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

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Abstract

A labeling system for green gases, such as green hydrogen and bio-methane, could enable retailers to leverage consumers' willingness to pay for environmental quality while promoting the adoption of these cleaner alternatives. However, the significant cost gap between green and conventional gases raises concerns about the efficacy of such a label, particularly in markets with complex value chains such as road transportation. We develop a stylized model of a gas-based road transport market to evaluate whether the market's organization could be as efficient as a labeling policy when consumers lack direct information about production methods. 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. Producers can use vertical restraints to convey quality information to consumers without the label. The informational problem creates a trade-off between the intensity of competition (driven by perceived qualities) and cost efficiency. Implementing an optimal label policy depends on the cost gap between qualities and consumers' expectations about the share of green gas 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.

Keywords: Label, Vertical Restraints, Innovation, Green Gases

JEL Classification: L13 , L15 , L42 , Q42

1 Introduction

Green gases, such as biomethane and green hydrogen (H2), are promising energy vectors to decarbonize hard-to-abate end sectors with complex value chains, such as transportation, industry and heating. However, these gases face a significant challenge: they are not cost-competitive compared to their fossil counterparts.[1] Therefore, their uptake depends on consumers' willingness to pay for environmental quality. One straightforward way for policymakers to support these higher-cost, environmentally friendly products is through labeling policies. In the European Union (EU), a labeling scheme based on guarantees of origin (GoOs) is already in place for biomethane, and a similar system was recently adopted for H2 (Velazquez Abad & Dodds, 2020). Alternatively, a market's organization can also provide quality information. For instance, in the early gasoline market, a fuel station vertically integrated with an oil producer was a signal of high-quality fuel (Lewis, 2008; Melaina, 2007). This paper compares label policies and market organization as tools to convey quality information to consumers in markets with complex value chains.

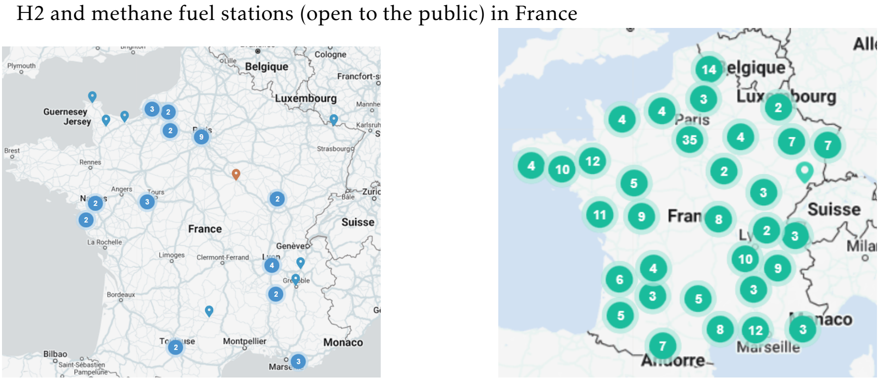
Our focus is the transportation sector, where market organization has historically played a role in signaling product quality. Today, it is the second largest emitter, accounting for about 21% of global carbon dioxide (CO2) emissions in 2023. Although electrification is the primary pathway to decarbonization, it has limitations for long-distance trucks and buses, where performance remains constrained. Gas-powered solutions, such as Fuel Cell Electric Vehicles (FCEVs) and Natural Gas Vehicles (NGVs), are an attractive alternative, with a driving range and refueling time similar to Internal Combustion Engine Vehicles' (ICEVs) (Geffray & Hermine, 2023; Hardman, Chandan, Shiu, & Steinberger-Wilckens, 2016; Hardman, Shiu, Steinberger-Wilckens, & Turrentine, 2017). Furthermore, these technologies do not face challenges related to battery degradation or certain supply chain risks associated with critical materials (Geffray & Hermine, 2023; International Energy Agency, 2019). However, FCEVs and NGVs only offer a significant emission reduction potential if the fuel used to power them comes from a low-carbon source. As Trencher, Taeihagh, and Yarime (2020) note, most FCEVs today still rely on H2 derived from fossil fuel reformation. Similarly, in 2021, biomethane accounted for only 14% of the total gas consumption of NGVs in France (Geffray & Hermine, 2023). This indicates that CO2 emissions are being shifted from the road to gas production processes (Steinhilber, Wells, & Thankappan, 2013), highlighting the need to promote a transition from fossil to green gases (Ajanovic & Haas, 2019).

