sufficiently important quantity of green H2 under a label policy, the latter's cost needs to remain relatively affordable. We focus on the case $l = 0$ for the rest of our analysis. Depending on the size of the cost difference between qualities, as well

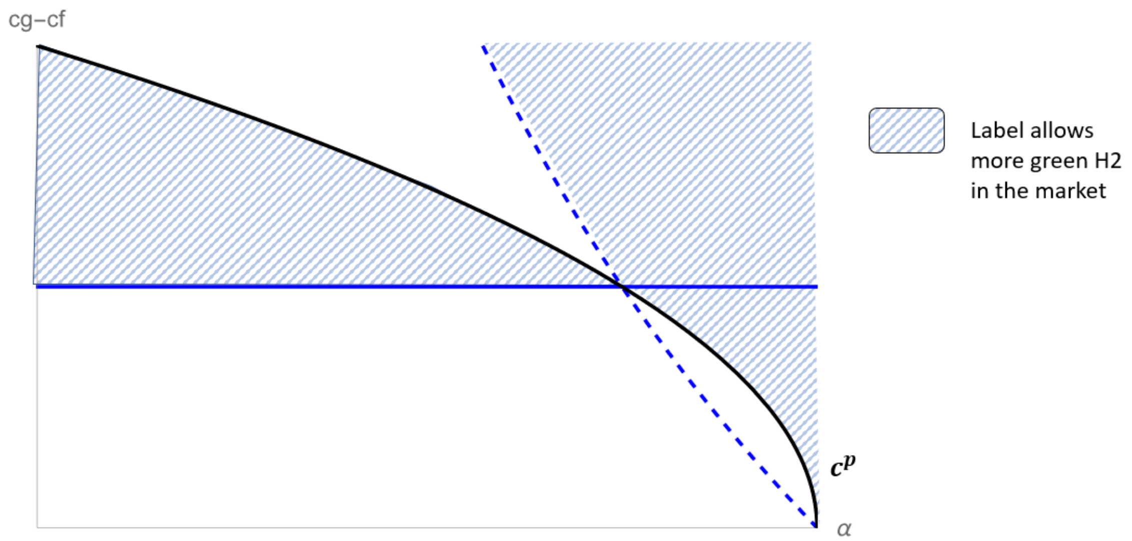


Figure 4: Green H2 quantity in the market

as consumers' expectations regarding the share of high-quality H2 in the market, a label policy may lead to more high-quality quantity in the market compared to a laissez-faire scenario (see Figure 4). This is the case when $c^p < c_g - c_f$ for high levels of α, i.e., when without the label the low-quality producer does not merge with the independent station, and the latter's quality is perceived as high. With the label, the independent station's quality would no longer be perceived as high, increasing the demand for stations' 1 high-quality H2. The label also allows increasing the high-quality quantity available in the market when $\frac{1}{2} < c_g - c_f \leq c^p$, i.e., when without the label the low-quality producer merges with the independent station. This can be explained by a smaller price difference between qualities compared to the laissez-faire scenario, combined with always having a covered market. Thus, a label can simultaneously result in large profits for the high-quality producer, as well as a more high-quality H2 in the market (compared to the laissez-faire).

5.3 Socially optimal policy

In this context, one may wonder whether society would then be better off with or without the labeling system from a welfare perspective. We compare social welfare with and without the label, i.e., when producers use vertical restraint to convey quality information. Overall, regardless of the size of α and the cost difference between qualities, society is better off without the label if its cost is high. Indeed, regardless of the low-quality producer's and independent station's equilibrium strategy, the welfare difference always decreases with the label cost:

$$\frac{\partial(SW^{SS} - SW^{SVI})}{\partial l} = \frac{\partial(SW^{SS} - SW^{PVI})}{\partial l} = \frac{-(49 - 17(c_g - c_f + l))}{81} < 0 \qquad (17)$$

as $c_g + l - c_f < 1$. Thus, if $0 < l$, then a label policy may never welfare-enhancing. Producers' and stations' joint profits with the label are not high enough to compensate for the consumer surplus loss related to market power. We aim to assess when government intervention is socially desirable, thus we focus on the case $l = 0$.

