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COMMONWEALTH OF MASSACHUSETTS
DEPARTMENT OF PUBLIC UTILITIES

PETITION OF BOSTON GAS COMPANY D/B/A NATIONAL GRID FOR APPROVAL OF AN INCREASE IN BASE DISTRIBUTION RATES	: : : : : : :	D.P.U. 20-120

SURREBUTTAL TESTIMONY OF BENJAMIN W. GRIFFITHS

on Behalf of
the Massachusetts Office of Attorney General

Exhibit AG-BWG-Surrebuttal-1

April 30, 2021

Hearing Officer Marc Tassone

Table of Contents

List of Exhibits

1. Introduction

Q. Please provide your name, title, and organization.

A. My name is Benjamin Griffiths. I am an Energy Analyst working for the Massachusetts Office of the Attorney General ("AGO") in the Energy and Telecommunications Division. My business address is One Ashburton Place, Boston, MA, 02108.

Q. Have you previously submitted direct testimony in this proceeding?

A. Yes. I submitted direct testimony in this proceeding on March 26, 2021.

Q. What is the purpose of your surrebuttal testimony?

A. Now that the Boston Gas Company, d/b/a National Grid ("National Grid," "NG," or the "Company") has provided responses to the issues that I raised in my direct testimony, I have concerns about many choices that the Company employed in their Marginal Cost Study ("MCS") and the critiques they offered of my alterative values. The purpose of this surrebuttal testimony is to explain the shortcomings of National Grid's MCS, to show that certain variables that the Company used in its regressions are theoretically and practically flawed, and to propose alternative marginal costs that are more accurate than those proposed by the Company. More specifically: (1) for distribution plant additions, I propose a revised regression that includes a variable accounting for system size and/or system quality (which NG asserts is important); (2) for distribution operations expense, I do not object to NG's proposed regression based on the discussion offered by NG in their rebuttal testimony; and (3) for distribution maintenance expense, I propose that the

Department adopt the regression that I provided in Exhibit AG-BWG-3 p2 (provided in my direct testimony). My revised results, which include variables to account for system size/quality and correct for flaws in National Grid's regressions, indicate that the system's marginal costs are higher than I originally estimated.

I appreciate the Company's efforts to provide theoretical and statistical justification for the specific analyses it used to produce its MCS. Statistical analysis is about understanding and describing trends; having the Company's explanations for analytical choices allows for more fulsome conversation on the topic of marginal costs.

Q. How is your surrebuttal testimony organized?

A. Section 2 of my surrebuttal testimony summarizes the Company Witness Bartos's rebuttal testimony. *See* Exh. NG-MFB-Rebuttal-1. Section 3 returns to the Company's distribution capacity-related marginal costs analysis (Exh. NG-MFB-2) and discusses a variety of methodological flaws which, when corrected, indicate that marginal costs are higher than those proposed by the Company. Section 4 addresses the Company's distribution operations expense analysis (Exh. NG-MFB-3 p1) and explains that, based on NG's rebuttal testimony, I do not object to the Company's estimate for distribution operations expense and adopts it for the purposes of computing the Company's overall marginal costs. Section 5 returns to Company's distribution maintenance expense analysis (Exh. NG-MFB-3 p2) and shows that the Company misrepresents certain trends in system quality, making their estimates too low. Section 6 summarizes these findings

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and offers my revised marginal cost values for distribution plant and distribution maintenance expense, as well as total marginal cost values.

2. Summary

Q. Please summarize the Company's Marginal Cost Study and the expanded discussion in its rebuttal testimony on its MCS.

A. The Company proposes no numerical changes to its MCS. The values sponsored in Exhibits NG-MFB-2 through NG-MFB-6 remain the values it proposes in rebuttal testimony. In response to my concerns about two exhibits in particular, NG-MFB-2 and NG-MFB-3, the Company explains its choices. Across the three analyses (for distribution plant additions, distribution operations expense, and distribution maintenance expense), the Company's arguments fall into two categories. First, in several places, the Company argues that that marginal cost analyses should attempt to include a metric measuring system size/quality. *See* Exh. NG-MFB-Rebuttal-1, at 2, 8, 12-14, 24, 33. Second, the Company argues that various dummy variables, which I excluded, should be included because they are statistically significant and "account for important changes in the data." *See* Exh. NG-MFB-Rebuttal-1, at 31 and 43.

