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Willingness to Pay to Avoid Outages: Reliability Demand Survey

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By

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I. Introduction

In recent years, electricity has become ever more vital to our economy and our everyday life. Disruptions to electricity delivery are becoming more and more costly. Our communication and information systems—for example, email, cell phones, computers—require electricity. Our payment systems, e.g., credit card processing, require electricity. Our transportation systems, including metro systems and gasoline station pumps, require electricity. Much of our business and industry depends on electricity, from our computer systems to assembly lines. Even our books are increasingly read on electronic devices. The future promises to continue the trend toward more and more vital functions becoming dependent on electricity, e.g., electric vehicles. At the same time, our electrical grid is aging and requires investment to avoid increasing reliability problems. This investment was recently estimated at $673 billion by the American Society of Civil Engineers.[1]

The Reliability Demand Survey (RDS), a recent survey sponsored by Build Energy America, Potomac Communications Group, and YouGov/Definitive Insight, made clear the importance that residential customers attach to reliability. Of more than 500 respondents, 95% said either that outages should be "very rare" or that there should be no outages except for those related to major storms or extreme weather. Additionally, 64% responded that power outages lasting for more than 24 hours cause "really significant problems" for their households. The same survey showed that 62% of customers would not find it acceptable for there to be multiple two-day outages per year even if they were paid $500 per outage, while 37% would not find it acceptable even if they were paid $1000 per outage. And further, 45% of customers would pay a monthly fee of between $10 and $40 to ensure that they would never experience an outage lasting for more than four hours. Despite this, almost three-quarters of the survey respondents reported having experienced an outage in the previous year. These customers reported experiencing an average of four outages during that year.

Who are the customers that demand highly reliable electricity service? What are their observable characteristics? What has been their outage experience? What problems do they experience during an outage? Can we quantify the value of reliable electricity service to different groups of customers? Answering these questions helps us to understand the factors that make reliable electricity so important, to target programs to different customer groups, and to determine the value provided by expenditures that enhance reliability.

The RDS gathers information about the value that respondents place on reliable electricity, their demographic characteristics, their attitudes, their outage experience, and the problems they face

[1] Ashley Halsey, "Nation's aging electrical grid needs billions of dollars in investment, report says," *Washington Post,* April 26, 2012.

during an outage. This paper focuses on the relationship between the value that customers place on reliable electricity, their demographic characteristics, and their outage experience. It is the first in a series that reports on on-going analysis of the RDS survey. Because the analysis is on-going, future analysis may augment or update the results in this paper.

Key findings about the respondents and their demand for reliable service are the following:

1. Respondents demand a high level of reliability. Many of them experience significant problems if outages last several hours. Most of them experience significant problems if outages last more than 12 hours. Yet the level of reliability that many customers report experiencing is somewhat less than they expect.

2. The value that customers place on reliability differs greatly. Some of the characteristics that we examine are associated with these differing values, but many are not.

3. The variation in the value of reliability by customer characteristics differs depending on the type of outage. Customers who are willing to pay more to avoid multiple shorter outages are not necessarily the same customers who highly value reliability when faced with a multi-day outage.

4. When looked at in isolation, some customer characteristics are informative about the value that customers place on reliability, but many are not. One of the few characteristics that is consistently important in distinguishing customers' value of reliability is the region they live in. Age, number of bedrooms in their home, education level, and having their own generation are characteristics that are also important, as is previous experience with outages.

5. When combinations of multiple characteristics are examined, we find that we are better able to identify attributes of customers that are associated with their value of reliability. However, there is still considerable heterogeneity across customers.

II. The survey

The Reliability Demand Survey (RDS) was a national opinion survey of over 500 Americans that was conducted in April 2012. It was jointly sponsored by Build Energy America and Potomac Communications Group of Washington, DC and conducted by YouGov Definitive Insights of Portland, OR. The survey contained 134 questions, including the parts of multi-part questions. It contained questions about customers' experience with outages, the problems they experience as the result of outages, their attitudes, and their demographic characteristics. Importantly, it contained a series of questions about customers' willingness to pay to avoid outages and their willingness to be paid to volunteer for lengthy interruptions.

In this paper, we focus on two questions about the value customers place on reliable electricity. The first[2] question analyzed below asked if they would be willing to experience an outage of two days if they were paid amounts ranging from $250 to $1000 per interruption. The second question analyzed below asked if they were willing to pay amounts that ranged from $10 to $40 per month to ensure that they would never experience an outage of more than four hours.

III. Analysis approach and results

Our analysis of the survey data consists of three phases. First, we examine customers' outage experience, the problems that customers experience, and their attitudes toward outages. As detailed below, we find that customers generally demand a high level of reliability, yet the number of outages reported by a sizeable proportion of customers is somewhat greater than they think they should be experiencing.

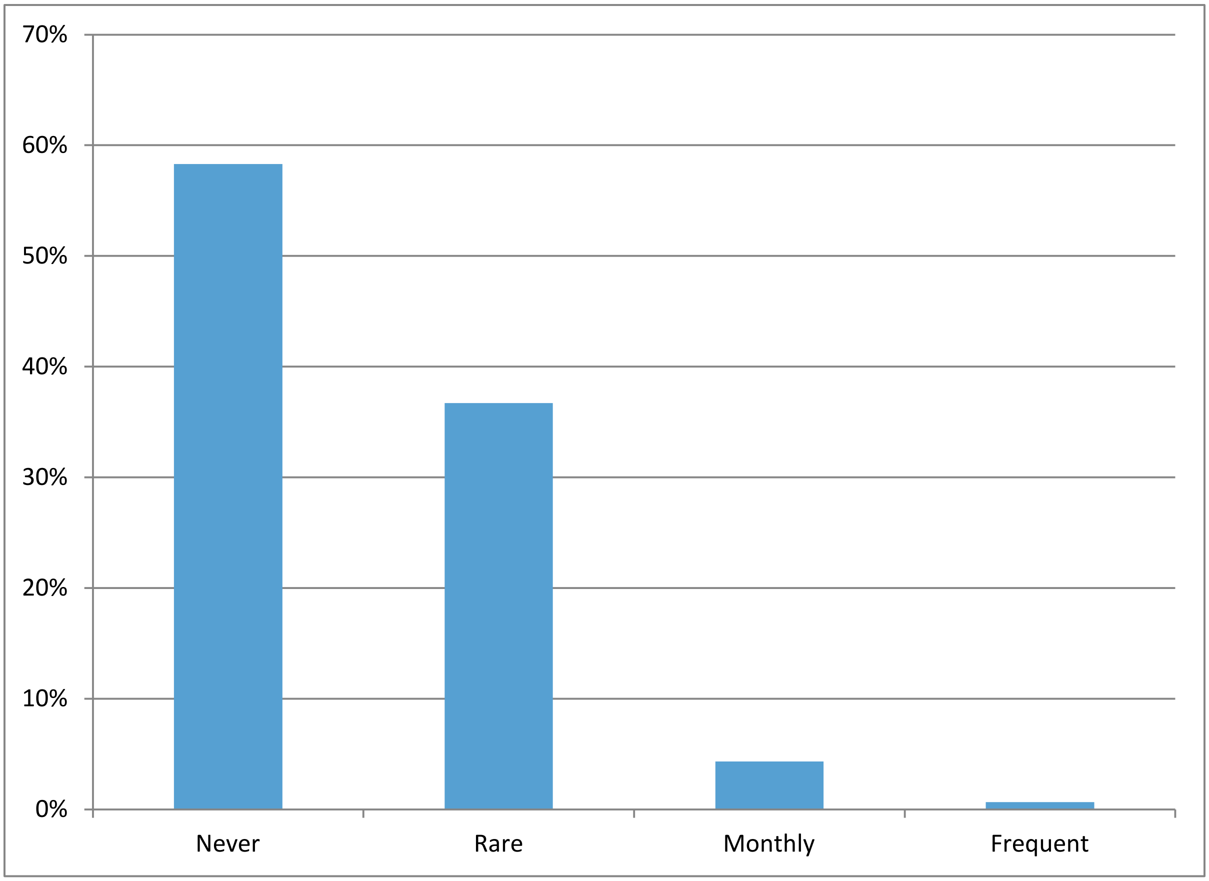
Second, we examine the relationship between individual customer characteristics and the value customers placed on reliability measured as their willingness to pay to avoid outages or the amount that they would require to be paid to accept an outage. Third, we examine the relationship between combinations of individual customer characteristics and customer willingness to pay to avoid outages or the amount they would require to be paid to accept an outage. We find that combinations of customer characteristics are more revealing than are single characteristics of customer groups that highly value of reliability. Yet there is still considerable heterogeneity among customer groups that is not explained by the customer characteristics we analyze.

III.A. Outage experience and problems experienced

The survey respondents made clear the importance that they accorded reliable electricity service. As shown in Figure 1, 95% of respondents said that either outages should be "very rare" or that there should be no outages except for those related to major storms or extreme weather.

[2] The questions were actually asked in the reverse order to that presented above but are analyzed below in the order given in the text.

Figure 1: How frequently is it acceptable for power outages to occur?



Yet 72% of the respondents reported that they had experienced an outage (either weather-related or non-weather-related) in the preceding year. Of those who experienced an outage, the average number of outages experienced was four. Figures 2 and 3 show the distributions of outages experienced by those respondents who had an outage. While “very rare” is not defined in the survey, a reasonable definition might be greater than one or two outages. A majority of customers who experienced at least one non-weather-related outage experienced more than one non-weather-related outage, and more than one-third experienced more than two outages.

