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STAKEHOLDERS' PERSPECTIVES ON HYDROGEN POLICY: A FACTOR ANALYSIS

UCD-ITS-RR-05-22

A report from the Hydrogen Policy Project of the Hydrogen Pathways Project

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1. Introduction

In the context of a study of the policy process related to the adoption of hydrogen as a transportation fuel, an online survey was administered in May of 2005. The survey, sent to a sample about 4,000 individuals, obtained measures of stakeholders' perspectives on a wide variety of issues related to hydrogen policy. A total of 502 responses were received. Details on the survey sampling scheme, respondents' characteristics, and general descriptive statistics, can be found in Collantes (2005).

Factor analysis is a statistical data-reduction technique that aims at explaining the common variance in a number of variables with one single variable called "factor." Much of the value in—to many the Achilles heel of—factor analysis is that it elicits the incorporation of subjective expert judgments from the analyst. Conceptually, the idea of factor analysis is to use more than one variable to capture a hypothetical underlying (or latent) continuous construct. This technique found its first applications in psychometrics and has been widely adopted in the social sciences. One example relevant to policy analysis would be the operationalization of the concept of environmentalism. Environmentalism is not a measurable characteristic—rather it is a continuous latent construct. Obtaining measurements of the different aspects that define environmentalism, and running a factor analysis of them, could yield one single variable, a factor, which captures this concept. A good introduction to factor analysis can be found in Dillon (1984).

The hydrogen policy survey was designed, among other things, to investigate some of the underlying concepts present in the policy debate. Such latent constructs include: policy beliefs, policy preferences, stakeholders interests, hydrogen production pathway preferences, hydrogen education policy beliefs, and research policy preferences. This report presents the factor analyses that identify the underlying constructs in each of these areas. The results have value in and of themselves as they help understand the map of policy-related attitudes among participants in the policy debate over hydrogen. Also, the factors identified can be used as explanatory variables in further analyses of the same dataset.

This report is structured as follows. Section 2 presents a factor analysis of the set of normative policy belief statements in the survey. Section 3 presents a factor analysis of the statements related to policy preferences. Section 4 presents a factor analysis of the organizations' market interests. Section 5 presents a factor analysis of the preferences for hydrogen production pathways. Section 6 presents a factor analysis of the beliefs in terms of the synergies between markets for a number of technologies and markets for fuel-cell vehicles. Section 7 presents a factor analysis of research policy preferences. Section 8 presents a factor analysis of education policy beliefs. Finally, section 9 presents a discussion of the results, their interpretations, and implications for policy.

2. Factor Analysis of Policy-Belief Statements

We carried ou an iterated principal components factor analysis of policy-belief questions in the survey. A policy belief represents the degree of agreement with a given policy. In this sense, it is a normative belief. Responses to these statements were collected on a five-point Likert scale anchored by “strongly disagree” and “strongly agree.” To identify factors, we look at a portfolio of criteria. First, we require multiple loadings of at least 0.5, a commonly accepted level of significance (Rencher, 2002). Statements that load on only one factor are dropped from the analysis. Second, we study the scree plots looking for eigenvalues greater than one while paying attention to the shape of the curve. A sharp fall in the eigenvalues curve often suggests that the factors on the upper side of the fall should be retained. Third, we use a measure of reliability to evaluate the consistency of the group of items as a representation of a single unidimensional construct. For example, we may try to measure the preference of a certain *type* of policy by obtaining measures of preference for *specific* policies that arguably fall within that type. A measure of reliability indicates how reliable these measures of specific policies are as a representation of the underlying concept, namely the type of policy. Fourth, we try to determine whether the items in a given factor represent an underlying concept.

As indicated in Table 1, only two factors were identified from the responses to our set of policy-belief statements. This table shows the varimax-rotated factor loadings of the statements that were found to belong in a factor, for the US-based subsample. The following policy-belief statements were dropped from the analysis because they did not show sufficiently high commonalities and therefore could not be combined to represent common underlying policy beliefs:

a- Environmental regulations should be standard-based, not technology-based
b- Government regulations can accelerate technological innovation
c- All policy benefits and costs can be reflected reasonably well in a cost-benefit analysis
d- Sequestration is a promising way to deal with CO_2 emissions from hydrogen production.
e- Anthropogenic CO_2 emissions are a significant cause of global warming.
f- Governmental policies should be more concerned with helping lower-income groups than helping higher-income groups
g- In general, market-based policies are more effective than command-and-control policies
h- In general, protecting the economy is more important than protecting the environment

In other words, responses to each of these statements show no significant association to the responses to any other statement in the policy-belief group. As a consequence, they cannot be combined with any other statement to form a factor that represents a common latent policy belief.