The Company's critiques are limited to the variables that should be included in the regression analyses, and are not about how my values were actually computed. The Company offers no criticism of my numerical methods or the computational accuracy of my results.

Q. Please summarize your conclusions about the Company's MCS.

A. The Company's MCS has a number of shortcomings and flaws, discussed in detail below, which have resulted in a marginal cost estimate that is too low. In rebuttal testimony, the Company makes a valid theoretical point regarding the potential impact of accelerated pipe removal programs on marginal costs, stating that such a variable is necessary to account for system size/quality.

As described below, the specific variables that NG uses do not accurately capture such costs (*i.e.*, pipe removal and replacement costs). I agree that one or more variables should be used to capture costs for pipe removal and replacement in order to accurately estimate the marginal cost of distribution plant additions expense, and I propose a new regression using main-related variables to account for system size/quality. Exh. AG-BWG-Sur-2 p1.

Turning to distribution operations expense, upon consideration of NG's rebuttal, I do not object to the Company's estimate for distribution operations expense. Exh. NG-MFB-3 p1. Lastly, for distribution maintenance expense, I disagree with the Company's inclusion of a main-related variable because its specific variable is arbitrary and does not align temporally with the system size/quality dynamics the Company seeks to represent. Moreover, I demonstrate that reasonable modifications to the Company's Exhibit NG-MFB-3 p2 reveal that the true marginal costs of distribution maintenance expense align with my initial estimates in Exhibit AG-BWG-3 p2.

Q. Please describe how you have tried to capture system size/system quality in these revised regressions.

A. As an initial matter, the Company is inconsistent in how it attempts to capture these phenomena (system size/system quality), relating to both the applicable timeframe and to the types of costs measured. In Exhibit NG-MFB-2, the Company relies on a variable related to the length of plastic pipe on the system over the full 1988–2019 period. In Exhibit NG-MFB-3 p1, the Company relies on a variable related to the total length of mains (irrespective of material) for the 2001–2019 period. In Exhibit NG-MFB-3 p2, the Company relies on a variable related to the total length of cast-iron main for the 2005–2019 period. The Company does not offer much argument for why it included three different variables to capture system size/quality, rather than a single, consistent variable across all three regressions.

That said, the Company does have a valid point about the value of capturing system size/quality. As I discuss in greater detail below, I propose to include such variables in my revised marginal cost of capacity-related distribution plant analysis. *See* Section 3. Although I investigate the use of similar variables in my analysis of the marginal cost of distribution maintenance expense, I ultimately exclude them because more parsimonious models yield near-identical results. *See* Section 5. As noted above, I propose to adopt the Company's analysis for marginal cost of distribution operations expense, which includes a system size/quality-related variable. *See* Section 4.

Q. Please summarize your estimate of marginal cost per Dth delivered.

A. I developed my proposed regressions in accordance with the Department's directives and standards related to marginal cost studies. As shown on Exhibit AG-BWG-Sur-4 p2, and supported by the remainder of my testimony and exhibits, I have estimated that the annual loss-adjusted marginal distribution capacity-related cost of service at a customer's meter is $380.64 per Dth of Design Day Demand, and $0.3620 per Dth of delivery quantities. My revised results indicate that the system's marginal costs are higher than I originally estimated. Below is a discussion of my analysis and how I derived my proposed marginal costs.

3. Marginal Cost of Capacity-Related Distribution Plant

Q. What analysis did the Company use to calculate the marginal cost of capacity-related distribution plant and the Company's specific estimate of the marginal cost of capacity-related distribution plant?

A. As discussed in Exhibit NG-MFB-2 and Exhibit NG-MFB-Rebuttal-1, at 7-8, the Company created a regression that relates annual (*i.e.*, incremental) distribution plant additions to seven independent variables:

(a) 2-Year Lag Change in Normalized Peak Years 2009 and after;

(b) Total Feet of Plastic Pipe on the System;

(c) Dummy variables to control for the periods 2009, 2013, 2018, and 2013-2019;

(d) Autoregressive Term with lag 4.