Figure 2: Number of non-weather-related outages for respondents who experienced at least one non-weather-related outage

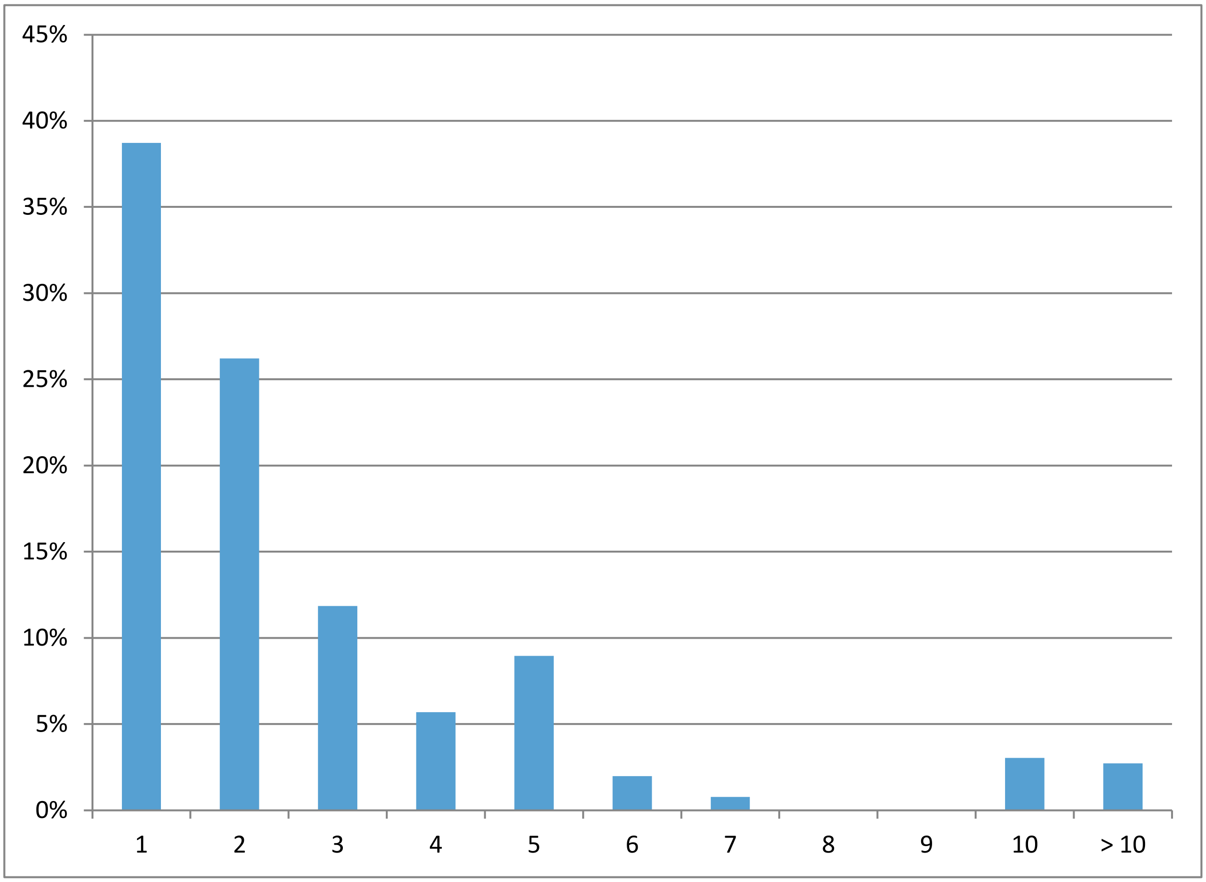
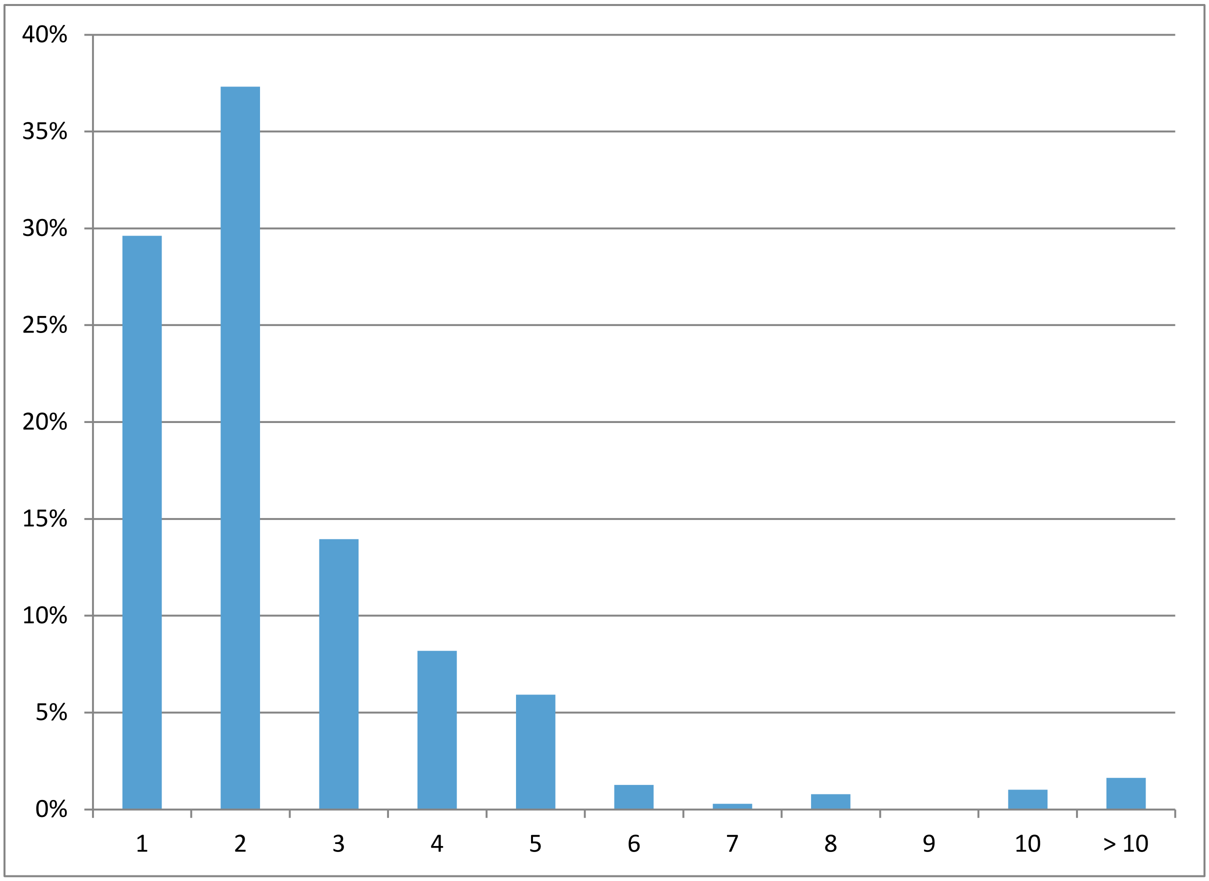
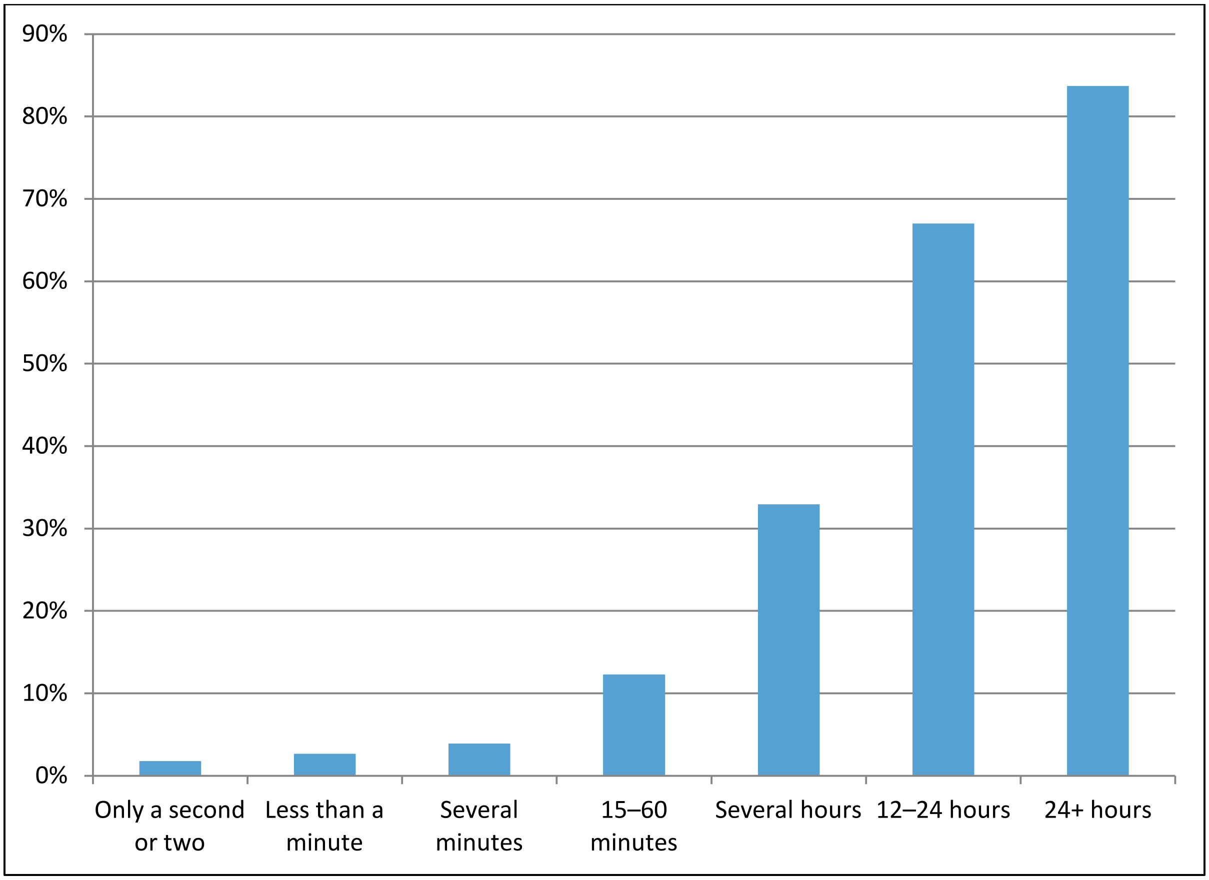


Figure 3: Number of weather-related outages for respondents who experienced at least one weather-related outage



The length of the outage affects the problems that it causes customers. As shown in Figure 4, one-third of respondents reported significant problems during outages lasting several hours, two-thirds reported significant problems during outages lasting 12–24 hours, and 84% reported significant problems during outages greater than a day.