We build on the literature on labels in vertically related markets (Bonroy & Lemarié, 2012; Fulton & Giannakas, 2004; Lapan & Moschini, 2007) and propose a stylized model of a gas-based road transport market. A complex value chain characterizes this market, with fuel producers upstream and fuel stations downstream. We aim to assess whether the market's organization could be as effective as a label policy in terms of conveying information and social welfare. We consider two types

[1] For instance, fossil-fuel-based H2 has a unit cost of 0.7-2.5 USD/kg, while production from renewable sources costs around 3.2–7.7 USD/kg (International Energy Agency, 2020a). Fossil-fuel-based methane (natural gas) costs 7.2 USD/MBtu, while biomethane is 16.4 USD/MBtu (International Energy Agency, 2020b).

of producers: a low-quality producer relying on fossil fuel production and a high-quality producer using green technology.[2] These producers supply fuel stations that are fully aware of the fuel's quality, but this information may be difficult to communicate to consumers. We assume a scenario where only two stations serve the market. This assumption reflects the significant barriers to the deployment of new fuel infrastructure, which limits competition and creates conditions where only a small number of stations operate. According to Zhao, Liu, and Jamasb (2022), the few operating H2 stations are located today far apart in hydrogen industrial clusters (Figure 1).[3] Although there is a similar issue for biomethane, it is less severe. For example, the number of methane fuel stations (both fossil and biomethane) in Italy—one of the most advanced biomethane markets in Europe—is roughly ten times smaller than that of gasoline stations (Noussan, Negro, Prussi, & Chiaramonti, 2024). Investing in new fuel stations is costly—about 0.6 to 2 million USD for H2 stations and 0.6 to 1 million USD for biomethane fuel stations (ADEME, 2022; International Energy Agency, 2019). This market structure raises concerns about potential anti-competitive behavior and the effectiveness of policy instruments.[4]

Fig. 1 H2 and methane fuel stations (open to the public) in France



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

Source: https://www.gaz-mobilite.fr/stations-gnv-france/

We first focus on how labels affect the downstream market's organization. A label increases the costs of the high-quality product but allows exploiting consumers' willingness to pay for environmental quality. In a similar setup, Bonroy and Lemarié (2012) consider retailers that always buy from both producers and show that a label would increase the high-quality quantity sold in the market.[5] In contrast to their paper, we consider that producers can specialize and exclusively supply one station

[2] Infrastructure-intensive industries often start with state-owned monopolies; however, in the case of biomethane and hydrogen, there are already well-established players along the supply chain.

[3] H2 clusters are geographic areas with integrated hydrogen ecosystems that aim to secure demand and create synergies among supply chain actors (e.g., the Zero-Emissions Valley in Auvergne Rhône-Alpes, France).

[4] A slow uptake of FCEVs and NGVs may exacerbate this situation because they face the classic chicken-and-egg dilemma: widespread adoption requires a simultaneous increase in both vehicles and fueling infrastructure.