Using this equation, the Company proposes that the marginal cost of distribution plant equals $1,177/Dth. Exhibit NG-MFB-2 p1.

Q. What are the Company's critiques of your analysis?

A. The Company makes two main critiques of my model. First, the Company believes that a model of distribution plant additions should include a variable to reflect system size/quality. Exh. NG-MFB-Rebuttal-1, at 12-14. Second, the Company believes that, all else equal, it is more important to include a variable related to system quality than a variable related to sendout. Exh. NG-MFB-Rebuttal-1, at 15.

Q. Now that the Company has provided some discussion of its analysis, do you have any new comments or concerns about its model of distribution plant costs?

A. Yes, I do. First, the Company's regression model does not appear to measure the marginal cost of distribution plant additions with respect to demand. *Contra* Exh. NG-MFB-1, at 9-10; Exh. NG-MFB-Rebuttal-1, at 7-8. Instead, the Company's sponsored regression appears to actually measure how quickly the marginal cost of demand changes over time—not the marginal cost of demand itself. To illustrate this concept, this is equivalent to the Company thinking it is measuring the speed of a moving car when it is, in fact, measuring how quickly that car is accelerating.[1] Alternatively, this is the difference between asking "how big is the system" and "how quickly are we expanding it."

Second, while Witness Bartos offers some thoughtful comments about how accelerated pipe-replacement programs could affect system costs, the Company's specific model will be hard pressed to capture the sought-after trend because it does not include a

[1] In calculus terns, the first derivative of distance with respect to time is speed, and the second derivative of distance with respect to time is acceleration. The first shows how quickly a car is moving across space (*i.e.*, speed), the second shows how quickly a car's speed is changing (*i.e.*, acceleration).

variable to capture how the accelerated replacement programs changed the rate of pipe removal. As currently structured, the Company's regression only captures the long-term trend in "system size" and does not capture "system quality."

Based on these two issues, I conclude that the Company's proposed regression is flawed. To this end, I will offer an alternative regression which calculates marginal costs and accounts for system size and system quality changes through the addition of several variables which account for short-term and long-term system dynamics.

Q. Why do you suggest that the Company's analysis may not actually compute marginal cost of distribution plant additions with respect to demand?

A. Marginal cost is traditionally defined as the "the change in the **total cost** generated by producing one more unit of output." Krugman et al., at 169 (emphasis added).[2] Total cost is just as it sounds: the total cost of producing a product. (In the case of the MCS, the "product" is notionally normalized peak demand.) The Company's analysis does not assess marginal costs in this way. Instead, the Company bases its calculations on incremental cost data. Calculating marginal costs using incremental cost/demand data can result in practical, theoretical, and interpretive problems.

In Exhibit NG-MFB-2 p1, the Company's cost-related variable is "Real 2019 $ Total Capacity Related Additions," and the Company's demand-related variable is "2-Year Lag Change in Normalized Peak Years 2009 and after." Exh. NG-AG-47-1, at 2, 7.

[2] Paul Krugman, Robin Wells, and Martha Olney, "Essentials of Economics," Worth Publishers (2007), https://www.google.com/books/edition/Essentials_of_Economics/VqFNV6YZGUwC?hl=en&gbpv=1&dq=%22marginal+cost%22+%22total+cost%22+one+additional+unit&pg=PA170&printsec=frontcover.

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The Company makes clear that the "total" in the cost variable's name relates to its capture of the total quantity of annual additions. Exh. NG-MFB-Rebuttal-1, at 21-22. The Company's cost-related variable captures how annual capital additions have changed over time; the Company's demand-related variable measures how normalized peak demand has changed over time. (In calculus lingo, the Company took first derivative of total cost and total demand with respect to time before it undertook its regression analysis.)