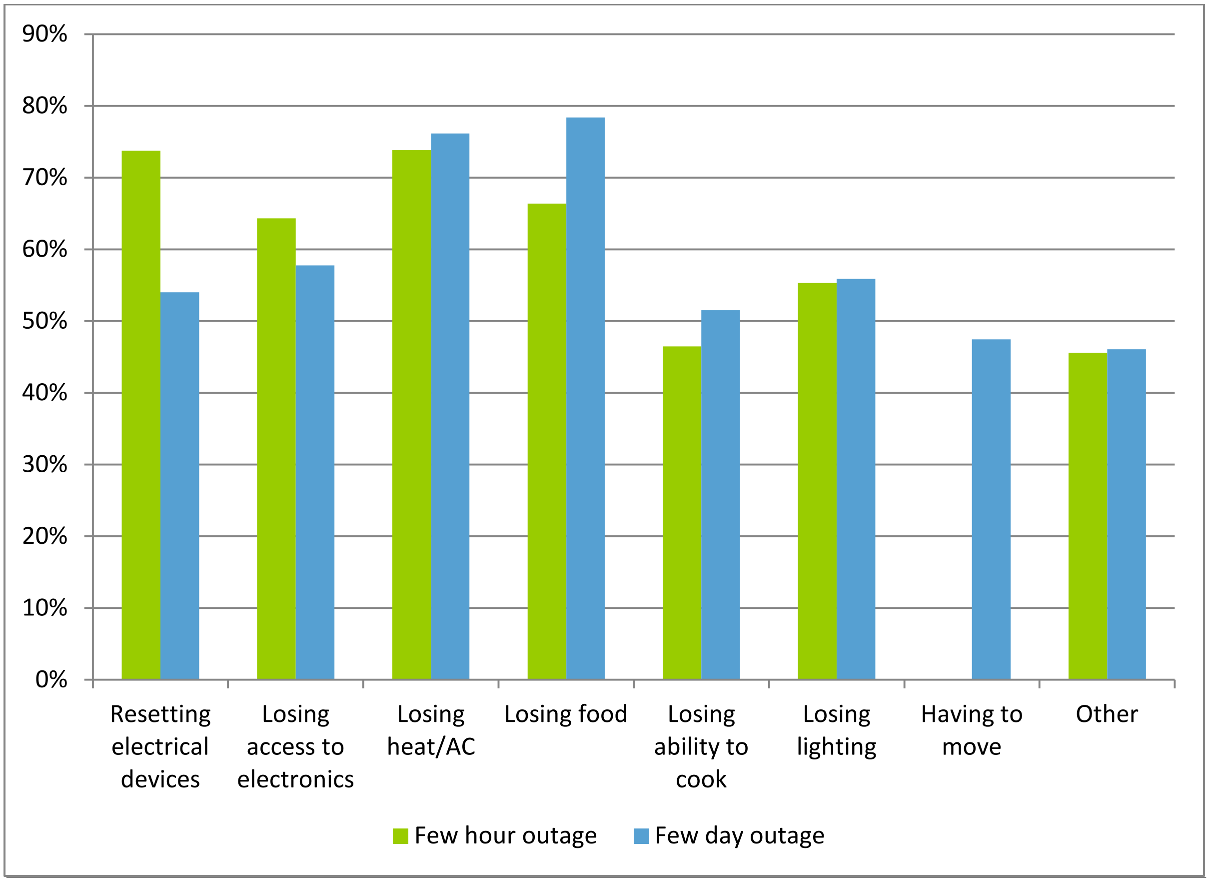
Figure 4: When are outages significant problems?



While the majority of respondents experienced outages of less than four hours, a sizeable number of respondents experienced outages of lengths that caused them significant problems. Twenty-two percent of respondents experienced weather-related outages of between 4 and 24 hours, and 11% experienced weather-related outages of one day or more.

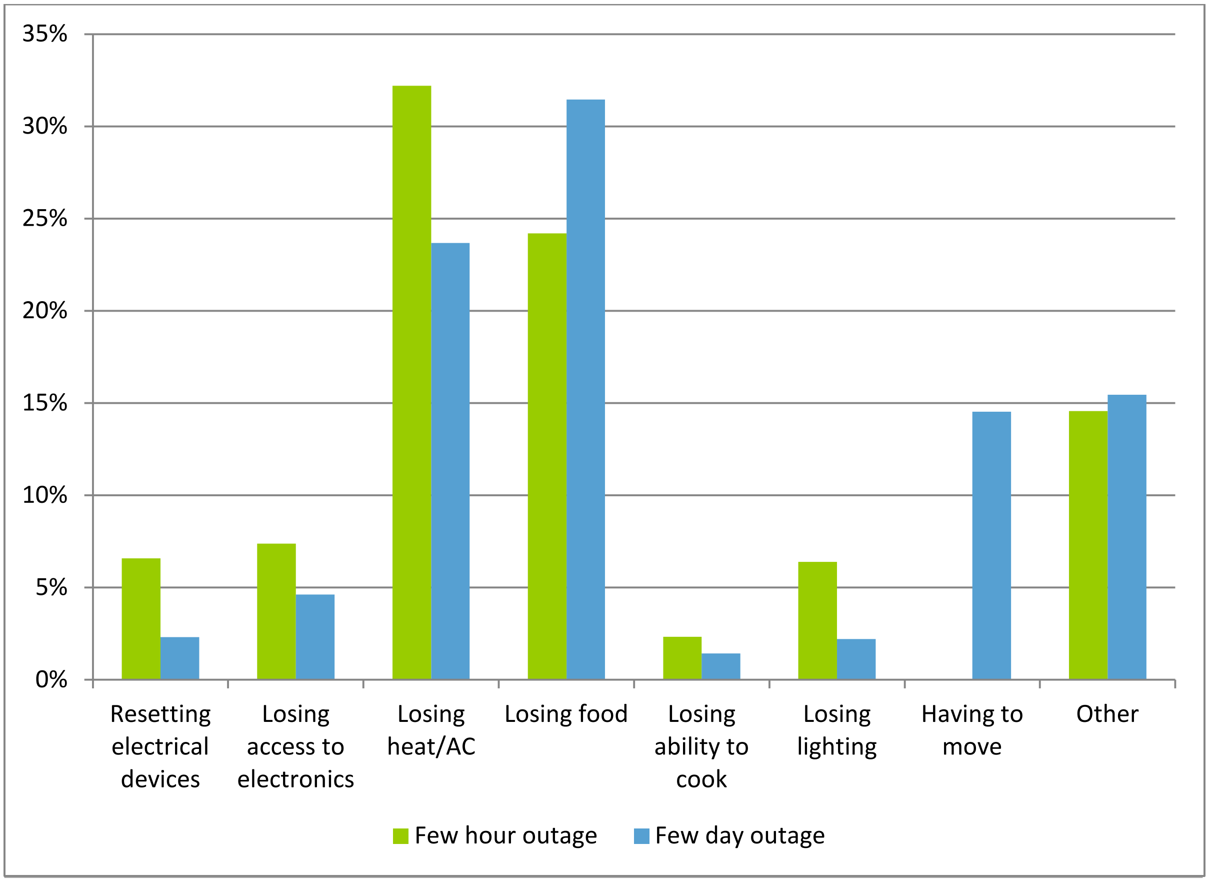
The survey respondents also reported on the problems that outages cause for their households. For both outages lasting a few hours and several days, they reported these problems and then picked the single most important problem. As we see in Figure 5, for both outages lasting a few hours or a few days, losing heat or air conditioning is a big problem for three-quarters of the respondents. Losing the food in the refrigerator is also a problem. Figure 6 shows that these are the most often reported single most important problems. Reflecting the growing importance of electronics in our lives, 64% of respondents report that losing access to various electronics is a problem for both multi-hour and multi-day outages.

Figure 5: What are the various hassles associated with outages?



When asked to pick the single greatest problem, as shown in Figure 6, losing heat or air conditioning and losing food were the two biggest problems. Having to move out (for multi-day outages) and "other" were the next two categories named. Compared to these problems, the other categories were cited by fewer respondents.

Figure 6: What is the single biggest hassle associated with outages?



III.B. Single customer characteristics and what they reveal about the value of reliability

The demographic characteristics that were covered in the survey and examined in our analysis were age, number of bedrooms in their home, educational level, type of secondary fuel if any, whether or not they have a generator, whether they own or rent their home, income level, the number and total length of outages they have experienced (distinguished by weather- and non-weather-related causes), the region of the country in which they live, gender, whether their home was a single family home or not, and whether they worked from home (including operating a farm).[3]

Table 1 compares the average value of reliability by selected customer demographic characteristics. The average value of reliability is calculated based both on the required interruption payment and also on the willingness to pay to avoid an outage greater than four hours. The required interruption payment is calculated from a series of two questions that asked respondents if they would be willing to experience an outage of two days if they were paid amounts ranging from $250 to $1000 per interruption.[4] The willingness to pay amount is calculated from two questions that asked respondents if they were willing to pay amounts ranging from $10 to $40 per month to ensure that they would never experience an outage of more than four hours.[5]

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[3] Two of the questions—whether or not they have a generator and whether they work from home—were not asked directly but were volunteered in response to open-ended questions about the problems they face or costs they incur when they experience an outage.