Proposition 5. *A label policy is socially optimal when the cost difference between qualities is such that without government intervention the low-quality producer prefers to exploit the information problem ($c^p < c_g - c_f$) and if the utility gain from quality information allows compensating producers' market power. This is the case for $\alpha \in [\frac{20}{23}; 1[$ and $\alpha \in]0; \frac{4}{7}]$.*

Proof. See Appendix A.5. □

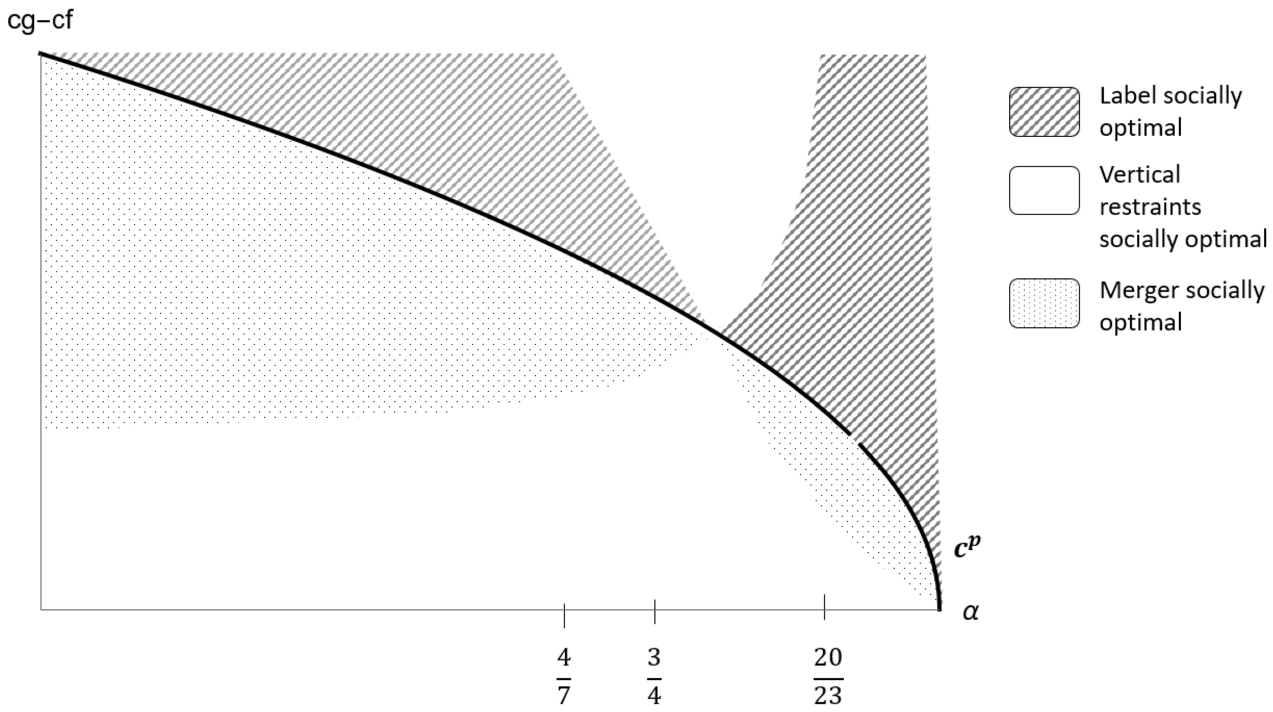


Figure 5: Socially desirable label

A label policy is never socially optimal if without government intervention the cost difference between qualities is such that the low-quality producer and independent station 2 merge at equilibrium. Conversely, when the cost difference between qualities is such that the low-quality producer does not merge with the independent station 2 a label policy could be socially optimal (see Figure 5). Indeed, without the label, the low-quality producer exploits the informational problem and consumers get a lower quality than anticipated. When consumers are very optimistic $\alpha \in [\frac{20}{23}; 1[$ or pessimistic $\alpha \in]0; \frac{4}{7}]$ about the share of high-quality H2 in the market, then society would be better off with the label. The latter solves the informational problem and increases consumers' surplus (as consumers value environmental quality). Furthermore, competition is relaxed allowing larger joint profits for producers and stations. Instead, when consumers are not very optimistic or pessimistic about the share of high-quality H2 in the market, a label policy is not socially optimal. In that case, without the label, the stations' perceived qualities are relatively close, and downstream competition is high. The label would increase prices at the expense of consumers and the utility gains from environmental quality would not be large enough to compensate for producers and station high joint profits.