For both variables, Witness Bartos appears to overlook that the units she utilizes for cost and demand data are not totals, but in fact are rates-of-change (*e.g.*, total costs measured in real dollars verses incremental costs measured in dollars-per-year; or total demand measured in Dth versus change-in-demand measured in Dth-per-year.).[3] *Contra* Exh. NG-AG-47-1 at 2, 7. Using these mislabeled variables, the Company then attempts to assess marginal costs by estimating the relationship between incremental cost (*i.e.*, annual capital additions) and incremental demand (*i.e.*, annual change in normalized peak demand). Exhs. NG-MFB-2 p1; NG-MFB-Rebuttal-1, at 8. (I corrected the demand-related error in direct testimony (Exhs. AG-BWG-1, at 24, AG-BWG-2 p1), and thereby decided to use a variable for total demand. Upon further examination, the cost-related specification is also in error.)

[3] To make this more concrete, the money in my bank account (dollars) is a *total*, while the paycheck I deposit into my bank account each week (dollars-per-week) is a *rate*. Critically, it is not possible for somebody else to know how much money is in my bank account based only on the size of my paycheck; nor is it possible for them to know my weekly salary based only on the perusal of my bank balance on a single day.

While the Company implies that marginal cost analyses based on total values and marginal cost analysis based on incremental values are equivalent (*e.g.*, Exh. NG-MFB-Rebuttal-1, at 8, stating, "[b]oth models contain a measure of normalized peak demand, although the specifications are different"), they are not equivalent. The result is this: the Company's marginal costs appear to be actually measuring how quickly marginal costs change over time. While this is potentially an interesting academic question, the Company's sponsored measurement may not say anything about the absolute level of marginal costs of distribution plant additions with respect to demand, which is the notional purpose of this analysis. A marginal cost study must calculate marginal cost. *See* D.P.U. 17-170, at 320-321.

Q. Is there a simple fix to the Company's reliance on incremental demand and cost?

A. Yes. The fix is incredibly simple. Instead of running regressions on incremental costs and incremental normalized peak demand, the regressions should be based on cumulative (*i.e.*, absolute) level of capital additions and absolute level of normalized peak demand over the 1988–2019 timeframe. In practice this is easy because the Company already provides a variable for the absolute (or total) level of normalized peak demand (the "Combined_Norm_pk" variable in Attachment NG-AG-8-2-1 (Confidential)) and it is easy to calculate the absolute level of capital additions just by adding up the year-over-year costs (provided as the "RI_CapAd" variable in the same datafile).[4] The values of

[4] Just to be clear, by "add up," I mean that the first year of the cumulative costs reflects just the capital additions made in 1988; the second year of cumulative costs reflects the sum of capital additions made in 1988 and 1989; and so on, until the final year of the cumulative costs reflects the sum of all capital additions between 1988 and 2019.

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my new cumulative capital additions variable ("Cum_CapAd") are provided in Appendix A, §3.a (Confidential).

Q. How have cumulative cost of capital additions changed over time?

A. Cumulative plant additions have increased over the last 30 years and the rate has accelerated in the past decade—in line with the Company's pipe-replacement thesis. Figure 1, below, depicts capital additions between 1988 and 2019. The Company notes that, starting in 2010, the Company started an accelerated pipe removal program—first through the Targeted Infrastructure Recovery Factor program or ("TIRF") and later through the Company's Gas System Enhancement Plan ("GSEP"). Exh. NG-MFB-Rebuttal-1, at 13. To aid with visualization, I distinguish between these two periods.

Figure 1: Cumulative Distribution Plant Additions over Time ($)

[redacted]

In the earlier period (before 2010), costs increase at a near constant rate of $79 million per year while in the later period (after 2010) they increase at about $249 million per year. Over their respective time periods, these very simple trends account for about 99% of all variability in costs (R squared = 0.99).[5]

Q. Given the increase in spending starting in 2010, how did the Company seek to account for the pipe replacement programs in their regression?

A. Witness Bartos states that she sought to include a term to measure "system size/condition" and she relied on her Plastic Pipe variable reflect TIRF and GSEP costs. Exh. NG-MFB-Rebuttal-1, at 8. She explains, "[g]enerally, as leak-prone pipe is removed, it is replaced with plastic pipe, so leak-prone pipe replacement activities can be estimated by the amount of plastic pipe on the system. Therefore, as the amount of plastic pipe increases, plant additions would also be expected to increase." Exh. NG-MFB-Rebuttal-1, at 14. Witness Bartos further notes that this is the "only independent variable [in the Company's model] that was capturing the effects of the Company's main replacement program." Exh. NG-MFB-Rebuttal-1, at 14.