[4] All respondents were asked how likely they were to participate in a program in which their utility interrupted them for two days at a time, for no more than two or three times each year, if they were paid $500 per interruption. If they responded that they were highly likely to participate, then they were asked how likely they were to participate in the program if they were paid $250 per interruption. Conversely, if they were not highly likely to participate for $500, then they were asked how likely they were to participate if they were paid $1000 per interruption. This resulted in a differentiation of respondents into groups of customers who would participate if paid $250 or less, $250–$500, $500–$1000, and more than $1000 per interruption. In analyzing the respondents' required payment, we used the midpoint of the two interior groups and assumed $200 for respondents in the lower group and $2000 for respondents in the upper group.

[5] All respondents were asked how likely they were to pay $20 per month for a solution in which their utility guaranteed that they would never experience an outage lasting longer than four hours. If they responded that they were highly likely, then they were asked how likely they were to pay $40 per month. Conversely, if they were not highly likely to participate for $20, then they were asked how likely they were to pay $10 per month. This resulted in a differentiation of respondents into groups of those who would pay less than $10, $10–$20, $20–$40, and $40 or more per month. In analyzing the respondents' willingness to pay, we used the midpoint of the two interior groups and assumed $5 for respondents in the lower group and $50 for respondents in the upper group.

Table 1: Value of reliability differentiated by selected customer characteristic

Age (Years)	< 35	35–44	45–54	55–64	65+
Required interruption payment ($/interruption)	930	955	1112	1034	1168
Willingness to pay to avoid outage ($/month)	15	16	15	19	18
Number of bedrooms	**≤1**	**2**	**3**	**4+**	
Required interruption payment ($/interruption)	901	945	1060	1115	
Willingness to pay to avoid outage ($/month)	15	17	15	19	
Education	**High school**	**College**	**Post graduate**		
Required interruption payment ($/interruption)	1053	1037	992		
Willingness to pay to avoid outage ($/month)	16	18	14		
Generator	**No**	**Yes**			
Required interruption payment ($/interruption)	1023	1199			
Willingness to pay to avoid outage ($/month)	17	8			
Region	**NE**	**S**	**MW**	**W**	
Required interruption payment ($/interruption)	1084	907	1024	1111	
Willingness to pay to avoid outage ($/month)	15	19	17	14	
Number of nonweather-related outages	**0**	**1**	**2**	**3+**	
Required interruption payment ($/interruption)	968	1069	997	1175	
Willingness to pay to avoid outage ($/month)	17	17	14	16	
Number of weather-related outages	**0**	**1**	**2**	**3+**	
Required interruption payment ($/interruption)	1022	911	1075	1104	
Willingness to pay to avoid outage ($/month)	17	16	16	16	
Length of nonweather-related outages (minutes total)	**0**	**< 20**	**20 to 120**	**> 120**	
Required interruption payment ($/interruption)	971	866	936	1314	
Willingness to pay to avoid outage ($/month)	17	18	13	15	
Length of weather-related outages (hour total)	**0**	**< 5**	**5 to 15**	**> 15**	
Required interruption payment ($/interruption)	1035	909	1066	1119	
Willingness to pay to avoid outage ($/month)	17	16	14	17	
Home ownership	**Own**	**Rent**			
Required interruption payment ($/interruption)	1071	924			
Willingness to pay to avoid outage ($/month)	17	16			
Single family home	**No**	**Yes**			
Required interruption payment ($/interruption)	972	1066			
Willingness to pay to avoid outage ($/month)	16	17			
Work from home	**No**	**Yes**			
Required interruption payment ($/interruption)	1023	1116			
Willingness to pay to avoid outage ($/month)	16	18			

Red and green numbers denote statistical significance. The statistical significance of differences between the average value of reliability for differences in each customer characteristic segment (e.g., aged less than 35 or greater than 65) were determined by using a t-test. [6] Numbers that are shown in green are significantly more than numbers in the same row that are shown in red. For example, customers who are less than 35 years old place a statistically significantly lower value on reliability as measured by the required interruption payment when compared to customers aged 65 or older.

Table 1 illustrates four aspects of the relationship between customers' value of reliability and their demographic characteristics and outage experience. First, the average value of reliability varies by certain customer characteristics. For four of the customer characteristics—age, region, and number and total length of non-weather-related outages—the variation in the average value of reliability as measured by the required interruption payment is statistically significant. Older people require a significantly higher payment for a two-day interruption than do younger people. Similarly, people who have experienced more frequent or longer-lasting non-weather-related outages in the preceding year require a significantly higher payment than those who have experienced shorter or no outages.

When measured by the willingness to pay to avoid outages longer than four hours, we find that the variation in the average value of reliability is statistically significant for four other characteristics—number of bedrooms in their home, educational level, whether or not they have a generator, and the region in which they live. Respondents living in homes with more bedrooms have a higher willingness to pay, perhaps because they have more children, which may make outages more difficult for them. People who have a generator are less likely to pay a monthly fee to avoid an outage, perhaps because their generator already provides that service for them.

Second, we find that the value of reliability varies significantly by region. In fact, region is the only characteristic for which the value of reliability is statistically significant by both measures. Third, the pattern of regional differences differs by outage type. For longer outages, respondents in the West required a higher interruption payment than those in the South. Conversely, to avoid a shorter outage, respondents in the South were willing to pay more than those in the West or Northeast. This suggests that different categories of customers view the two types of outages differently.

Fourth, these observations together indicate that there is substantial heterogeneity among customers. Customer reliability value differs by certain demographic characteristics and outage experience. It differs by region. And it differs by type of outage. Further, for many other customer characteristics, the variation in the value of reliability is not statistically significant. This also suggests that there is considerable variation in the value of reliability within these customer segments.[7] In general,

[6] A standard level of statistical significance of 5% is used.

[7] Thus, the precision with which we are able to measure differences in the value of reliability based on a single characteristic is somewhat limited.

different customers have different needs, expectations, and patterns of electricity usage, all of which affect the value that they place on reliability. Some of this heterogeneity is unobserved or not captured by looking at a single customer characteristic at a time. In the next section, we expand our analysis to look at multiple customer characteristics.

III.C. Combinations of customer characteristics and what they reveal about the value of reliability

Table 2a displays the average required interruption payment for selected customer categories defined by two characteristics—for example, age and number of bedrooms. For comparison purposes, in the first row, it repeats the numbers shown in Table 1 (the average required interruption payment for customer categories without controlling for a second customer characteristic). The remaining cells contain the average required interruption payment for customer categories defined by two characteristics, with the two characteristics identified in the row and column headings.

Key findings that emerge from the study of Tables 2a and 2b include the following. The first row of Table 2a, which shows the average required interruption payment distinguished by only one customer characteristic, is generally a shade of yellow indicating moderate required interruption payments compared to the higher and lower required payments in the rest of the table. However, there are exceptions. For example, for longer non-weather-related outages, the numbers are often shown in a light green, indicating a higher average required interruption payment.

Likewise, the first row of Table 2b, showing the average willingness to pay to avoid an outage longer than four hours, is distinguished by only one customer characteristic. It is also generally a shade of yellow, indicating moderate willingness to pay. An exception is customers with a generator, who are less willing to pay to avoid an interruption, perhaps (as noted above) because their generator already provides that service.

Table 2a: Value of reliability (required interruption payment) differentiated by two selected customer characteristics