[5] They consider interlocking relationships (Rey & Vergé, 2008), where upstream competitors engage with the same competing downstream retailers.

at a time. In our analysis, we demonstrate that at equilibrium, producers always specialize, but society would be better off if they served all stations. Thus, our study highlights how the low uptake of gas-powered vehicles can allow producers and stations to exert market power. We then consider a *laissez-faire* scenario (without the label policy). In this case, the producers' qualities are perceived as homogeneous, allowing the low-quality producer to 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 seek strategies to provide quality information at the station level. The market's organization can reveal information about the final product in road transportation. Indeed, while price remains a major factor in purchase decisions, consumers also show preferences for specific stores or brands.[6] Brand loyalty can signal higher quality, but it can also have the opposite effect. For instance, following the 2010 BP oil spill, BP stations saw margins decline by 2.9 cents per gallon, and sales volume fell by 4.2% (Barrage, Chyn, & Hastings, 2014). Thus, to some degree, company-owned stations, compared to independent ones, do provide a quality signal. We assume that the high-quality producer merges with one of the fuel stations and that vertically integrated stations sell only one quality. This strategy enhances the perceived quality of the merged station. An independent station, meanwhile, may or may not purchase from a vertical structure, making its quality uncertain. Consumers today are confronted with contradictory information. For instance, while many gas-based mobility solutions claim to rely exclusively on green gases, most of the production still comes from fossil fuel sources. This context makes it difficult to assess to what extent consumers expect to have access to a high-environmental quality product when purchasing from an independent station. We assume that when producers do not inform consumers about quality, consumers anticipate an average quality level influenced by their perceived high-quality market share. 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 only holds when the cost difference between qualities is small. 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. We find that such a strategy is never profitable. Compared to the scenario without government intervention, a label would facilitate the diffusion of green gases, enabling 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

[6] According to the NACS (2020) survey, 58% of consumers cited price as their primary concern in 2020, down from 71% in 2015. Additionally, nearly two-thirds of consumers (62%) preferred a particular store or chain, up from 36% in 2002 (Blumberg, G. P., 2002).

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 implement information campaigns to address the prevalent misconceptions regarding the availability of green gases in the market. Low-quality H2 production benefits today from freely allocated emission permits to mitigate the risk of carbon leakage, i.e., the relocation of industrial activities outside the EU (RTE, 2020). If consumers are not excessively pessimistic or optimistic about the available high-quality quantity, then, when combined with a high carbon price, a label policy may no longer be welfare-enhancing. However, if consumers are very pessimistic or optimistic, a high carbon price could create 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 high-quality quantity in 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 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. Concludes.

2 Theoretical Framework

This section describes the organization of the gas-based transport market value chain.

2.1 Supply-side

We consider a vertically related market with producers upstream and fuel stations downstream.

Upstream market (Producers) We consider that there is a fossil producer (f) offering a low environmental quality produced at a marginal cost c_f. There is also a green producer (g) selling a high environmental quality product. 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 gas ($c_g > c_f$). Producer i ($i \in \{g, f\}$) distributes its product to fuel station at a wholesale price w_i.

Downstream market (Fuel Stations) Today, this market is highly concentrated, only a few distantly located fuel stations distribute gas (Figure 1). Thus, we consider that in our relevant market, only two fuel stations 1 and 2 compete for consumers. Stations incur a unit distribution cost d. We assume that stations perfectly observe the producer's quality, but this information is not passed on to consumers. Fuel station j ($j \in \{1, 2\}$) distributes gas at a retail price p_j.

2.2 Demand-side

We consider a continuum of consumers each owning a gas vehicle.[7] Consumers have a reservation price of v for fuel, large enough to have a covered market. In our framework, consumers are already vehicle owners; thus, there is no outside option regarding the use of gas. 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_i, 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 gas in the market $\alpha \in]0;1[$. The indirect utility of a non informed θ-type consumer buying gas at price p is then:

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

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:

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

To simplify the exposition of the model, we assume that the true quality of green gas is equal to $s_g = 1$, while the true quality of fossil gas 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.