Q. Does Witness Bartos's model formulation account for TIRF or GSEP costs appropriately?

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[5] As an aside, the simple trends shown in Figure 1 are what I was referring to about the Company's inappropriate differencing. *See* Exh. AG-BWG-1, at 17-19; *contra* Exh. NG-MFB-Rebuttal-1, at 21-22. My concern was not that the Company was calculating year-over-year changes to the distribution plant account, which could also include retirements, adjustments, or transfers, but instead that they were considering incremental, rather than cumulative, capital additions. Trends that are blindingly obvious when shown in aggregate (*i.e.*, capital additions were *incredibly* stable over the 1988-2009 and the 2010-19 periods) can be obscured if you focus on the year-to-year variability. Trying to explain each wiggle and wriggle of costs is hard because there is just some level of random variation and the resulting analysis may miss the forest for the trees.

A. Given increased spending starting in 2010, it does seem reasonable to try to capture accelerated pipeline replacement. However, Witness Bartos's regression falls short of what it intends to capture. Witness Bartos suggests that the plastic pipe variable can help control for both "system size" and "system condition." Exh. NG-MFB-Rebuttal-1, at 8. As formulated, the Company's analysis only really accounts for system size (*i.e.*, the total length of plastic pipe). It does not directly account for system condition because it only focuses on how the quantity of plastic pipe on the system increased over the past 30 years. As plastic pipe installation has accelerated in recent years, the Company's regression will tend to *overstate* historic pipe lengths and *understate* pipe additions in the TIRF/GSEP era (*i.e*, since 2010).

If the Company believes that accelerated pipe replacement is driving the recent cost trend, then it should utilize one variable that reflects the long-term (presumably demand-dependent) trend in plastic pipe additions, and a different (higher) rate of plastic pipe additions in the 2010–2019 period to account for the TIRF and GSEP programs. Had the Company wanted to account for both system size *and* system quality, a more appropriate causal model would include a way to measure pipe installation in both periods, requiring the use of three variables:

(A) Plastic Pipe 1988-2019;

(B) Dummy Variable for Years 2010-2019;

(C) Interactive term for Plastic Pipe in Years 2010-2019.

Term (A) is included by the Company already and should account for the long-term trend in plastic pipe additions. Term (B) is a dummy variable reflecting possible changes in the *level* of spending in the TIRF and GSEP compared to a 1988–2019 baseline.[6] Term (C), the interactive term, captures the *incremental* effect of the TIRF and GSEP over and above system size, starting in 2010. Term (B), the dummy variable, is not strictly necessary but for models with interactive terms it is generally advised to include both subcomponents being multiplied together. In this case, because Term (C) equals Term (A) x Term (B) we should include Terms (A) and (B). In statistics this concept is sometimes known as the "hierarchical principle."

Q. Is it possible to develop a new regression model which corrects the Company's misspecified demand term, and includes a measure of system quality?

A. Yes. From a pure theory standpoint, a high-quality regression would relate cumulative capital additions to (a) total level of normalized peak demand, (b) total length of plastic pipe, (c) a dummy variable for the 2010–2019 period, (d) an interactive term for plastic pipe in the 2010–2019, and (e) total sendout. The purpose of each these terms, except sendout, was discussed above.[7] This theoretically pure regression would have the following equation:

[6] The Company includes a Dummy Variable for the 2013–2019 period, but it is not clear that its inclusion is theoretically related to the pipe replacement programs.
[7] In my direct testimony, I suggested that a sendout related term might reasonably be added to the model to capture how total flows affect costs. *See* Exh. AG-BWG-1, at 10-11. In rebuttal testimony, the Company voiced no conceptual concern about the addition of such a variable. Exh. NG-MFB-Rebuttal-1, at 15.