		Age					Number of bedrooms				Generator		Own or rent		Number of nonstorm outages				Total length of all nonstorm outages (minutes)				Region				Number of storm outages				Total length of all storm outages (hours)				Single family home?		Work from home?	
		< 35	35 - 44	45 - 54	55 - 64	65+	1	2	3	4+	No	Yes	Own	Rent	0	1	2	3+	0	1 - 20	20 - 120	> 120	Midwest	Northeast	South	West	0	1	2	3+	0	up to 5	5 - 15	> 15	No	Yes	No	Yes
Single characteristic		930	955	1112	1034	1168	901	945	1060	1115	1023	1199	1071	924	968	1069	997	1175	971	866	936	1314	1024	1084	907	1111	1022	911	1075	1104	1035	909	1066	1119	972	1066	1023	1116
Age	< 35	930					909	915	940	955	930		920	942	887	887	1065	958	865	889	797	1243	1014	1200	784	785	943	876	733	1055	963	710	828	1029	929	931	931	913
	35 - 44		955				1063	1046	869	1021	959		966	935	902	1057	1011	883	940	903	768	1132	799	1094	902	947	940	1023	906	990	929	1120	753	965	989	931	962	890
	45- 54			1112			968	441	1131	1463	1112	1102	1207	680	928	1253	1163	1226	943	775	1213	1495	1196	1026	828	1282	1171	935	1093	1188	1201	805	1300	1208	853	1189	1120	995
	55 -64				1034		933	1036	1090	1008	996		1071	924	890	1212	620	1410	895	1224	790	1402	1081	950	772	1438	1068	857	1194	924	1068	908	1298	961	936	1074	1003	1474
	65+					1168	493	1247	1220	1112	1174		1157	1290	1291	970	890	1281	1312	604	939	1242	888	1085	1255	1442	1123	891	1283	1397	1136	1134	1076	1360	1224	1144	1139	
Number of bed-rooms	1	909	1063	968	933	493	901				905		1275	838	1071	604	692		1071	559		1045	1085	813	1023	759	853	894		1115	917	958		939	888		973	521
	2	915	1046	441	1036	1247		945			942		877	1032	969	1023	607	1034	994	572	861	1170	874	1102	903	918	982	734	970	956	991	782	1104	944	993	824	959	707
	3	940	869	1131	1090	1220			1060		1061	1026	1081	920	948	1159	1034	1267	964	1082	962	1318	1017	1176	851	1226	1013	920	1063	1269	1019	1060	963	1219	1003	1076	1040	1628
	4+	955	1021	1463	1008	1112				1115	1090		1149	874	944	1337	1327	1154	913	1089	1185	1451	1133	1036	941	1295	1165	1023	1226	925	1165	780	1478	1126	1070	1121	1075	1611
Generator	No	930	959	1112	996	1174	905	942	1061	1090	1023		1066	920	962	1048	1012	1169	968	839	935	1313	1015	1083	905	1100	1026	880	1065	1094	1038	880	1044	1123	979	1053	1017	1116
	Yes			1102					1026			1199	1172		1119				1056				1224	1113			873	1339			873					1307	1199	
Own or rent	home_own	920	966	1207	1071	1157	1275	877	1081	1149	1066	1172	1071		978	1190	955	1266	991	1025	1019	1278	1042	1060	929	1287	1071	858	1142	1156	1079	934	1158	1138	1050	1077	1058	1281
	home_rent	942	935	680	924	1290	838	1032	920	874	920			924	945	833	1134	834	928	516	712	1445	939	1129	845	789	913	1019	845	936	938	848	833	1048	913	964	935	798
Number of nonstorm outages	0	887	902	928	890	1291	1071	969	948	944	962	1119	978	945	968				968				815	966	865	1229	1032	743	977	931	1041	800	918	921	971	966	961	1118
	1	887	1057	1253	1212	970	604	1023	1159	1337	1048		1190	833		1069				860	955	1312	1156	1134	833	1119	979	1004	1242	1087	979	1291	1265	834	911	1191	1072	1019
	2	1065	1011	1163	620	890	692	607	1034	1327	1012		955	1134			997			722		1261	1007	1349	716	964	903	1595	947	935	931	863		1294	989	1001	1029	726
	3+	958	883	1226	1410	1281		1034	1267	1154	1169		1266	834				1175	981	1037	993	1357	1475	1224	1152	928	1174	885	1128	1316	1200	803	1220	1362	1056	1229	1140	1477
Total length of nonstorm outages (minutes)	0	865	940	943	895	1312	1071	994	964	913	968	1056	991	928	968			981	971				814	1004	868	1188	1047	703	966	1002	1065	776	918	891	957	981	965	1118
	1 - 20	889	903	775	1224	604	559	572	1082	1089	839		1025	516		860	722	1037		866			1093	952	700	739	822	835	876	956	822	911	712	984	617	1059	931	432
	20 - 120	797	768	1213	790	939		861	962	1185	935		1019	712		955		993			936		881	1233	820	858	811	889	1088	1144	811	1130	750	1082	924	942	936	
	> 120	1243	1132	1495	1402	1242	1045	1170	1318	1451	1313		1278	1445		1312	1261	1357				1314	1423	1257	1251	1312	1204	1681	1360	1295	1212	1174	1569	1389	1352	1295	1270	1690
Region	Midwest	1014	799	1196	1081	888	1085	874	1017	1133	1015	1224	1042	939	815	1156	1007	1475	814	1093	881	1423	1024				1016	842	838	1472	1016	979	799	1440	936	1057	1009	1226
	Northeast	1200	1094	1026	950	1085	813	1102	1176	1036	1083	1113	1060	1129	966	1134	1349	1224	1004	952	1233	1257		1084			1232	938	1057	991	1247	981	897	1016	1143	1041	1093	930
	South	784	902	828	772	1255	1023	903	851	941	905		929	845	865	833	716	1152	868	700	820	1251			907		834	946	1000	953	888	808	1254	986	944	881	915	743
	West	785	947	1282	1438	1442	759	918	1226	1295	1100		1287	789	1229	1119	964	928	1188	739	858	1312				1111	1051	879	1533	1205	1044	941	1648	1303	864	1312	1086	1377
Number of storm outages	0	943	940	1171	1068	1123	853	982	1013	1165	1026	873	1071	913	1032	979	903	1174	1047	822	811	1204	1016	1232	834	1051	1022				1022				955	1079	1026	950
	1	876	1023	935	857	891	894	734	920	1023	880	1339	858	1019	743	1004	1595	885	703	835	889	1681	842	938	946	879		911				816	1051	1018	882	935	866	1397
	2	733	906	1093	1194	1283		970	1063	1226	1065		1142	845	977	1242	947	1128	966	876	1088	1360	838	1057	1000	1533			1075			1053	1110	1063	1008	1102	1068	1212
	3+	1055	990	1188	924	1397	1115	956	1269	925	1094		1156	936	931	1087	935	1316	1002	956	1144	1295	1472	991	953	1205				1104	1638	855		1178	1172	1082	1106	1086
Total length of Storm outages (hours)	0	963	929	1201	1068	1136	917	991	1019	1165	1038	873	1079	938	1041	979	931	1200	1065	822	811	1212	1016	1247	888	1044	1022				1035				974	1086	1039	950
	1 - 5	710	1120	805	908	1134	958	782	1060	780	880		934	848	800	1291	863	803	776	911	1130	1174	979	981	808	941		816	1053	855		909			757	1003	929	654
	5 - 15	828	753	1300	1298	1076		1104	963	1478	1044		1158	833	918	1265		1220	918	712	750	1569	799	897	1254	1648		1051	1110				1066		1074	1064	1034	
	> 15	1029	965	1208	961	1360	939	944	1219	1126	1123		1138	1048	921	834	1294	1362	891	984	1082	1389	1440	1016	986	1303		1018	1063	1178				1119	1213	1082	1075	1452
Single family home?	No	929	989	853	936	1224	888	993	1003	1070	979		1050	913	971	911	989	1056	957	617	924	1352	936	1143	944	864	955	882	1008	1172	974	757	1074	1213	972		992	715
	Yes	931	931	1189	1074	1144		824	1076	1121	1053	1307	1077	964	966	1191	1001	1229	981	1059	942	1295	1057	1041	881	1312	1079	935	1102	1082	1086	1003	1064	1082		1066	1043	1421
Work from home?	No	931	962	1120	1003	1139	973	959	1040	1075	1017	1199	1058	935	961	1072	1029	1140	965	931	936	1270	1009	1093	915	1086	1026	866	1068	1106	1039	929	1034	1075	992	1043	1023	
	Yes	913	890	995	1474		521	707	1628	1611	1116		1281	798	1118	1019	726	1477	1118	432		1690	1226	930	743	1377	950	1397	1212	1086	950	654		1452	715	1421		1116

Table 2b: Value of reliability (willingness to pay to avoid outage) differentiated by two selected customer characteristics