Table 1. Factor loadings on policy-belief statements

	Factor loadings		
Policy belief statement	**1**	**2**	**Uniqueness**
Governments should be first adopters of hydrogen vehicles	-0.03004	0.79635	0.36492
Governments should provide funds for the development of hydrogen fueling infrastructure	-0.01935	0.86008	0.25989
Governments should provide funds for demonstration programs on hydrogen technologies/systems	0.01621	0.80261	0.35556
More international collaboration is desirable on policies related to hydrogen	0.22209	0.58801	0.60492
The external costs of energy PRODUCTION should be internalized	0.96654	-0.00907	0.06571
The external costs of energy USE should be internalized	0.86504	0.02428	0.25112

The Scree plot for the varimax-rotated solution in Figure 1 shows that indeed two factors are distinctly identified.

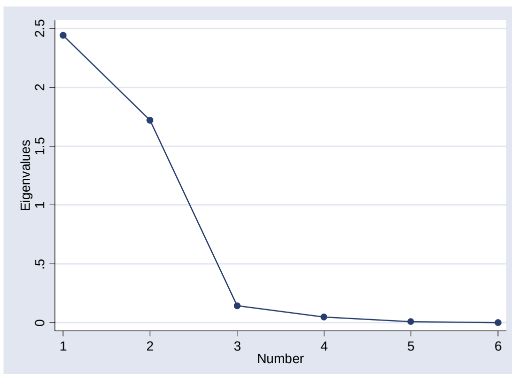

Figure 1. Scree plot of policy-belief factor analysis

The first factor—*government lead*—is composed of the statements with shaded loading cells in column "2" of Table 1. To estimate reliability, we use the Cronbach's alpha because it is the measure that makes the least restrictive assumptions, and because it is widely adopted in the social sciences (Bollen, 1989). Cronbach's alpha for these four statements is 0.843 for US-based respondents and 0.813 for non-US-based respondents. Values of 0.7 or more are generally accepted as high (Nunnaly and Bernstein, 1994.) Therefore, these four statements are reliable measures of the latent concept (in this case a policy belief) captured by the factor. This concept is explained in the following paragraph.

The government lead factor purports to capture the underlying policy belief that governments should take an active role, particularly financial, to help moving forward toward a potential adoption of hydrogen as a transportation fuel. As characterized by the operational statements, government investments may take the form of early purchases of hydrogen vehicles, financing the deployment of a hydrogen delivery infrastructure, and funding demonstration programs.

The second factor—*pro internalization*—comprises the statements with shaded loading cells in the column 1 of Table 1. The Cronbach's alpha for these two statements is 0.899 for US-based respondents and 0.869 for non-US-based respondents. This factor intends to capture the underlying policy belief that energy-related external costs should be internalized.

3. Factor Analysis of Policy-Preferences

We obtained measures of stakeholders' preferences on a variety of specific policy tools. Policy preferences differ from policy beliefs primarily in that they represent the degree of actual support that a respondent would lend to a given policy. To measure these preferences, we employed a five-point Likert-type scale anchored by "strongly oppose" and "strongly support." An iterated principal components factor analysis of these measures yielded, for the US-based subsample, the varimax-rotated factor loadings presented in Table 2.

Table 2. Factor loadings on policy preferences questions

	Factor loadings			
Variable	**1**	**2**	**3**	**Uniqueness**
A tax on gasoline to account for its air pollution costs	0.14875	0.83461	0.02316	0.28076
A tax on gasoline to encourage less driving	0.11408	0.74235	-0.00665	0.43586
A carbon tax	0.05329	0.83683	0.10316	0.28624
A tax on gasoline as a source of revenue for the development of a hydrogen infrastructure	0.49195	0.35211	0.55445	0.32659
Promote basic research on hydrogen technologies at universities	0.07349	0.00790	0.52116	0.72292
Economic incentives ("carrots") for firms to accelerate the market introduction of fuel-cell vehicles	0.32251	-0.00275	0.75491	0.32609
Regulation that ensures liability insurance of hydrogen infrastructure at reasonable prices	0.39773	0.06362	0.56136	0.52264
A mandate on the quantity/percentage of hydrogen-fueled vehicles produced	0.86957	0.05441	0.24275	0.18197
A mandate on the quantity/percentage of zero-emission vehicles produced	0.75480	0.33618	-0.01302	0.31708
A mandate on the quantity/percentage of fueling stations that offer hydrogen	0.86211	0.01584	0.27997	0.17813
Regulating the minimum percentage of hydrogen to be produced from renewable sources of energy	0.52508	0.19995	0.19796	0.64512

Two policy-preference statements were dropped from the analysis because they failed to reach the 0.50 factor loading threshold. These statements are:

a- Incentives for buyers of vehicles that bring societal benefits relative to standard gasoline vehicles
b- Increasing fuel-efficiency requirements on new light-duty vehicles

By every measure, at least two factors—the loadings of which are shown in columns 1 and 2 of Table 2—can clearly be identified. A third factor, which we chose to retain, can be argued for on somewhat less solid grounds, and is shown in column 3. Had we retained only factors with eigenvalues bigger than one, we would have obtained only two factors. In this alternative solution, one of the factors would essentially result from the collapsing of factors 1 and 3 into a single factor.[1] Such a two-factor solution however would not contribute significantly to our understanding of the map of policy preferences—it would basically show a split between preferences of hydrogen-related policies and other transportation energy policies. We discuss each of the three factors we retained separately.