Today green H2 has a cost ranging from approximately 2.5 to 5.5€/kg, rendering it less cost competitive in comparison to fossil-fuel-based H2, which possesses a production cost of 2€/kg when combined with CCS techniques (International Energy Agency, 2019). Consequently, the desirability of implementing a label policy hinges upon consumers' perceptions regarding the proportion of high-quality H2 available within the market. This is the case when consumers are very optimistic or very pessimistic. In accordance with the pressing issue of climate change, governmental entities, and industrial stakeholders have put forward H2-based mobility solutions which should supposedly rely exclusively on green H2. However, it is worth noting that, according to the International Renewable Energy Agency (2018), approximately 95% of today's H2 production is derived from fossil fuel sources, and thus a majority of FCEVs use H2 from fossil fuels (Trencher et al., 2020). This context makes it difficult to assess to what extent are consumers optimistic about the proportion of high-quality H2 accessible within the market. If consumers were to be informed about the current production landscape, it is possible that their beliefs would lean towards a relatively pessimistic view regarding the share of high-quality hydrogen within the market. In such a case, our findings indicate that the implementation of a label policy would be socially optimal. These findings suggest that in addition to the label policy, governments could work on information campaigns to eliminate these noisy perceptions regarding the share of green H2 that is available in the market.

Today, low-quality H2 producers benefit from freely allocated emission permits. Besides the label policy, the EU could stop freely allocating these emission permits or even put in place a carbon tax. In that case, a label policy may no longer be socially optimal. This would be the case if the tax is such that the cost difference between qualities becomes very low. Indeed, without government intervention, we would have two vertically integrated chains, thus eliminating the double marginalization from producers' specialization. Else, if the tax is such that the cost difference between qualities is not too low, then a label policy could be socially optimal depending on consumers' perception of the proportion of green H2 available in the market. Thus, it could also be interesting to survey consumers to better assess their perceptions and determine whether a carbon tax would be socially desirable in the early years of this market.

5.4 Competition in the downstream market

We have seen that with a label, at equilibrium, producers specialize. This is true in a highly concentrated market. Our result does not hold with a larger number of stations. Indeed, more competition in the downstream market would bring down the stations' margins to zero. In such a case, producers would make the same profits as when they serve both stations. Notice that, in our setup, producers retrieve the same joint profits with two vertically integrated chains and with a label when they serve all stations provided that $l = 0$. Thus, with a larger number of stations in the downstream market, the high-quality producer would be better off without the label: $\pi_G^{PVI} = \frac{(2+c_f-c_g)^2}{9} - E > \pi_G^{NS} = \frac{(2+c_f-c_g-l)^2}{9} - E$. Today, the downstream market is highly concentrated, with only a few operating stations in distant H2 clusters (Figure 2). Without a simultaneous ramp-up of vehicles and fuel stations, given the significant investment costs of around 0.6–2 million USD per station, this market will likely stay highly concentrated. FCEVs suffer from the chicken-and-egg dilemma, the government would need to simultaneously promote investments in fuel stations and FCEV purchases to avoid anti-competitive behavior.

6 Conclusion

Green gases, such as biomethane or green hydrogen, are promising energy vectors for the decarbonization of different end sectors such as transportation, industry, and heating. However, they are not cost-efficient which constitutes an important entry barrier. Labels are a policy tool allowing firms to exploit consumers' willingness to pay for environmental quality and charge them a slightly higher price. The cost gap between green gases and their conventional counterparts raises concerns regarding the effectiveness of a label in markets characterized by a complex value chain such as road transportation. Alternatively, a market's organization can also provide quality information in markets characterized by a complex value chain such as road transportation. Today, the H2 road transport market is highly concentrated which raises concerns about possible anti-competitive behavior. This paper has assessed the conditions under which a label policy for green H2 is a better tool than the market's organization in terms of conveying quality information to consumers and social welfare.