3 Labels for green gases

Labeling systems for green gases are relevant for the transportation sector, they prevent infrastructure duplication while making quality differentiation possible. These systems allow retailers to exploit consumers' willingness to pay for green quality compared to undisclosed quality (Mulder & Zomer, 2016). We study the equilibrium outcome when distributing high-quality gas requires stations to incur a label with a unit cost of $l \in [0;1[$.

Assumption 1 $c_g + l - c_f < 1$ *the label cost is sufficiently low such that the market remains covered.*

Producers may serve both stations or sell exclusively. Conversely, in Bonroy and Lemarié (2012) upstream producers always serve both retailers (interlocking

[7]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 fuel quality.

relationships as defined by Rey and Vergé (2008)). In our setting, the nature of competition between stations is determined by the producers' choices. When each producer serves a single station exclusively, the stations compete with differentiated products, resulting in strictly positive profits. Conversely, if producers serve both stations, competition occurs with homogeneous products, leading to downstream equilibrium prices equal to marginal cost. In this case, the stations' margins are zero.[8]

In stage 1, producers decide on the wholesale prices for their respective qualities and whether to specialize or not. We show that, as long as the label cost is not too high, there exists a unique Nash equilibrium in pure strategies.

Proposition 1 *Under a label policy, at equilibrium, producers always distribute their gas exclusively through one station. However, private incentives diverge from societal interests, as social welfare would be maximized if producers supplied both stations.*

Proof See Appendix A.1. □

When producers do not specialize, overall demand increases, but specialization allows for higher margins. The price effect outweighs the volume effect so that producers always prefer to specialize, creating two successive quasi-monopolists for each quality. In Bonroy and Lemarié (2012), the distribution of the label's burden depends on the heterogeneity of retailers relative to consumers. In contrast, we analyze a setting where retailers have identical operational costs. Consequently, the economic burden of the label is shared between the high-quality producer and the station it supplies. Regardless of the market structure, social welfare consistently decreases as the cost of the label increases.

4 Vertical Restraints

With a labeling system, at equilibrium, producers prefer to specialize, which harms social welfare. This raises the question of what the equilibrium outcome would be without the label.

In the absence of any intervention by the high-quality producer, stations engage in price competition with homogeneous products in stage 2. 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: $\pi_g = -E < 0$. As a result, without a labeling system, the high-quality producer may seek alternative strategies to convey quality information at the station level.

The organization of the market can serve as a mechanism to reveal information about the final product, particularly in road transportation. For example, in the early gasoline market, vertical integration with a gas station was perceived as a signal of high-quality fuel (Lewis, 2008; Melaina, 2007). In this context, we consider a scenario where the high-quality producer merges with station 1, using this

[8] The intermediate case, where one producer specializes while the other serves both stations, is never an equilibrium (see Appendix A).

strategy to signal environmental quality. We thus assume that stations operating as part of a vertical structure sell (and signal) only one quality (single-fuel stations), whereas independent stations may choose whether or not to source from the vertical structure.

In a scenario where the high-quality producer merges with station 1, the perceived quality sold by station 2 may be "uncertain" if the station remains independent. In such a case, the indirect utility of a θ-type consumer is:

$$U = \begin{cases} v + \theta s_g - p_1 & \text{if it buys from station 1} \\ v + \theta(\alpha s_g + (1-\alpha)s_f) - p_2 & \text{if it buys from station 2} \end{cases} \quad (3)$$

which results into the following demand for each station :

$$D_1(p_1, p_2) = \frac{1 - \alpha - p_1 + p_2}{1 - \alpha} \quad \text{and} \quad D_2(p_1, p_2) = \frac{p_1 - p_2}{1 - \alpha} \quad (4)$$

Else, if the low-quality producer merges with station 2, we have two competing vertically integrated supply chains, with a high-quality product sold by the vertically integrated station 1 and a low-quality product sold by the vertically integrated station 2. The demand for each station is:

$$D_1(p_1, p_2) = 1 - p_1 + p_2 \quad \text{and} \quad D_2(p_1, p_2) = p_1 - p_2 \quad (5)$$

We first consider the decision of the high quality producer to deal exclusively with its own station.