The first factor comprises the statements with shaded cells in column 1 of Table 2. For these statements, we found a Cronbach's alpha of 0.857 for US-based respondents and 0.816 for non-US-based respondents. This factor purports to capture the underlying preference for policies that require the supply of some minimum level of socially-desirable technologies, in this case zero-emission technologies (at the end use and upstream stages of the energy cycle) and hydrogen-based transportation system. While the factor loading on the last statement is significantly lower than those in the first three statements and the Cronbach's alpha slightly increased when this statement was excluded, we decided to keep it in because of two reasons: a) its factor loading is greater than 0.5, and b) the statement fits the underlying concept that this factor purports to measure. To reflect the conceptual liaisons between these statements, we call this factor *pro-regulatory mandates.* It is intriguing that the support for a tax on gasoline to support the development of a hydrogen refueling infrastructure has a rather high factor loading (0.49). This may indicate that stakeholders with higher loadings on this factor do not necessarily intend to place all the burden of compliance on industry, but they would be open to a taxing strategy to support industry efforts.

The second factor we identified encompasses the statements with shaded cells in column 2 of Table 2. The Cronbach's alpha corresponding to these three statements is 0.850 for US-based respondents and 0.767 for non-US-based respondents. This factor purports to capture the underlying policy preference for implementing end-user taxation as a means to internalize externalities like criteria pollutant emissions, fuel consumption, traffic congestion, and greenhouse-gas emissions. To summarize this concept, we label this factor *pro internalizing taxes*. The marginally significant loading on the support of a mandate on zero-emission vehicles may suggest that this factor is related to a concern for tailpipe emissions and to the preference for strong policy action to address this concern.

The third factor includes the four statements with shaded loading cells in column 3 of Table 2. The Cronbach's alpha of these statements is 0.765 for US-based respondents and 0.699 for non-US-based respondents. Looking at the eigenvalues scree plot in Figure 2, we also notice that the corresponding eigenvalues falls close to one. The contribution of this third factor to the proportion of the explained variance is, however, significantly bigger than that of the next factor (0.1158 versus 0.0213)—this fact is reflected in the scree plot, which shows a reasonably steep jump from the third to the fourth points.

Retaining this third factor is to a certain extent a judgment call on our part. We believe that the three-factor solution is conceptually richer than the two-factor one, while the statistical evidence

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[1] Such two-factor solution would exclude the statement "Promote basic research on hydrogen technologies at universities," while it would include the statement "Increase fuel efficiency standards." The former would not reach the adopted 0.50 loading threshold, while the latter would.

to prefer a two-factor solution is not definitive. This factor purports to capture the preference for policies to stimulate the key areas that would facilitate the commercialization of hydrogen vehicles: basic research, the deployment of a refueling infrastructure, incentives to production, and liability issues. In some sense, these policies reflect a less anxious approach that fosters the normal course of technological innovation. To reflect this concept, we label this factor *innovation facilitation*.

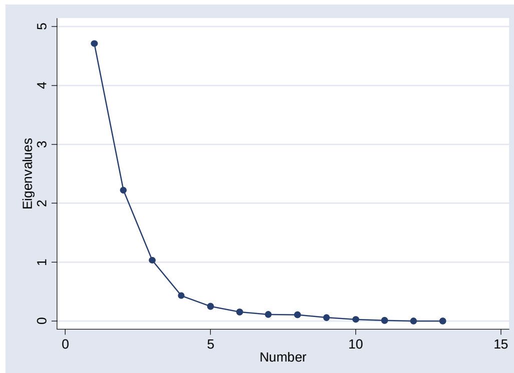

Figure 2. Scree plot of policy-preference factor analysis

4. Factor Analysis of Organizations' Interests

Stakeholders' policy activity in any policy area, including the environment and energy, is driven not only by belief systems but also by economic interests. For certain actors, like environmental non-profit organizations, societal benefits are the exclusive driving interest. Organizations that respond to shareholders are predominantly motivated by economic interests. Within this group, variation is often found in terms of the importance that each organization gives to societal goods (e.g. product environmental friendliness) in its business model. The marketing of socially beneficial products, however, is usually not a consequence of related organization's belief systems, but rather part of a broader market strategy.