		Age					Number of bedrooms				Generator		Own or rent		Number of nonstorm outages				Total length of all nonstorm outages (minutes)				Region				Number of storm outages				Total length of all storm outages (hours)				Single family home?		Work from home?	
		< 35	35 - 44	45 - 54	55 - 64	65+	1	2	3	4+	No	Yes	Own	Rent	0	1	2	3+	0	1 - 20	20 - 120	> 120	Midwest	Northeast	South	West	0	1	2	3+	0	up to 5	5 - 15	> 15	No	Yes	No	Yes
	Single characteristic	15	16	15	19	18	15	17	15	19	17	8	17	16	17	17	14	16	17	18	13	15	17	15	19	14	17	16	16	16	17	16	14	17	16	17	16	18
Age	< 35	15					10	20	12	15	15		15	15	18	13	10	12	18	17	8	7	16	11	16	16	16	10	15	13	16	16	11	10	15	15	15	14
	35 - 44		16				12	11	20	15	17		17	15	16	15	8	26	16	17	10	19	19	16	16	15	18	11	16	15	19	15	10	16	17	16	17	9
	45- 54			15			25	10	11	20	15	6	15	15	14	19	18	11	14	20	11	16	16	14	14	14	13	15	19	12	13	10	18	21	14	15	15	18
	55 -64				19		18	20	15	23	19		19	19	20	20	16	17	20	16	18	18	21	20	22	10	18	22	16	24	18	15	19	28	19	19	18	30
	65+					18	25	15	18	22	18		18	21	15	19	22	22	15	26	20	19	17	12	25	14	19	22	13	20	19	24	13	15	18	18	18	
Number of bed-rooms	1	10	12	25	18	25	15				15		12	15	11	18	22		11	26		8	13	11	22	12	14	14		16	13	16		17	13		15	14
	2	20	11	10	20	15		17			17		15	19	21	17	9	12	20	10	18	11	17	15	18	15	19	13	16	11	19	16	11	12	18	14	17	9
	3	12	20	11	15	18			15		15	6	15	17	15	14	12	19	15	20	12	15	16	14	17	14	17	15	12	15	17	15	10	14	18	15	15	25
	4+	15	15	20	23	22				19	19		20	10	19	20	19	17	19	19	10	20	21	18	21	15	16	18	23	24	16	16	25	24	14	19	18	23
Generator	No	15	17	15	19	18	15	17	15	19	17		17	16	17	17	14	16	17	19	13	16	18	15	19	14	17	16	16	17	17	16	14	18	16	17	17	18
	Yes			6					6			8	9		5				6				6	5			6	10			6					9	8	
Own or rent	home_own	15	17	15	19	18	12	15	15	20	17	9	17		17	17	14	16	17	16	13	17	18	15	19	14	16	18	17	17	16	17	14	19	14	17	16	20
	home_rent	15	15	15	19	21	15	19	17	10	16			16	16	16	14	18	16	24	13	10	14	15	19	16	19	11	14	12	19	13	13	11	18	10	16	14
Number of nonstorm outages	0	18	16	14	20	15	11	21	15	19	17	5	17	16	17				17				19	15	21	12	17	17	14	21	17	16	9	24	17	17	17	10
	1	13	15	19	20	19	18	17	14	20	17		17	16		17				20	14	17	17	19	18	13	17	13	18	15	17	18	16	15	15	18	17	16
	2	10	8	18	16	22	22	9	12	19	14		14	14			14			15		14	17	9	10	16	17	8	18	9	17	10		13	14	14	13	23
	3+	12	26	11	17	22		12	19	17	16		16	18				16	14	21	14	15	14	11	18	21	15	19	15	17	16	16	27	14	18	15	15	23
Total length of nonstorm outages	0	18	16	14	20	15	11	20	15	19	17	6	17	16	17			14	17				19	15	21	12	17	17	14	21	17	16	9	23	17	17	17	10
	1 - 20	17	17	20	16	26	26	10	20	19	19		16	24		20	15	21		18			19	13	23	18	23	17	13	15	23	17	12	13	21	17	19	13
	20 - 120	8	10	11	18	20		18	12	10	13		13	13		14		14			13		13	13	14	13	10	15	15	17	10	17	17	13	10	15	13	
	> 120	7	19	16	18	19	8	11	15	20	16		17	10		17	14	15				15	17	15	11	18	15	11	20	13	15	11	21	14	13	16	14	29
Region	Midwest	16	19	16	21	17	13	17	16	21	18	6	18	14	19	17	17	14	19	19	13	17	17				21	11	13	14	21	13	9	18	18	17	17	18
	Northeast	11	16	14	20	12	11	15	14	18	15	5	15	15	15	19	9	11	15	13	13	15		15			15	15	17	11	15	14	13	15	14	15	15	5
	South	16	16	14	22	25	22	18	17	21	19		19	19	21	18	10	18	21	23	14	11			19		18	18	16	22	18	18	16	22	17	20	18	26
	West	16	15	14	10	14	12	15	14	15	14		14	16	12	13	16	21	12	18	13	18				14	13	18	18	14	13	15	22	14	16	13	14	21
Number of storm outages	0	16	18	13	18	19	14	19	17	16	17	6	16	19	17	17	17	15	17	23	10	15	21	15	18	13	17				17				17	16	17	16
	1	10	11	15	22	22	14	13	15	18	16	10	18	11	17	13	8	19	17	17	15	11	11	15	18	18		16				14	15	19	12	19	16	10
	2	15	16	19	16	13		16	12	23	16		17	14	14	18	18	15	14	13	15	20	13	17	16	18			16			15	14	20	15	16	15	29
	3+	13	15	12	24	20	16	11	15	24	17		17	12	21	15	9	17	21	15	17	13	14	11	22	14				16	19	18		15	18	16	16	19
Total length of Storm outages	0	16	19	13	18	19	13	19	17	16	17	6	16	19	17	17	17	16	17	23	10	15	21	15	18	13	17			19	17				17	17	17	16
	1 - 5	16	15	10	15	24	16	16	15	16	16		17	13	16	18	10	16	16	17	17	11	13	14	18	15		14	15	18		16			15	16	16	11
	5 - 15	11	10	18	19	13		11	10	25	14		14	13	9	16		27	9	12	17	21	9	13	16	22		15	14				14		13	14	13	
	> 15	10	16	21	28	15	17	12	14	24	18		19	11	24	15	13	14	23	13	13	14	18	15	22	14		19	20	15				17	15	18	17	22
Single family	No	15	17	14	19	18	13	18	18	14	16		14	18	17	15	14	18	17	21	10	13	18	14	17	16	17	12	15	18	17	15	13	15	16		16	13
	Yes	15	16	15	19	18		14	15	19	17	9	17	10	17	18	14	15	17	17	15	16	17	15	20	13	16	19	16	16	17	16	14	18		17	16	21
Work from	No	15	17	15	18	18	15	17	15	18	17	8	16	16	17	17	13	15	17	19	13	14	17	15	18	14	17	16	15	16	17	16	13	17	16	16	16	
	Yes	14	9	18	30		14	9	25	23	18		20	14	10	16	23	23	10	13		29	18	5	26	21	16	10	29	19	16	11		22	13	21		18

By comparison, average values of reliability for customer groups defined by multiple customer characteristics display more variability than when only one characteristic is used. These are shown as the off-diagonal elements of Tables 2a and 2b. As an example, older respondents tend to have higher average required interruption payments than do younger respondents when another characteristic is held constant, such as number of bedrooms, region (South or West), or many of the outage experience variables.

When controlling for a second customer characteristic, a number of customer characteristics distinguish customers' willingness to pay. First, experiencing long non-weather-related outages tends to illicit a higher average required interruption payment than shorter interruptions. This is consistent with the results in Table 1. However, the effect is more pronounced for certain segments of the population—for example, customers who work from home. The same is true for weather-related outages, although the effect is less pronounced. It is worth noting that the trend toward lower average required interruption payments for shorter outages experienced does not necessarily extend to zero outages, which often have a higher average required interruption payment than the very short outages.

Second, when controlling for a second customer characteristic, older customers, on average, value reliability more highly than younger customers by both measures of the value of reliability. The same is true of customers with more bedrooms compared to those with fewer bedrooms, and of customers who own their home compared to those who rent.

Third, as we saw in Table 1, regional differences exist as well. Customers in the West often have a higher average required interruption payment than customers in the South. The effect is more pronounced for older people, more bedrooms, single family home or home ownership, and working from home, as well as outage experience. By contrast, customers in the South often have a higher average willingness to pay to avoid a four or more hour outage than customers in the West. Again this effect is more pronounced for older people, more bedrooms, single family home or home ownership, and working from home, as well as outage experience.

Fourth, customers who own a generator are much less willing to pay to avoid a four or more hour outage while they tend to have a somewhat higher required payment for a two-day interruption. They have already indicated their desire for reliability by purchasing a generator, but it may be costly or difficult to keep on hand sufficient fuel to run the generator for two days.

Tables 2a and 2b provide a visual display of the characteristics associated with different values of reliability. However, it is important to distinguish not only the size but also the statistical significance of differences in the average value of reliability between customer segments.

Table 3a displays customer characteristics for which there are statistically significant differences in average required interruption payments when a second customer characteristic is held constant. Table 3b provides this information for the willingness to pay to avoid an outage. Differences in a particular customer characteristic are given by the column headings in the blue rows (for example age categories). The second customer characteristic that is held constant (for example, 2 bedrooms) is given by the row headings. Within Table 3a are the average required interruption payments for the combination of the two customer characteristics.

In Tables 3a and 3b (as in Table 1), the statistical significance of the differences between the average value of reliability for each customer segment is measured by using a t-test.[8] Green numbers denote an average required interruption payment that is statistically significantly greater than that in other cells in the same row that are displayed in red. Let us take age and region as an example in the first panel of Table 3a. We see that among people living in the West, those aged 45 and older (green numbers) have a statistically significantly higher average required interruption payment than do people aged less than 45 (red numbers). In addition to the green and red color coding for statistical significance, we also use blue. Blue signifies that the value of reliability is statistically significantly greater than other cells in the same row that are displayed in red **and** that it is statistically significantly less than other cells in the same row that are displayed in green.

Key findings from Tables 3a and 3b include the following. First, the general findings in Table 1 are confirmed. For example, the required interruption payment in Table 3a is generally higher for people over 65 than for those under 35, as well as for people who have experienced more and longer outages. Similarly, the willingness to pay to avoid an outage over four hours is generally higher for respondents with four or more bedrooms, some college education, and those without a generator.

Second, we continue to find that there are significant differences by region. It is still the case that respondents in the West tend to have a higher required interruption payment but lower willingness to pay to avoid an outage over four hours than respondents in the South. In addition, there are significant regional differences involving the Midwest and Northeast.

[8] The statistical significance of the results in Tables 3a and 3b is based on a 5% significance level. That means that if we were to draw a different random sample of customers, we would expect that 95% of the results would be the same in the new sample. However, because of random variation from sample to sample, 5% of the results would be expected to differ. Thus, future work will address this econometric issue.