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$$Cumulative\ CapAd = \beta_0 + \beta_1 NormPk + \beta_2 PlasticFt + \beta_3 Dummy2010to2019 + \beta_4(Dummy2010to2019 \times PlasticFt) + \beta_5 TotSend + \epsilon$$

In practice, this model shows that the long-term plastic pipe trend (captured with β_2) is not significant and that there is autocorrelation of the residuals with lag 1. (The short-term plastic pipe trend, captured with β_4, is significant.) It should not be surprising that the long-term plastic pipe variable is not significant because it is almost perfectly correlated with peak demand (correlation between the Company's "Plas_ft" and "Combined_Norm_pk" variables over the full 1988–2019 period equals 0.997).[8] Intuitively, this outcome makes sense because a significant amount of plastic pipe added over the past thirty years was likely used to serve increasing demand. Historically speaking (*i.e.*, TIRF/GSEP aside), I would generally expect that increases in forecasted demand drove the need for new mains, which in turn, increased plant costs. The final "base" model is thus:

$$Cumulative\ CapAd = \beta_0 + \beta_1 NormPk + \beta_2 Dummy2010to2019 + \beta_3(Dummy2010to2019 \times PlasticFt) + \beta_4 TotSend + \beta_5 AR(1) + \epsilon$$

Q. What are the results for this "base" model?

A. This base model: (a) has higher predictive power than what the Company currently proposes, (b) does not require any non-causal dummy variables, (c) requires fewer

[8] *See* Appendix A, §3.b.

variables overall, (d) includes only variables which are statistically significant, and (e) does not include any autocorrelation in the residuals. This model, with the restated cost term and the inclusion of variables for pipe-replacement costs, also indicates that the marginal cost of distribution plant is higher than I proposed in my direct testimony. The revised model has an R squared value of 0.998, meaning that 99.8% of variability in costs can be accounted for with this model (the Company's model has a somewhat lower R squared of 0.9595). Exh. NG-MFB-2 p1 line 13. Visually speaking, model fit is very good. Figure 2 depicts how the model's predicted values track to observed values cumulative costs over the 1988–2019 period.

Figure 2: Model Fit for Cumulative Distribution Plant Additions (Observed versus Predicted Values, 1988-2019)

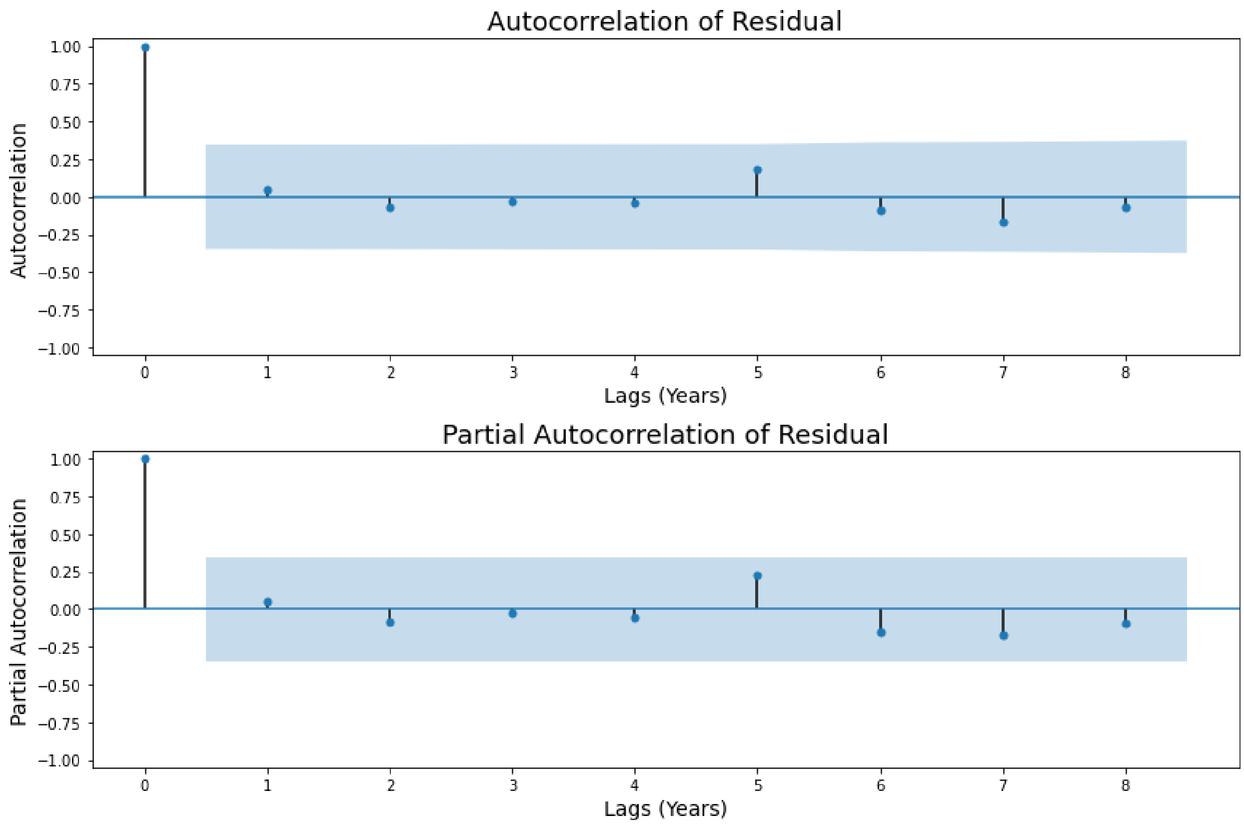
[redacted]