Lemma 1 *There exists a unique Nash Equilibrium where the high-quality producer supplies exclusively its own station and the low quality producer always serves the independent station.*

Proof See Appendix A.2. □

The high-quality producer has no incentive to serve the independent station. At equilibrium, the low-quality producer always serves the independent station at its profit-maximizing wholesale price. 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. 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 now examine the low-quality producer's decision to merge with station 2.

Proposition 2 *The decision of the low-quality producer to merge with station 2 is driven by 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. Conversely, when the cost difference is smaller, the low-quality producer opts to differentiate itself from the high-quality producer to reduce the intensity of competition. This reflects a trade-off between competition intensity (shaped by perceived product 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 high-quality market share become more optimistic. Thus, the more optimistic consumers are about the presence of the high quality 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 such case, unless high-quality becomes highly cost-competitive, the low-quality producer continues to exploit the informational problem. As a result, consumers purchasing from the independent station receive a lower quality product than they initially anticipated.

Proposition 3 *The merger between the low-quality producer and station 2 is socially optimal when $c^{\hat{w}} \leq c_g - c_f \leq c^p$ for α high, and when $c^{\bar{w}} \leq c_g - c_f \leq c^p$ for α low.*

Proof See Appendix A.4. □

The merger between the low-quality producer and the independent station is not socially optimal when the cost difference between qualities is very low, and α is low as depicted in Figure 2. In that case, without the merger, high-cost efficiency combined with increased downstream competition (resulting from the close perceived qualities) leads to low prices.[9] The merger relaxes competition and increases prices to the detriment of consumers. Conversely, a merger is socially optimal when the cost difference between qualities is very high, i.e., when $c^p < c_g - c_f < c^{\hat{w}}$ (respectively $c^p < c_g - c_f < c^{\bar{w}}$) for α very low (respectively α high). Indeed, a merger reduces the low-quality producer's price for its lower-than-anticipated quality.

5 Discussion and Policy implications

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

[9] Here, similar to Brécard (2017), misperception about quality is not necessarily detrimental to social welfare.