The market interests of the organizations that the respondents represent were captured with the question "To the interests of your organization, how important is the short-term development of markets for each of these end-use products?" Three response options were offered: "not important", "somewhat important," and "very important." An iterated principal components factor analysis was performed and a varimax rotation was applied to the solution. Table 3 shows the items that were included in the factor analysis with their loadings in each of the factors we kept. Three items—the organizations' interests in gasoline internal combustion vehicles, in gasoline hybrids, and in alternative-fuel vehicles—were excluded from the analysis as they did not help identify significant additional factors.

Table 3. Factor loadings on organization interests' items

	Factor loadings			
Organization interests	**1**	**2**	**3**	**Uniqueness**
Gasoline plug-in hybrid electric vehicles	0.07234	0.87199	0.03577	0.23311
Battery electric vehicles	0.12032	0.72457	0.11778	0.44665
Hydrogen internal combustion engine vehicles	0.74929	0.08214	0.21712	0.38468
Hydrogen hybrid electric vehicles	0.80508	0.23554	0.31562	0.19674
Hydrogen plug-in hybrid electric vehicles	0.60950	0.47983	0.32647	0.29169
Fuel-cell vehicles	0.60515	-0.02082	0.53827	0.34363
Hydrogen-fueled buses	0.68891	0.02776	0.48893	0.28557
Hydrogen energy stations	0.57855	-0.00488	0.62964	0.26880
Hydrogen stationary applications	0.27006	0.12944	0.85412	0.18080
Hydrogen portable applications	0.31071	0.14201	0.75125	0.31892

The shaded cells in each column refer to the items used to conceptually interpret the factors. Two points should be noted. First, columns 2 and 3 highlight cells with factor loading below the 0.5 threshold we have adopted. These cells should be seen as adding secondary support to the conceptual interpretation of the factor. Second, some items have significant loadings in two factors. In our interpretation, this result is not only acceptable but also expected—organizations may have an interest in any of these items for more than one reason. This notion is elaborated upon below.

As Figure 3 shows, only the first two eigenvalues are bigger than one, and this would suggest keeping just two factors. However, other considerations led us to keep three factors instead. First, in all three factors we find multiple loadings well in excess of our threshold value of 0.5. Second, the three factors have appealing, coherent conceptual interpretations. Third, the Cronbach's alphas for the groups of items in each factor are high.

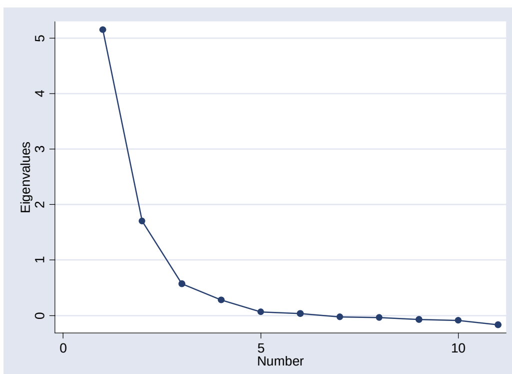

Figure 3. Scree plot of organization interests factor analysis

The first factor includes the six items with shaded cells in column 1 of Table 3, which have a Cronbach's alpha of 0.910 for US respondents and 0.876 for non-US respondents. This factor represents the underlying interest in introducing hydrogen in the transportation sector in the short term, regardless of the technology used to convert hydrogen into energy. Logically, the factor includes the interest in energy stations, where hydrogen-fueled vehicles would refuel. To reflect the conceptual meaning of this factor, we label it *hydrogen interest*.

The second interest factor—*plugged vehicles*—comprises the three highlighted items in column 2 of Table 3. The Cronbach's alphas of these items are 0.762 and 0.741 for US and non-US respondents respectively—values over the generally acceptable threshold of 0.70. The underlying interest captured by these items is in grid-fed electric battery drivetrains. Our analysis showed that the interest in gasoline hybrid electric vehicle had a marginally significant loading (0.46) on this factor too, which suggests for this factor an underlying more general relation to transportation battery technologies. This item was excluded however on the basis of the following factors: a) we believe it wouldn't contribute to obtaining a more conceptually clear factor definition because much of the constituency of gasoline hybrid electric vehicles differs substantially from the constituencies of the three items retained in the factor; b) including this item would slightly lower the Cronbach's alpha measure of reliability; c) this item's loading in the plugged vehicles factor was lower than the 0.5 threshold; d) given the market significance of this technology item, it will likely be useful to our analysis to keep it not as part of a factor, but rather as a separate variable.

The third factor—*fuel cell applications*—includes the five items in the third column of Table 3, which have a Cronbach's reliability alpha of 0.904 for US respondents and 0.890 for non-US respondents. The items involved suggest that the underlying interest captured by this factor is that in the market introduction of fuel cells in transportation as well as other niches. Those items reflecting fuel cell applications in the transportation sector have, logically, significant loadings in the first factor too. While the loading on the hydrogen-fueled buses item is slightly below the 0.5 threshold, we decided to keep it in this factor because it adds to the conceptual robustness of the factor and because its inclusion increased the reliability of the group.