According to my revised model, the marginal cost of distribution additions, with respect to demand, is $3,567.23/Dth (compared with the Company's $1,177/Dth). The model also indicates that the marginal cost of distribution additions, with respect to sendout, is $1.05/Dth (compared with the Company's zero). The relevant statistics are presented in Table 1, below. Figure 3 presents the ACF / PACF residuals plot for the base model. It shows that there is no autocorrelation of the residuals after the inclusion of the AR(1) term. (For full statistical analysis of this regression, *see* Appendix A, §3.c, (Confidential).)

Table 1: Summary Regression Results for Base Model of Distribution Plant

Full Name	Variable Name	Coefficient Value	T Test	P Value
Constant	const	-3,018,341,765	45,425,370,684,426	0.0000
Normalized Peak Demand (Dth)	Combined_Norm_pk	3,567.2294	55.2030	0.0000
Interactive: Feet of Plastic Main, 2010-2019	Plas_2010_2019	163.6493	66.0416	0.0000
Dummy: Years 2010-2019	D_2010_After	-3,641,957,360	-3,076,643,298,688,130	0.0000
Total Sendout (Dth)	Tot_send	1.0522	2.5961	0.0094
Autoregessive Var (Lag 1)	ar.L1	0.7286	3.6624	0.0002

Figure 3: ACF / PACF Plot for "Base" Model of Distribution Plant



Q. Can we be confident that this model accurately accounts for the system quality measurements that the Company believes that a good regression model should include?

A. Yes. We can be confident that it captures the TRIF/GSEP trend because the demand-related marginal cost remains relatively constant if we swap the plastic pipe variable with a cast-iron pipe variable (leaving all other variables unchanged). After all, the Company is replacing leak-prone cast-iron pipe with plastic. Exh. NG-MFB-Rebuttal-1, at 13. An equation for this sensitivity is thus:

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$$Cumulative\ CapAd = \beta_0 + \beta_1 NormPk + \beta_2 Dummy2010to2019 + \beta_3(Dummy2010to2019 \times CastIronFt) + \beta_4 TotSend + \beta_5 AR(1) + \epsilon$$

In practice, running this model shows that the sendout term is modestly non-significant (P = 0.157; higher than the Company's threshold of 0.1). Removing the sendout variable from this model and rerunning the regression yields a set of coefficients which are all significant and a model without any autocorrelated residuals. (For full statistical analysis of this regression, *see* Appendix A, §3.d, (Confidential).)

After swapping plastic pipe for cast iron pipe, the GSEP sensitivity model's R squared increases to 0.999, and the cast-iron pipe variable changes from a positive value to negative value. This change in sign is expected for the cast-iron pipe variable because it reflects the fact that *removing* pipe costs money. A summary of this model can be found in Table 2, below.