We followed the literature about labels in vertically related markets and build a stylized model to analyze the equilibrium outcome under a label policy in a highly concentrated market. We found that producers and stations prefer to exploit the double marginalization to the detriment of social welfare. However, a label would allow the high-quality producer to make positive profits, even for large values of its fixed costs thus easing the diffusion of green H2. The market's organization can also provide information about the final product in road transportation. Namely, producers can use vertical restraints to convey quality information to consumers. Although, today, most of the promoted H2-based mobility solutions supposedly rely exclusively on green H2, still approximately 95% of production comes from fossil fuel sources. This context makes it difficult to assess to what extent are consumers optimistic about the proportion of high-quality H2 accessible within the market. We found that depending on the cost difference between qualities, the low-quality producer and the independent retailer may engage in anticompetitive behavior. If it is large, then the low-quality producer prefers to exploit double marginalization, whereas when it is small, the low-quality producer prefers to merge with the independent station and reduce the intensity of competition. The more consumers are optimistic about the share of high-quality H2 in the market, the smaller the threshold value of the cost difference between qualities below which the low-quality producer does not exploit the informational problem. Overall, we show that the merger is socially optimal for large values of the cost difference between qualities. Indeed, high-cost efficiency combined with high downstream competition resulting from the close perceived qualities would lead to lower prices. Instead, when the cost difference is large, the merger reduces the low-quality producer's high price for its lower-than-anticipated quality. Finally, we compared social welfare under a label policy against the alternative. We found that only a free label would be welfare-enhancing. Furthermore, the label is only socially optimal for values of the cost difference between qualities such that the low-quality producer prefers to exploit the informational problem, provided of having very pessimistic or optimistic consumers. In that case, a label policy would simultaneously allow consumers to choose their preferred quality and producers to have high enough profits to compensate for the consumer surplus loss related to market power. Today green gases are not cost-efficient; thus, our findings indicate that the implementation of an optimal label policy highly depends on consumers' perceptions. In addition to the label policy, governments could work on information campaigns to eliminate these noisy perceptions regarding the share of green H2 that is available in the market. Today, low-quality H2 production benefits from freely allocated emission permits to limit the risk of carbon leakage, i.e., the relocation of industrial activities outside the EU (RTE, 2020). If consumers are not very pessimistic or optimistic about the share of high-quality H2 available in the market, when combined with a carbon tax, then a label policy may no longer be welfare-enhancing. Instead, if consumers are very pessimistic or optimistic, a carbon tax could allow a cost difference between qualities such that the label policy provides the largest welfare. If consumers were to be informed about the current production landscape, it is possible that their beliefs would lean towards a relatively pessimistic view regarding the share of high-quality hydrogen within the market. In such a case, the label would be socially optimal.

Our stylized model of an H2-based transport sector leaves room for future research. Indeed, we have abstracted from the decision regarding which type of vehicle to purchase (e.g., ICEV, BEV, etc.) and focused on the decision regarding the type of H2 fuel. Including a preliminary stage in our two-stage game would allow us to account for competition with other fuels or other forms of electrical vehicles, as well as the decision to purchase a vehicle. Another aspect that deserves attention is the alliances between upstream producers in this market to cope with the investment cost associated with high-quality H2 and its progressive diffusion.

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A Appendix

A.1 Proof of Proposition 2

Welfare is always larger when producers serve simultaneously both stations compared to when they serve only one station at a time:

$$SW^{NS,NS} - SW^{S,S} = \frac{7}{162}[1 - 2(c_g - c_f + l)]^2 > 0$$

If $c_g - c_f + l > \frac{5}{9}$, welfare is larger when the high-quality producer specializes and the low-quality producer serves both stations. If $\frac{5}{9} \geq c_g - c_f + l \geq \frac{4}{9}$, society is better-off when none of the producers specialize. Otherwise, if $\frac{4}{9} \geq c_g - c_f + l$ welfare is higher when the low-quality producer specializes and the high-quality producer serves both stations. □

A.2 Proof of Lemma 1

We study the equilibrium outcome when the high-quality producer does not deal exclusively. First, we assume that at stage 1 the high-quality producer serves both stations, i.e. it is a monopolist in the upstream market. Thus, there is only high-quality H2 in the market and demand is:

$$D(p) = v + 1 - p \tag{18}$$

In stage 2, the high-quality producer's station 1 and the independent station 2 compete to serve consumers. Station 1 (resp. 2) has a marginal cost $c_g + d$ ($w_g + d$). We have three possibilities:

1. If $w_g < c_g$, then station 2 serves all market with $p = c_g + d - \epsilon$, and makes $\pi_2 > 0$. However, this implies that the high-quality producer makes negative profits since $w_g - c_g < 0$.

2. If $w_g = c_g$, then each station serves half the market with $p = c_g + d$, and makes $\pi_1 = \pi_2 = 0$. However, this implies that the high-quality producer makes negative profits since $\pi_g = \frac{D(p)}{2}(c_g - c_g) + \frac{D(p)}{2}(c_g + d - c_g - d) - E < 0$.

3. If $w_g > c_g$, then station 1 serves all market with $p = w_g + d - \epsilon$ and makes $\pi_1 > 0$. The high-quality producer makes positive profits since $\pi_g = (w_g - c_g - d)D(p) - E \geq 0$.