5. Factor Analysis of Hydrogen Production Pathways

Responses on preferences for different pathways of hydrogen production were elicited with the question "For the SHORT TERM, would you support policies that promote the following sources of energy for the production of hydrogen?" A list of alternatives followed the question with five-point response alternatives anchored by strongly oppose and strongly support.

An iterated principal components factor analysis was carried out on the alternatives. We found that a two-factor solution was the only satisfactory one based on our portfolio of criteria. We found potential solutions with higher numbers of significant factors with clear conceptual interpretations, but the Cronbach's alphas for the related alternatives were too low. The factor loadings of the two-factor solution for the US-based subsample are presented in Table 4.

Table 4. Factor loadings on hydrogen production pathway preferences

	Factor loadings		
Variable	**1**	**2**	**Uniqueness**
Coal with CO_2 sequestration	0.16338	0.58498	0.63111
Coal without CO_2 sequestration	-0.10933	0.71023	0.48362
Natural gas with CO_2 sequestration	0.36047	0.62046	0.48509
Natural gas without CO_2 sequestration	0.07392	0.64062	0.58415
Geothermal	0.69730	0.14730	0.49207
Petroleum/Coke	0.03541	0.69872	0.51054
Wind	0.88471	0.04367	0.21538
Solar	0.89381	-0.01288	0.20093
Biomass	0.77754	0.11224	0.38284

The only alternative that was excluded is nuclear, which did not show commonality with other production pathways. The first factor, defined by the alternatives with shaded cells in the first loadings' column of Table 4, captures an underlying preference for policies that favor hydrogen production using renewable sources of energy. We call this factor *renewable pathway*. The alternatives composing this factor have a Cronbach's reliability alpha of 0.892 and 0.888 for US- and non-US-based respondents, respectively.

The second factor includes the alternatives whose loadings are shaded in column 2 of Table 4, and purports to capture a latent preference for policies that favor hydrogen production from fossil sources of energy. These alternatives have Cronbach's alphas of 0.785 for the US-based subsample and of 0.796 for the non-US-based subsample. We call this factor *fossil pathway*.

The eigenvalues plot in Figure 4 also seems to suggest a two-factor solution. However, this plot reflects the loadings before we forced the software to retain only two factors. That solution yielded a robust factor including the renewable production options, plus two other factors with low reliabilities and unclear interpretations. While the two-factor solution highlighting preferences for renewable and fossil-fuel pathways (with the nuclear pathway as a stand-alone alternative) is a natural and solid one, the analysis suggests that marginally significant commonalities may exist between alternatives within the fossil pathway factor. Considerations like these remind us that, when building models, not only the factors should be considered as explanatory variables but also the variables that comprise them.

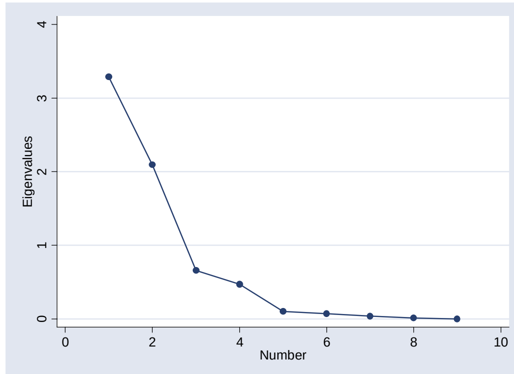

Figure 4. Scree plot of the factor analysis of hydrogen production preferences

6. Factor Analysis of Technologies' Impacts on Fuel-Cell Vehicles Commercialization

This section concerns the factor analysis of responses to the question "How would the development of markets for each of the following technologies impact the later development of markets for fuel cell vehicles?" A list of technologies followed the question with response options given as a five-point Likert-type scale anchored by very negatively and very positively.

Table 5 shows the varimax-rotated factor loadings for the US-based subsample, obtained with a maximum likelihood factor analysis. To find this three-factor solution, we dropped from the factor analysis two technologies that did not have significant commonalities with others: battery electric vehicles and compressed natural gas vehicles. This solution passes a chi-squared test against a solution with more factors.

Table 5. Factor loadings for impact of technologies' factor analysis

	Factor loadings			
Technology	**1**	**2**	**3**	**Uniqueness**
Gasoline hybrid electric vehicles	0.71444	0.11183	0.29781	0.38837
Gasoline plug-in hybrid electric vehicles	0.95118	0.11448	0.28660	0.00000
Hydrogen hybrid electric vehicles	0.25907	0.07279	0.92534	0.07132
Hydrogen plug-in hybrid electric vehicles	0.31829	0.11799	0.82490	0.20431
Hydrogen internal combustion vehicles	0.17590	0.09906	0.89065	0.16599
Stationary fuel cells	0.11299	0.76901	0.11893	0.38171
Portable fuel cells	0.10269	0.96984	0.09644	0.03947

The pattern of the scree plot in Figure 5 is consistent with the choice of a three-factor solution.