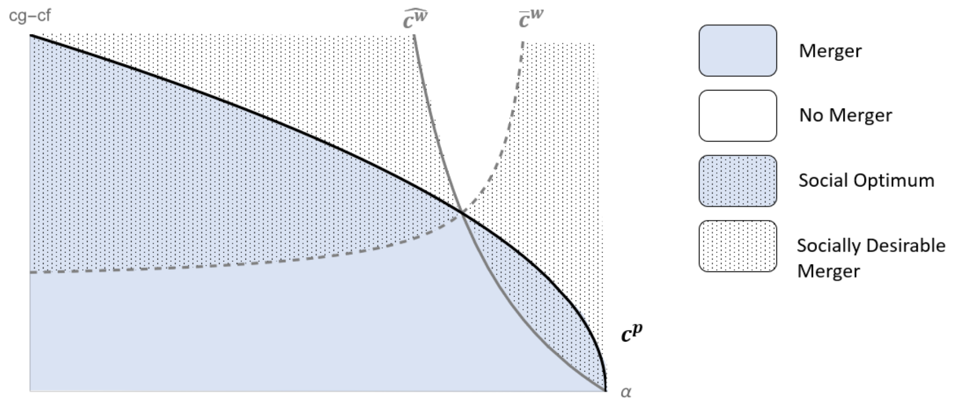


Fig. 2 Laissez-faire outcome

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 $\pi_F^{SVI}(l) + \pi_2^{SVI}(l) = \pi_F^{PVI}(l)$ 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 $\pi_G^{SVI}(l) = \pi_G^{PVI}(l)$. Furthermore, the joint profits are the same as when producers serve all stations, but this is never an equilibrium as 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 not-cost competitive high-quality products by exploiting consumers' willingness to pay for quality. We find that under a label policy, producers specialize leading to two successive quasi-monopolists for each quality and high retail prices $p_g^{SS} - p_g^{SVI} > 0$ and $p_g^{SS} - p_g^{PVI} > 0$. Nevertheless, the specialization allows the high-quality producer to make positive profits even for high values of the fixed cost E, thus easing the market penetration of green gases. Instead, a regulator may be more concerned about whether the label enables to have a greater quantity of green gases in the market than in 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 gas in the market decreases with the latter's cost. Thus, to guarantee a sufficiently important quantity of green gas 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

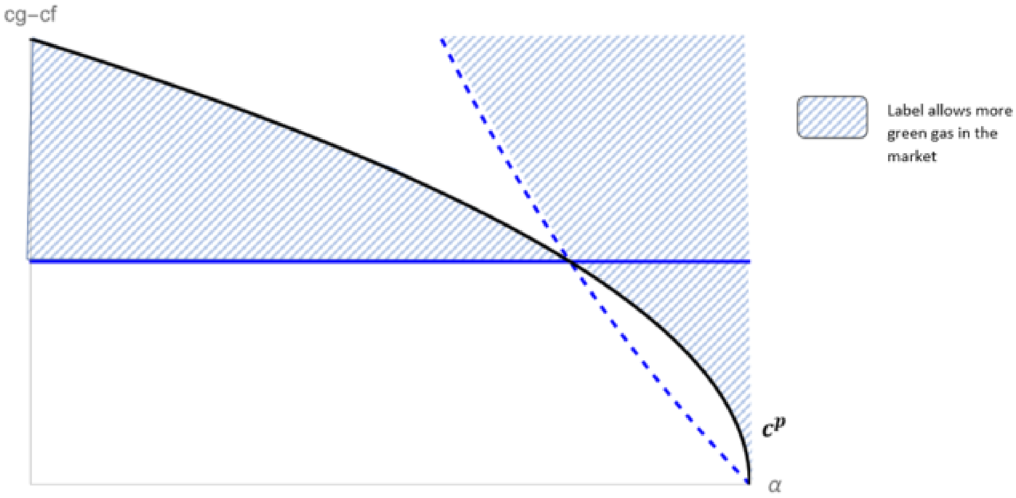


Fig. 3 Green gas quantity in the market

cost difference between qualities, as well as consumers' expectations regarding the high-quality market share, a label policy may lead to more high-quality quantity in the market compared to a laissez-faire scenario (see Figure 3). 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. 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. Thus, a label can simultaneously result in large profits for the high-quality producer, as well as a more high-quality in the market (compared to the laissez-faire).

5.3 Socially optimal policy

In this context, one may wonder whether society would 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 $\frac{\partial(SW^{SS}-SW^{SVI})}{\partial l} < 0$. Thus, if $l > 0$, 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 4 *A label policy is socially optimal when the cost difference between qualities is such that, in the absence of government intervention,the low-quality producer prefers to exploit the information problem ($c^p < c_g - c_f$) and when the utility gain from quality information allows compensating producers' market power. This occurs when α is either very high or sufficiently low.*