Table 3a: Statistically significant differences in the value of reliability (required interruption payment) differentiated by two selected customer characteristics

Age (Years)	< 35	35–44	45–54	55–64	65+
2 bedrooms	915	1046	441	1036	1247
3 bedrooms	940	869	1131	1090	1220
4+ bedrooms	955	1021	1463	1008	1112
College	908	927	1248	1061	1156
Does not own generator	930	959	1112	996	1174
Home owner	920	966	1207	1071	1157
No nonweather-related outages	887	902	928	890	1291
South	784	902	828	772	1255
West	785	947	1282	1438	1442
2 weather-related outages	733	906	1093	1194	1283
Single family home	931	931	1189	1074	1144
Don't work from home	931	962	1120	1003	1139
Work from home	913	890	995	1474	2000

Number of bedrooms	≤1	2	3	4+
Age 45–54	968	441	1131	1463
Age 65+	493	1247	1220	1112
Post graduate	716	861	952	1218
Home owner	1275	877	1081	1149
1 nonweather-related outage	604	1023	1159	1337
2 nonweather-related outages	692	607	1034	1327
nonweather-related outage length < 20 minutes	559	572	1082	1089
West	759	918	1226	1295
Weather-related outage length 5–15 hours	474	1104	963	1478
Work from home	521	707	1628	1611

Generator	No	Yes
Age 55–64	996	1800
4+ bedrooms	1090	1766
Post graduate	974	2000
1 nonweather-related outage	1048	1745
2 nonweather-related outages	1012	301
Weather-related outage length < 5 minutes	880	2000

Education	High school	College	Post graduate
Generator	919	1285	2000
Weather-related outage length < 5 hours	720	1137	724
Work from home	538	1239	1125

Region	MW	NE	S	W
Age <35	1014	1200	784	785
Age 55–64	1081	950	772	1438
Age 65+	888	1085	1255	1442
3 bedrooms	1017	1176	851	1226
Post graduate	926	1101	726	1158
No generator	1015	1083	905	1100
Home owner	1042	1060	929	1287
Home renter	939	1129	845	789
No nonweather-related outages	815	966	865	1229
3+ nonweather-related outages	1475	1224	1152	928
No weather-related outages	1016	1232	834	1051
2 weather-related outages	838	1057	1000	1533
3+ weather-related outages	1472	991	953	1205
Weather related outage length 5–15 hours	799	897	1254	1648
Single family home	1057	1041	881	1312

Number of nonweather-related outages	0	1	2	3+
Age 55–64	890	1212	620	1410
1 bedroom	1071	604	692	1326
3 bedrooms	948	1159	1034	1267
4+ bedrooms	944	1337	1327	1154
No generator	962	1048	1012	1169
Generator	1119	1745	301	1285
Home owner	978	1190	955	1266
Midwest	815	1156	1007	1475
1 weather-related outage	743	1004	1595	885
Weather-related outage length < 5 hours	800	1291	863	803
Weather-related outage length 5–15 hours	918	1265	750	1220
Weather-related outage length > 15 hours	921	834	1294	1362
Single family home	966	1191	1001	1229

Number of weather-related outages	0	1	2	3+
Home owner	1071	858	1142	1156
No nonweather-related outages	1032	743	977	931
2 nonweather-related outages	903	1595	947	935
Nonweather-related outage length > 120 minutes	1204	1681	1360	1295
Midwest	1016	842	838	1472
West	1051	879	1533	1205
Weather-related outage length 5–15 hours		1051	1110	656

Length of nonweather-related outages (minutes total)	0	< 20	20–120	> 120
Age <35	865	889	797	1243
Age 45–54	943	775	1213	1495
Age 55–64	895	1224	790	1402
Age 65+	1312	604	939	1242
High school	978	889	962	1344
College	973	980	956	1254
Post graduate	958	706	875	1393
1 bedroom	1071	559	568	1045
2 bedrooms	994	572	861	1170
3 bedrooms	964	1082	962	1318
4+ bedrooms	913	1089	1185	1451
No generator	968	839	935	1313
Home owner	991	1025	1019	1278
Renter	928	516	712	1445
1 nonweather-related outage		860	955	1312
2 nonweather-related outages		722	612	1261
Midwest	814	1093	881	1423
South	868	700	820	1251
West	1188	739	858	1312
No weather-related outages	1047	822	811	1204
1 weather-related outage	703	835	889	1681
2 weather-related outages	966	876	1088	1360
Weather-related outage length 5–15 hours	918	712	750	1569
Weather-related outage length > 15 hours	891	984	1082	1389
Not single family home	957	617	924	1352
Single family home	981	1059	942	1295
Don't work from home	965	931	936	1270
Work from home	1118	432		1690

Length of weather-related outages (hour total)	0	< 5	5–15	> 15
1 bedroom	917	958	474	939
4+ bedrooms	1165	780	1478	1126
High school	1122	720	1037	1176
Post graduate	982	724	1188	1297
No generator	1038	880	1044	1123
Generator	873	2000	1306	1047
2 nonweather-related outages	931	863	750	1294
3+ nonweather-related outages	1200	803	1220	1362
Midwest	1016	979	799	1440
West	1044	941	1648	1303
3+ weather-related outages	1638	855	656	1178
Not single family home	974	757	1074	1213

Home ownership	Own	Rent
Age 45–54	1207	680
1 nonweather-related outage	1190	833
3+ nonweather-related outages	1266	834
Nonweather-related outage length < 20 minutes	1025	516
West	1287	789

Single family home	No	Yes
Nonweather-related outage length < 20 minutes	617	1059
West	864	1312
Work from home	715	1421

Work from home	No	Yes
Age 65+	1139	2000
1 bedroom	973	521
3 bedrooms	1040	1628
4+ bedrooms	1075	1611
High school	1064	538
Nonweather-related outage length < 20 minutes	931	432
Nonweather-related outage length > 120 minutes	1270	1690

Table 3b: Statistically significant differences in the value of reliability (willingness to pay to avoid outage) differentiated by two selected customer characteristics

Age (Years)	< 35	35–44	45–54	55–64	65+
1 bedroom	10	12	25	18	25
2 bedrooms	20	11	10	20	15
3 bedrooms	12	20	11	15	18
College	16	18	17	18	22
Post graduate	12	13	11	22	13
No generator	15	17	15	19	18
2 nonweather-related outages	10	8	18	16	22
3+ nonweather-related outages	12	26	11	17	22
Nonweather-related outage length > 120 minutes	7	19	16	18	19
Northeast	11	16	14	20	12
South	16	16	14	22	25
1 weather-related outage	10	11	15	22	22
Weather-related outage length < 5 hours	16	15	10	15	24
Weather-related outage length > 15 hours	10	16	21	28	15
Work from home	14	9	18	30	30
Number of bedrooms	**≤1**	**2**	**3**	**4+**	
Age <35	10	20	12	15	
Age 45–54	25	10	11	20	
College	14	19	17	21	
Post graduate	12	10	12	19	
No generator	15	17	15	19	
Home owner	12	15	15	20	
Home renter	15	19	17	10	
No nonweather-related outages	11	21	15	19	
2 nonweather-related outages	22	9	12	19	
3+ nonweather-related outages	10	12	19	17	
Nonweather-related outage length < 20 minutes	26	10	20	19	
Nonweather-related outage length > 120 minutes	8	11	15	20	
2 weather-related outages	19	16	12	23	
3+ weather-related outages	16	11	15	24	
Weather-related outage length 5–15 hours	20	11	10	25	
Weather-related outage length > 15 hours	17	12	14	24	
Single family home	31	14	15	19	
Work from home	14	9	25	23	
Generator	**No**	**Yes**			
Age 35–44	17	7			
Age 45–54	15	6			
2 bedrooms	17	7			
3 bedrooms	15	6			
High school	17	7			
College	18	9			
Home owner	17	9			
No nonweather-related outages	17	5			
Non-eatherwrelated outage length > 120 minutes	16	7			
Midwest	18	6			
Northeast	15	5			
No weather-related outages	17	6			
3+ weather-related outages	17	6			
Weather-related outage length > 15 hours	18	6			
Single family home	17	9			
Doesn't work from home	17	8			

Region	MW	NE	S	W
Age 55–64	21	20	22	10
Age 65+	17	12	25	14
1 bedroom	13	11	22	12
High school	19	15	18	12
No generator	18	15	19	14
Home owner	18	15	19	14
No nonweather-related outages	19	15	21	12
3+ nonweather-related outages	14	11	18	21
No weather-related outages	21	15	18	13
3+ weather-related outages	14	11	22	14
Weather-related outage length 5–15 hours	9	13	16	22
Single family home	17	15	20	13
Doesn't work from home	17	15	18	14
Work from home	18	5	26	21

Education	High school	College	Post graduate
Age 65+	14	22	13
2 bedrooms	18	19	10
3 bedrooms	15	17	12
4+ bedrooms	14	21	19
No generator	17	18	14
Home owner	14	19	15
Home renter	20	16	11
Nonweather-related outage length < 20 minutes	23	21	13
No weather-related outages	19	18	12
Weather-related outage length < 5 hours	15	19	12
Weather-related outage length > 15 hours	12	17	24
Not a single family home	18	17	12
Doesn't work from home	16	18	14

Number of nonweather-related outages	0	1	2	3+
Age <35	18	13	10	12
Age 35–44	16	15	8	26
Age 45–54	14	19	18	11
2 bedrooms	21	17	9	12
3 bedrooms	15	14	12	19
Northeast	15	19	9	11
South	21	18	10	18
West	12	13	16	21
1 weather-related outage	17	13	8	19
3+ weather-related outages	21	15	9	17
Weather-related outage length 5–15 hours	9	16	10	27
Weather-related outage length > 15 hours	24	15	13	14
Work from home	10	16	23	23

Number of weather-related outages	0	1	2	3+
Age <35	16	10	15	13
2 bedrooms	19	13	16	11
3 bedrooms	17	15	12	15
High school	19	13	13	13
Post graduate	12	15	13	21
Home renter	19	11	14	12
2 nonweather-related outages	17	8	18	9
Nonweather-related outage length > 120 minutes	15	11	20	13
Midwest	21	11	13	14
Not single family home	17	12	15	18

Length of nonweather-related outages (minutes total)	0	< 20	20–120	> 120
Age <35	18	17	8	7
1 bedroom	11	26	14	8
2 bedrooms	20	10	18	11
4+ bedrooms	19	19	10	20
Home renter	16	24	13	10
South	21	23	14	11
No weather-related outages	17	23	10	15
Weather-related outage length 5–15 hours	9	12	17	21
Weather-related outage length > 15 hours	23	13	13	14
Not single family home	17	21	10	13
Don't work from home	17	19	13	14
Work from home	10	13		29

Length of weather-related outages (hour total)	0	< 5	5–15	> 15
Age <35	16	16	11	10
Age 35-44	19	15	10	16
Age 45–54	13	10	18	21
Age 55–64	18	15	19	28
Age 65+	19	24	13	15
2 bedrooms	19	16	11	12
3 bedrooms	17	15	10	14
4+ bedrooms	16	16	25	24
High school	19	15	11	12
Post graduate	12	12	9	24
Home renter	19	13	13	11
No nonweather-related outages	17	16	9	24
3+ nonweather-related outages	16	16	27	14
Midwest	21	13	9	18
West	13	15	22	14

Home ownership	Own	Rent
4+ bedrooms	20	10
Nonweather-related outage length > 120 minutes	17	10
Weather-related outage length > 15 hours	19	11
Single family home	17	10

Single family home	No	Yes
1 bedroom	13	31
Home renter	18	10
1 weather-related outage	12	19

Work from home	No	Yes
Age 55–64	18	30
Age 65+	18	30
2 bedrooms	17	9
No nonweather-related outages	17	10
Nonweather-related outage length > 120 minutes	14	29
Northeast	15	5

Third, we continue to find that for some characteristics, there are different patterns for different types of outages. This applies to ownership of a generator, region, education level, and a number of either weather- or non-weather-related outages. For customers who have not experienced an outage of either type, their required interruption payment tends to be lower, but their willingness to pay to avoid an outage longer than four hours tends to be higher than customers who have experienced one or more outages.