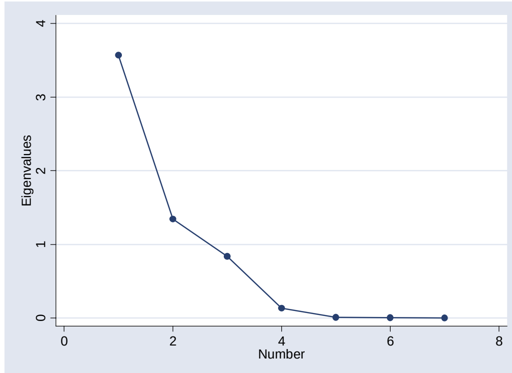

Figure 5. Scree plot of the factor analysis of technologies' impacts

The first factor—*hybrid-to-fuel cell impact*—includes the two variables indicated in column 1 or Table 5, and purports to represent the latent belief that the market development of gasoline hybrid vehicles would have a positive impact on the development of markets for fuel-cell vehicles. The Cronbach's alpha for the two involved variables is 0.873 for the US-based subsample and 0.852 for the non-US-based subsample.

We call the second factor *fuel cell-to-fuel cell impact*, and it includes the variables with shaded cells in column 2 of Table 5. This factor is a measure of the underlying belief that the development of markets for fuel-cell vehicles would be facilitated by the development of additional market niches for fuel cells. The reliability Cronbach's alphas for the two involved variables are 0.866 and 0.878 for US-based and non-US-based respondents, respectively.

The technologies with shaded cells in column 3 of Table 5 define the third factor—*hydrogen-to-fuel cell impact*. This factor purports to capture the latent belief that the market development of fuel cell vehicles would be promoted by the development of markets for vehicles running on hydrogen. The three technologies included in this factor have a Cronbach's alpha of 0.931 for US-based respondents and 0.908 for non-US-based respondents.

7. Factor Analysis of Research Policy Preferences

The survey elicits statements of preferences regarding policies to promote research on a variety of technologies related to hydrogen. Specifically, the question that does that is "How much would you support government programs for research, development, and/or demonstration in each of the following areas?" An iterated principal components factor analysis of the set of technologies presented following the question, shows that only one factor can reliably be identified. Table 6 shows the varimax-rotated loadings on the technologies involved in this factor.

Table 6. Factor loadings for technology research policy preferences

	Factor loadings	
Variable	**1**	**Uniqueness**
Fuel cell membranes	0.95168	0.09431
Fuel cell catalysts	0.93664	0.12270
Fuel cell durability	0.93180	0.13175
Fuel cell efficiency	0.90024	0.18956
Fuel cell sub-freezing operation	0.83166	0.30834

The Cronbach's alpha for these items is 0.961 for US-based respondents and 0.924 for non-US-based respondents. The identified factor purports to capture the latent preference for policies that support research on fuel cell technology. We name this factor *fuel cell research*.

Technology items that did not fall in any robust factor were:

a- Hydrogen storage
b- Hydrogen delivery
c- CO_2 sequestration
d- Hydrogen production from coal
e- Hydrogen production from natural gas
f- Hydrogen production from renewable sources of energy
g- Hydrogen production from nuclear energy.

Some of these items had significant (bigger then 0.5) loadings in other factors, but these factors were not sufficiently reliable: their Cronbach's alphas were lower than 0.8 and the higher loadings of the involved items were not consistent (they moved from factor to factor as we reduced the number of factors.) Specifically, Table 7 shows how some of these variables paired up, their measures of reliability, and the rotated factor loadings that each had in a factor analysis with no constraints on the number of factors retained.

Table 7. Reliability and factor loadings of variables excluded from the analysis

<table>
<tr><th rowspan="2"></th><th colspan="2">Cronbach's alpha</th><th>Factor loadings</th></tr>
<tr><th>US-based</th><th>Non-US-based</th><th>US-based</th></tr>
<tr><td>Hydrogen storage</td><td rowspan="2">0.866</td><td rowspan="2">0.699</td><td>0.685</td></tr>
<tr><td>Hydrogen delivery</td><td>0.762</td></tr>
<tr><td>Hydrogen production from coal</td><td rowspan="2">0.723</td><td rowspan="2">0.734</td><td>0.744</td></tr>
<tr><td>Hydrogen production from natural gas</td><td>0.766</td></tr>
</table>

While the factor loadings on these variables were significant for the unconstrained solution, we could no longer identify clear factors as the number of factors was reduced. An oblique rotation did not improve our results. Figure 6 shows the scree plot for the factor analysis with no constraints in the number of retained factors. The eigenvalues and the shape of the plot lend support to the one-factor solution.