Proof See Appendix A.5. □

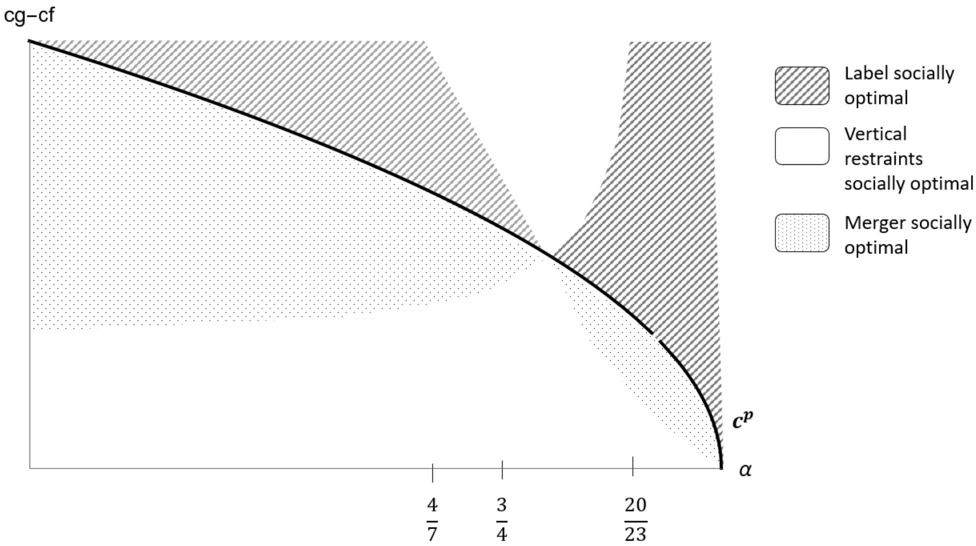


Fig. 4 Socially desirable label

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 4). 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 (α high) or pessimistic (α low) about the share of high-quality gas 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 gas 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 gases are less cost-competitive than fossil-fuel-based ones. Consequently, the desirability of implementing a label policy hinges upon consumers' perceptions regarding the proportion of high-quality quantity available within the market. This is the case when consumers are very optimistic or very pessimistic. Under the pressing issue of climate change, government entities, and industrial stakeholders have put forward gas-based mobility solutions which should supposedly rely exclusively on green gases. However, 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). We have a similar context for biomethane as it only represents 14% of methane consumption in the transport sector. This context makes it difficult to assess to what extent are consumers optimistic about the proportion of high-quality gas 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 gas 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 gas that is available in the market.

Today, low-quality H2 producers benefit from freely allocated emission permits, while natural gas does face a positive cost for them. Despite this, natural gas is still more cost-competitive than biomethane. Besides the label policy, to reduce the cost difference, the EU could stop freely allocating emission permits to gray H2, and set a price for CH4 emmisions. In that case, a label policy may no longer be socially optimal. Indeed, in that case, we would have two vertically integrated chains, thus eliminating the double marginalization from producers' specialization. Otherwise, if despite the aforementioned policies 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 gas available in the market. Thus, it could also be interesting to survey consumers to better assess their perceptions.

6 Conclusion

Green gases, such as biomethane and green hydrogen, are promising options for decarbonizing sectors like transportation, industry, and heating. However, they remain cost-inefficient. Labels can help firms exploit consumers' willingness to pay for environmental quality and charge higher prices. Yet, the cost gap between green gases and conventional alternatives raises questions about the effectiveness of labels in markets with complex value chains, such as road transportation. At the same time, market organization itself can convey quality information, but the high concentration in the gas road transport market raises concerns about anti-competitive behavior. This paper has examined when a label policy might be more effective than market organization for informing consumers and improving social welfare.

Using a stylized model based on the literature about labels in vertically related markets, we evaluated the outcomes of a label policy in a 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 market penetration of green gases. 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 gas-based mobility solutions supposedly rely exclusively on green gases, still a large share 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 gas 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 gas 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 gases that are 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 carbon pricing, then a label policy may no longer be welfare-enhancing. This also would be the case for higher values of the carbon emissions permit currently used by natural gas producers. Instead, if consumers are very pessimistic or optimistic, a high carbon price 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 gas within the market. In such a case, the label would be socially optimal.

This stylized model of the gas-based transport market leaves room for further research. One potential extension could include vehicle purchase decisions, such as choosing between ICEVs, BEVs, or gas-powered vehicles. This would account for competition with other fuels and vehicle technologies. Another area of interest is the role of upstream producer alliances to manage the high investment costs of green gas production and encourage its diffusion.