In stage 1, the high-quality producer sets its wholesale price. The only strategy which guarantees a strictly positive profit for the high-quality producer is setting $w_g > c_g$. That is, the high-quality producer chooses a wholesale price such that the independent station makes negative profits, i.e., it is "foreclosed".
Second, we assume that the low-quality producer serves station 2 instead. This is equivalent to the case where the high-quality producer dealt exclusively.

Thus, at the equilibrium, the high-quality producer deals exclusively, and the low-quality producer always serves the independent station at w_f^*. $\square$

A.3 Proof of Proposition 3

Merging with the independent station is a strictly dominant strategy for the low-quality producer if and only if

$$\Delta\pi_f = \pi_f^{PVI} - \pi_f^{SVI} - \pi_2^{SVI} = \frac{\alpha(1-\alpha-(c_g-c_f))}{9(1-\alpha)} \geq 0$$

this is the case when $c^p = \frac{\sqrt{\alpha}}{\sqrt{\frac{\alpha}{1-\alpha}}} \geq c_g - c_f$. Otherwise, when $c^p < c_g - c_f$ the low-quality producer prefers not to merge with the independent station. The threshold value of the cost difference between qualities c^p such that the low-quality producer and independent stations merge decreases with consumer's beliefs about the share of high-quality H2 available in the market:

$$\frac{\partial c^p}{\partial \alpha} = -\frac{1}{2}\sqrt{\frac{1}{1-\alpha}} < 0$$

$\square$

A.4 Proof of Proposition 4

We compare the social welfare when the low-quality producer and the independent station merge against the alternative. Social welfare is larger with two vertically integrated chains if and only if:

$$\Delta SW = SW^{PVI} - SW^{SVI}\frac{1}{72(1-\alpha)^2}\Big(1-\alpha+(c_g-c_f)(1-2\alpha)\Big)\Big((c_g-c_f)(9-10\alpha)-3(1-\alpha)\Big) \geq 0$$

If consumers are very optimistic about the share of high-quality H2 in the market $\alpha \in [\frac{3}{4}; 1[$, then a merger between the low-quality producers and the independent station is socially desirable if $\hat{c^w} = \frac{1-\alpha}{2\alpha-1} \leq c_g - c_f \leq \bar{c^w} = \frac{3(1-\alpha)}{10\alpha-9}$. Otherwise, if consumers are not very optimistic about the share of high-quality H2 in the market $\alpha \in]0; \frac{3}{4}[$, then a merger between the low-quality producer and the independent station is socially desirable when $\bar{c^w} \leq c_g - c_f \leq \hat{c^w}$. Notice that, $\hat{c^w}$ decreases with α:

$$\frac{\partial \hat{c^w}}{\partial \alpha} = -\frac{1}{(2\alpha-1)^2} < 0$$

whereas $\bar{c^w}$ increases with α:

$$\frac{\partial \bar{c^w}}{\partial \alpha} = \frac{3}{(10\alpha-9)^2} > 0$$

We know that c^p and $\hat{c^w}$ decrease with α, while $\bar{c^w}$ increases, then depending on the size of α merging might be a socially desirable outcome. Specifically, the merger is socially optimal when $\hat{c^w} \leq c_g - c_f \leq c^p$ for $\alpha \in [\frac{3}{4}; 1[$, and when $\bar{c^w} \leq c_g - c_f \leq c^p$ for $\alpha \in]0; \frac{3}{4}[$. We also have a socially optimal equilibrium when $\bar{c^w} = \hat{c^w} < c_g - c_f \leq 1$ for $\alpha \in [\frac{2}{3}; \frac{6}{7}]$, i.e., when the low-quality producer and independent station do not merge. □

A.5 Proof of Proposition 5

We compare social welfare with and without a label for high-quality H2. A label policy is never socially optimal if without government intervention the cost difference between qualities is such that the low-quality producer and independent station 2 merge at equilibrium.:

$$SW^{SS} - SW^{PVI} = \frac{-(1 - 2(c_g - c_f)^2)}{162} < 0 \tag{19}$$

Conversely, a label policy can be socially optimal if without government intervention the cost difference between qualities is such that the low-quality producer and independent station 2 do not merge at equilibrium. Specifically, this is the case when:

$$SW^{SS} - SW^{SVI} = \frac{(1 - \alpha + (c_g - c_f)(1 - 2\alpha))((c_g - c_f)(9 - 10\alpha) - 3(1 - \alpha)}{72(1-\alpha)^2} > 0 \tag{20}$$

this above equation holds when $c^p < c_g - c_f$ for $\alpha \in [\frac{20}{23}; 1[$ and $\alpha \in]0; \frac{4}{7}]$. □