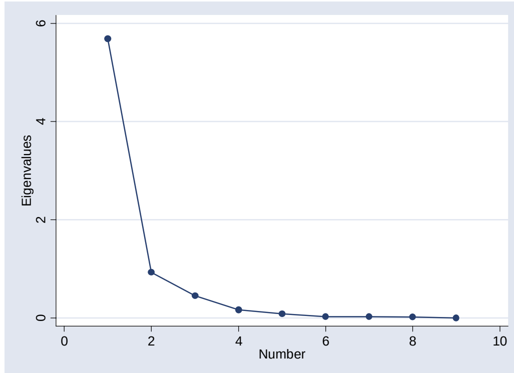

Figure 6. Scree plot of the factor analysis of research policy preferences

8. Factor Analysis of Education Policy Beliefs

The survey contained a section on hydrogen education policy. The general question in that section was "What groups should be given high priority in the SHORT TERM for education programs on the following subjects? (Select all that apply.)" Response options were presented as a matrix with areas of education in the rows and target populations in the columns, as illustrated in Table 8. The cells were coded as binary (0, 1) variables.

Table 8. Structure of the response options in the education policy section of the survey

Education area \ Target population	Consumers	Grade schools	High schools	Colleges	Gov't elected officials	Safety/ Permitting officials	Other	None	Don't know
Hydrogen safety issues									
Societal benefits of hydrogen									
Value of hydrogen vehicles to consumers									

An iterated principal components factor analysis was performed on this set of variables, excluding the "Other" column as we believe it would not contribute the identification of a conceptually useful factor. The scree plot of eigenvalues for the initial solution with no constraint in the number of factors is shown in Figure 7—five factors had eigenvalues of one or bigger. Our analysis led us to keep four factors—these are presented in Table 9 together with their varimax-rotated factor loadings.

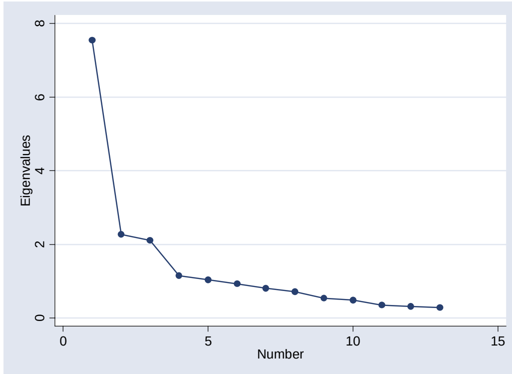

Figure 7. Scree plot of the factor analysis of hydrogen education policy beliefs

Table 9. Factor loadings for hydrogen education policy beliefs

Variable		Factor loadings				Uniqueness
Education area	**Target population**	**1**	**2**	**3**	**4**	
Hydrogen safety issues	Consumers	0.11932	-0.07726	0.17475	0.56859	0.62596
	None	-0.68159	-0.04800	-0.08779	-0.18565	0.49096
	Uncertain	0.04635	0.61644	-0.06304	-0.12507	0.59823
Societal benefits of hydrogen	Consumers	0.25485	-0.16503	0.25792	0.73863	0.29572
	Grade schools	0.12321	-0.09366	0.64858	0.20567	0.51309
	High schools	0.24616	-0.14869	0.71895	0.22614	0.34927
	Colleges	0.30885	-0.16355	0.61735	0.10061	0.48663
	None	-0.91662	-0.05037	-0.14869	-0.15820	0.11012
	Uncertain	0.01819	0.99153	-0.06793	-0.06482	0.00772
Value of hydrogen vehicles to consumers	Consumers	0.33023	-0.17519	0.16731	0.75508	0.26212
	Grade schools	-0.00251	-0.01175	0.56953	0.13754	0.65658
	High schools	0.07853	-0.02416	0.75109	0.17449	0.39866
	Colleges	0.17560	-0.08077	0.67654	0.12149	0.49017
	None	-0.66665	-0.07465	-0.20773	-0.34996	0.38439
	Uncertain	0.09400	0.72782	-0.10017	-0.17411	0.4210

The first factor is represented by the variables with shaded cells in column 1 of Table 9. In view of the negative loadings in these variables, this factor purports to capture the *opposite* of the belief that no education programs should be implemented in the short term. We will call this factor *pro education action*. The Cronbach's alpha for these three variables is 0.828 for the US-based subsample and 0.907 for the non-US-based subsample.

The second factor, including the variables with shaded cells in column 2 of Table 9, essentially intends to capture the lack of opinion about what education programs should be implemented. We name this factor *no opinion on education*. The intervening variables have Cronbach's alphas of 0.828 and 0.899 for the US-based subsample and the non-US-based subsample, respectively.

The third factor we identified is represented by the variables with shaded cells in column 3 of Table 9 and purports to capture the latent belief that education programs in the short term should target young populations (the consumers of the future) and should focus on the private and societal benefits of hydrogen. We call this factor *young population education*. The Cronbach's alpha for these six variables is 0.878 for the US-based subsample and 0.773 for the non-US-based subsample.