Fourth, distinguishing customers by multiple characteristics identifies more customer segments for which differences in the value of reliability are significance. For example, we find many segments of customers for which the required interruption payment is higher for three or more bedrooms than for two or fewer bedrooms, although this difference was not statistically significant in Table 1. It also allows us to hone in on those segments for which the statistically significant findings in Table 1 hold. For example, while the required interruption payment is higher for older than for younger respondents in Table 1, we see that that finding holds for some but not all customer characteristics.

As shown in this discussion of Tables 3a and 3b, there are a number of characteristics that, when observed in combination, can distinguish those customers that value reliability more highly from those who place less value on reliability. To further distill this information, we ask a final question: Which of the customer characteristics are most helpful in predicting customers' value of reliability?

We answer this question by using an econometric technique called cross-validation regression. Cross-validation is a technique that identifies the most important variables for out-of-sample prediction without over-fitting the regression to the particular sample at hand. It ensures that the results are statistically valid and suitable for prediction for another sample of customers.[9]

The cross validation regressions contain both individual customer characteristics and products of customer characteristics. The former can be thought of as analogous to Table 1, while the latter is the regression analogue of looking at two characteristics in Tables 2 or 3. The results of the cross validation regressions are given in Tables 4a and 4b.

[9] For an econometric point of view, one wants to identify variables that are important not only in the sample available but also in other samples that may be drawn. The cross validation technique partitions the sample and uses part of the sample for the regression estimation and the remainder of the sample for testing the ability of the regression to predict out-of-sample. Randomly repeating the partitioning enables one to select variables that are useful for prediction in this sample and other samples. For those technically inclined, we used k-fold cross validation, with a k = 10, 1000 random realizations, and three different seeds. To reduce run time to a manageable level, we conduct the cross validation in two steps. We first determine from cross validation which individual variables are important to out-of-sample prediction. Then, we determine which products of variables improve the out-of-sample prediction.

Cross validation avoids the failings of regression fishing. Regression fishing is the practice of picking variables to maximize the explanatory power of the regression in one particular sample. Regression fishing is likely to overstate the statistical significance of the variables picked and to over-fit the regression to the particular sample so that the results may not be valid outside of the current sample.

Table 4a: Cross validation regression results for predicting the value of reliability (required interruption payment)

Variable	Coefficient	T-statistic	Significance level
Number of bedrooms	93.579**	2.531	0.012
Another fuel - other × total length of storm outages	-8.111**	-3.288	0.001
Own generator × educational level - post-graduate	889.482**	5.617	0.000
Number of non-weather outages	13.092**	3.133	0.002
Total length of non-weather outages	0.164**	2.554	0.011
Total length of storm outages × educational level - post-graduate	2.447**	4.633	0.000
Total length of storm outages × another fuel - gas	-1.876*	-1.687	0.092
Total length of storm outages × own generator	-16.077**	-4.940	0.000
Total length of storm outages × work from home	2.648**	2.271	0.024
Number of non-weather outages × own generator	79.499**	3.756	0.000
Southern region	-153.373	-0.496	0.620
Southern region × age	9.143**	2.067	0.039
Southern region × number of bedrooms	-127.608*	-1.714	0.087
Southern region × educational level - post-graduate	-250.902*	-1.722	0.086
Constant	746.136**	6.504	0.000

Table 4b: Cross validation regression results for predicting the value of reliability (willingness to pay to avoid an outage over four hours)

Variable	Coefficient	T-stat	Significance level
Age	0.134**	2.155	0.032
Educational level - college	3.488*	1.951	0.052
Educational level - post-graduate × number of non-weather outages	-0.544*	-1.744	0.082
Another fuel - oil	4.417	1.441	0.150
Another fuel - wood × educational level - college	-5.688*	-1.882	0.060
Another fuel - wood × Western region	11.017**	2.593	0.010
Own generator	-10.071**	-4.443	0.000
Number of non-weather outages	-0.105	-1.364	0.173
Northeastern region	-2.911	-1.394	0.164
Western region	5.079	0.712	0.477
Western region × age	-0.227*	-1.827	0.068
Work from home × age	0.124**	2.195	0.029
Work from home × Northeastern region	-12.892**	-4.664	0.000
Constant	10.566**	3.164	0.002

We see that when the value of reliability is measured by the required interruption payment in Table 4a, the single variables that are important in predicting customer reliability value are number of bedrooms, number of non-weather-related outages, and the total length of non-weather-related outages.[10] We see that more bedrooms and more and longer outages increase customers' required interruption payments while living in the South reduces it. These findings are consistent with the results reported above.

We see that, in addition, a number of pairs of characteristics improve the out-of-sample prediction. In particular, the total length of storm outages, location in the South, owning a generator, and education at the post-graduate level, when paired with other characteristics, are important to identifying customer reliability value.

The way to interpret the coefficients can be illustrated by looking at the last several rows of Table 4a in which the coefficients on South, and South paired with several customer characteristics are listed. The coefficient of -153 on the Southern region measures that a respondent in the South will require an interruption payment that is $153 less than a respondent in another region. However, that effect varies by age, number of bedrooms, and educational level. A respondent in the South will require an interruption payment that increases by $9 for each year of age. So a 60-year old in the South will require $90 more than a 50-year old.

To interpret the next variable (the product of South and Number of bedrooms) it is most intuitive to compare it to the first variable, the number of bedrooms. The coefficient of 94 on the first variable indicates that the required interruption payment increases by $94 for each additional bedroom. This result holds for respondents outside of the South. To determine the result for respondents in the South, we combine the coefficients on the Number of bedrooms and on Southern region × number of bedroom to obtain -$34 (= $94 - $128). So for respondents in the South, the required interruption payment decreases by $34 for each additional bedroom.

In Table 4b, we see that when the value of reliability is measured by the willingness to pay to avoid outages over four hours (Table 4b), the single variables that are important are age, educational level, own generator, and number of non-weather outages.[11] We also see that variables that are important when paired with another customer characteristic include age, working from home, another fuel (wood), educational level, and location in either the West or Northeast.

[10] Location in the South was important to out-of-sample prediction (and was statistically significant) in the first step of the cross validation procedure which determined which individual variables are important to out-of-sample prediction prior to determining which products of variables are important to out-of-sample prediction.

[11] Location in the West or Northeast and presence of another fuel (oil) were important to out-of-sample prediction (and the regions were statistically significant) in the first step of the cross validation procedure which determined which individual variables are important to out-of-sample prediction prior to determining which products of variables are important to out-of-sample prediction.

Several points are worthy of note with respect to the explanatory power of the regression. First, the variables were selected to maximize out-of-sample predictive power not in-sample explanatory power. Second, considerable diversity in the value of reliability remains unexplained. The explanatory power of the regression as measured by the R^2 statistic is about 10%.[12] Further, including the pairs of variables that define more narrow segments of customers is important. It roughly doubles the explanatory power of the regressions.[13]

IV. Key conclusions

Several key findings about the respondents and their demand for reliable service emerge from the analysis described above. As noted previously, respondents demand a high level of reliability. Of those surveyed, 95% said that outages should be either "very rare" or that there should be no outages except for those caused by major storms or extreme weather. Yet the level of reliability that many customers report experiencing is somewhat less than they expect. Almost three-quarters of the survey respondents had experienced an outage in the previous year, and for these customers, they reported experiencing an average of four outages in that year. Many of them experience significant problems if outages last several hours. Most of them experience significant problems if outages last more than 12 hours. Finally, the survey showed that 62% of customers would not find it acceptable for there to be multiple two-day outages per year, even if they were paid $500 per outage; 37% would not find it acceptable if they were paid $1000 per outage.

Our analysis of customer characteristics that were associated with a demand for reliability showed that, when looked at in isolation, many customer characteristics have little ability to predict the value that customers place on electricity. There are exceptions. Older customers and those with more bedrooms in their homes tend to place a higher value on reliability. Regional location matters, as does education and ownership of a generator. Length and number of non-weather-related outages increases customers' value of reliability.

There is substantial variation in customer demand for reliability. Customers are diverse, and while some of the characteristics that are associated with variation in the value of reliability are observable, much of their diversity is not explained by the characteristics we examined. While accounting for multiple characteristics improves our ability to predict customers' value of reliability, considerable unexplained variation remains unexplained.

[12] The R^2 is 10% for the required interruption payment and 9% for the willingness to pay regression.

[13] It is important to reemphasize that the variables were chosen based on their out of sample predictive power and without reference to the R^2.

Finally, the value of reliability depends on the type of outage customers are facing. The characteristics that are important in predicting value of reliability differ depending on whether the question is about the required payment to volunteer for a multi-day outage or whether the question is about the customers' willingness to pay to avoid a an outage longer than four hours.