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Appendix A Proof of Proposition 1

In the context of labels where quality is known, the demand for a gas of quality i can be written as:

$$D_i(p_i, p_{-i}) = \begin{cases} 1 - p_g + p_f & \text{if } i = g \\ p_g - p_f & \text{if } i = f \end{cases} \tag{A1}$$

We solve the game by backward induction. At stage 2, we have four possible market configurations, depending on whether producers have decided to specialize and distribute exclusively through one station or not.

1. No exclusive distribution: stations compete in prices and sell both qualities. Thus, at equilibrium, the downstream prices equal the marginal costs for each quality: $p_g^* = d + w_g + l$ and $p_f^* = d + w_f$.
2. Only the high-quality producer specializes: the low-quality gas is sold by both stations while the high-quality gas is only by one, thus at the equilibrium we have $p_f^* = d + w_f$ and p_g^* is solution of:

$$\max_{p_g} \quad D_g(p_g, p_f^*)(p_g - d - w_g - l)$$

we have $p_g^* = \frac{1+2d+w_f+l+w_g}{2}$.

3. Only the low-quality producer specializes: the high-quality gas is sold by both stations while the low-quality gas is only by one, thus at the equilibrium we have $p_g^* = d + w_g + l$ and p_f^* is solution of:

$$\max_{p_j} \quad D_f(p_g^*, p_f)(p_f - d - w_f)$$

we have $p_j^* = \frac{2d+w_g+l+w_f}{2}$.

4. Both producers specialize: the station selling the high (respectively. low) quality sets the downstream p_g^* (p_j^*) such that it verifies:

$$\max_{p_j} \quad D_f(p_g, p_f)(p_f - d - w_f)$$

$$\max_{p_g} \quad D_g(p_g, p_f)(p_g - d - w_g - l)$$

we have $p_g^* = \frac{2+3d+w_f+2l+2w_g}{3}$ and $p_f^* = \frac{1+3d+w_g+l+2w_f}{3}$.

At stage 1, producer i choose the wholesale price of its quality and also decides whether to specialize or not. The wholesale equilibrium price verifies:

$$\max_{w_i} \quad D_i(w_g(p_g^*, p_f^*), w_f(p_g^*, p_f^*))(w_i(p_g^*, p_f^*) - c_i)$$

1. No exclusive distribution: we have $w_g^* = \frac{2-l+2c_g+c_f}{3}$ and $w_f^* = \frac{1+l+c_g+2c_f}{3}$.
2. Only the high-quality producer specializes: we have $w_g^* = \frac{3-l+2c_g+c_f}{3}$ and $w_f^* = \frac{3+l+c_g+2c_f}{3}$.
3. Only the low-quality producer specializes: we have $w_g^* = \frac{4-l+2c_g+c_f}{3}$ and $w_f^* = \frac{2+l+c_g+2c_f}{3}$.
4. Both producers specialize: we have $w_g^* = \frac{5-l+2c_g+c_f}{3}$ and $w_f^* = \frac{4+l+c_g+2c_f}{3}$.

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

Table A1 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).

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. □

Appendix B 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 gas in the market and demand is:

$$D(p) = v + 1 - p \tag{B2}$$

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^*. □

Appendix C Proof of Proposition 2

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 quantity available in the market:

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

□

Appendix D Proof of Proposition 3

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 gas 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 gas 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. □

Appendix E Proof of Proposition 4

We compare social welfare with and without a label for high-quality gas. 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.:

$$SW^{SS} - SW^{PVI} = \frac{-(1 - 2(c_g - c_f)^2)}{162} < 0 \tag{E3}$$

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:

$$SW^{SS} - SW^{SVI} = \frac{(1 - \alpha + (c_g - c_f)(1 - 2\alpha))((c_g - c_f)(9 - 10\alpha) - 3(1 - \alpha)}{72(1 - \alpha)^2} > 0 \tag{E4}$$

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

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