The fourth and last factor, identified in column 4 of Table 9, intends to capture the belief that education programs in all three areas—safety, societal benefits, and value to consumers—should, in the short term, target the consumer. We name this factor *consumer education*. The three variables that represent this factor have Cronbach's alphas of 0.806 and 0.669 for the US-based subsample and the non-US-based subsample, respectively. While the value of alpha is rather low for the latter subsample, we kept this factor on the arguments that it is conceptually strong and that the alpha for the subsample that we will analyze is still high.

9. Discussion

We performed factor analyses in a number of sets of variables from our dataset on hydrogen policy. The factors identified constitute proxies or measures of latent non-measurable constructs like policy preferences, policy beliefs, organization interests, beliefs about the impact of technologies on the development of markets for fuel cells, policy preferences about hydrogen production pathways, research policy preferences, and education policy beliefs. These factors could be used as explanatory variables in studies of the policy process related to hydrogen.

But what can these factors tell us in and of themselves? They give us great insight into the issues around which stakeholders tend to coalesce. Because of our research sampling scheme and the nature of the information collected, we can only argue that our results apply to the hydrogen policy subsystem. With respect to general policy beliefs, the two salient issues that characterize the subsystem are the role of government on financing a transition to hydrogen and the internalization of energy externalities. The latter is described by the *pro internalization* factor, including beliefs about internalization of externalities generated both in the production and consumption of energy. This result is interesting as it could have been expected that stakeholders who believed in the need to internalize externalities from energy production would not necessarily tend to believe in end-use internalization, and vice versa. Because the statement "Governmental policies should be more concerned with helping lower-income groups than helping higher-income groups" had a marginally significant loading on the same factor, we found that respondents with high scores in this factor tended to be concerned with equity as well. Thus, we interpret that these respondents tend to believe in "ability-to-pay" internalization. Probably, when answering these questions, respondents had in mind owners of gas guzzlers more than owners of polluting old vehicles.

The analysis of secondary policy preferences (levels of support for specific policy tools) identified three salient issues: regulatory mandates, internalizing taxes, and reduction of obstacles to commercialization. The latter comprises a set of fundamentally different policy measures that are that are linked by a common philosophy: facilitating the commercialization of hydrogen vehicles by addressing the main issues, like putting in place a refueling infrastructure, improve the core technologies, providing economic incentives to market introduction, and reducing insurance liability.

The stakeholder organizations' interests tend to center on three areas or technologies: transportation applications of hydrogen, fuel cells, and plug-in drivetrain technologies. The first two factors are interesting in that they load on some of the same variables. This is in fact a natural result that reflects the reality of the policy debate. Many stakeholders have an interest in the success of hydrogen, others in the success of fuel cells, and yet many of them have an interest in both hydrogen and fuel cells. For instance, a company with a hydrogen internal combustion agenda will not necessarily be interested in the success fuel cells. By the same token, a manufacturer of portable fuel cells would not necessarily be interested in the success of hydrogen since portable fuel cells often use methanol. Other organizations have an interest in the success of both hydrogen and fuel cells, and therefore will have high scores in both the *hydrogen in transportation* and *fuel cell applications* factors.

The debate over the short-term pathways to produce hydrogen is clearly divided between those who support production from renewable sources of energy and those who support production from fossil fuels. This result was expected. What is perhaps less intuitive is that support for production from coal and/or from natural gas fall in the same factor, regardless of whether production involves carbon capture and sequestration or not.

The analysis of beliefs about the impact of different technologies on the market introduction of fuel-cell vehicles yielded three factors: *hybrid-to-fuel cell impact*, *fuel cell-to-fuel cell impact*, and *hydrogen-to-fuel cell impact*. This analysis essentially captures the map of beliefs about transitional technologies. A group of stakeholders believes that gasoline hybrid electric vehicles would better help transition to fuel-cell vehicles, while other group believes that this would be better done by vehicles that consume hydrogen.

While the one-factor solution of the research policy preferences does not provide much to elaborate on, the analysis of the education policy beliefs is rich in insights. Stakeholders' beliefs tend to center on target populations rather than on education areas. The *pro education action* factor represents the belief that education programs should be implemented in all areas. Stakeholders with high negative scores in this factor are opposed to policies to educate any population about hydrogen, probably because of considering it premature or because they do not hold strong beliefs about the future of hydrogen adoption. The *no opinion on education* represents groups without sufficient information to make a judgment about education policy in any area. The *consumer education* factor represents the belief that education programs should be implemented that target consumers and that such programs should cover all three areas: safety, societal benefits, and value of hydrogen vehicles. The *young population education* factor indicates the existence of a salient belief regarding the importance of educating the "consumers of the future."

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