The demand-related term of this sensitivity is $3,731.42/Dth, about 4.6% higher than the "base" model presented in Table 1. The sendout related term drops to zero (compared with $1.05/Dth in the base model). Given the closeness of demand-related marginal cost estimates relying on two different pipe types, the Department should have added confidence that the base model's formulation accurately captures both system size and system quality. To that end, this sensitivity result provides added confidence that the true marginal cost of distribution plant, with respect to demand, is somewhere above $3,500/Dth, and the marginal cost with respect to sendout is near-zero.

Table 2: "TIRF/GSEP" Sensitivity Model Summary Regression Results

Full Name	Variable Name	Coefficient Value	T Test	P Value
Constant	const	-3,030,699,177	-76,501,400,168,380	0.0000
Normalized Peak Demand (Dth)	Combined_Norm_pk	3,731.4248	88.1894	0.0000
Interactive: Feet of Cast Iron Main, 2010-2019	CI_2010_2019	-532.0007	-57.5524	0.0000
Dummy: Years 2010-2019	D_2010_After	7,109,319,492	6,181,658,849,355,110	0.0000
Total Sendout (Dth)	Tot_send	--	--	--
Autoregessive Var (Lag 1)	ar.L1	0.8324	6.4532	0.0000

Q. What would happen if you add in the Company's proposed dummy variables to your new "base" model described in Table 1?

A. For this sensitivity, I start with the "base" model and add the three dummy variables that the Company proposes to control for the year 2009, year 2013, and year 2018. I do not include a dummy variable for the years 2013–2019, which the Company does utilize, given its similarity to my dummy for the period 2010–2019. This sensitivity model has an R Squared value of 0.999 and all variables are significant.[9] Table 3, offering summary statistics from this sensitivity, indicates that demand-related marginal costs are $3,425.17/Dth, and sendout-related marginal costs are $1.4048/Dth. So, after controlling for costs in 2009, 2013 and 2018, this sensitivity suggests that marginal costs with respect to demand are a little lower than the "base" model, while marginal costs with respect to

[9] There is marginal partial autocorrelation of the residuals at lag 8 but adding a AR(8) term to the model yields an non-significant variable. I am incredibly skeptical that this correlation is anything more than spurious.

sendout are a little higher. Given that these dummy variables offer *de minimis* incremental explanatory power, reduce model power (*i.e.*, reduce degrees of freedom), and yield marginal cost values in line with the "base" models, these variables should not be included. (For full statistical analysis of this regression, *see* Appendix A, §3.e, (Confidential).)

Table 3: Summary Regression Results for Dummy Sensitivity Model

Full Name	Variable Name	Coefficent Value	T Test	P Value
Constant	const	-2946533207	-4.70155E+13	0.0000
Normalized Peak Demand (Dth)	Combined_Norm_pk	3425.1753	58.7695	0.0000
Dummy: Years 2010-2019	D_2010_After	-3644167720	-4.10435E+15	0.0000
Total Sendout (Dth)	Tot_send	1.4048	4.2862	0.0000
Interactive: Feet of Plastic Main, 2010-2019	Plas_2010_2019	167.8483	60.5983	0.0000
Dummy: Year 2009	D_2009	135702482	8.07868E+12	0.0000
Dummy: Year 2013	D_2013	-114935202	-4.52417E+12	0.0000
Dummy: Year 2018	D_2018	-63017214	-3.02032E+12	0.0000
Autoregessive Var (Lag 1)	ar.L1	0.7704	4.845	0.0000

Q. Are the results of the "base" model described above and in Table 1 preferable to the Company's model sponsored in Exhibit NG-MFB-2 p1?

A. Yes. The "base" model discussed summarized in Table 1, above, is preferable to the Company's sponsored in Exhibit NG-MFB-2. This model: (a) corrects for the specification problems, (b) has better goodness of fit as measured using the R squared value, (c) explicitly accounts for pipe replacement programs, (d) is more parsimonious,

(e) lacks any non-causal dummy variables, (f) exhibits no autocorrelation in the residuals, and (g) contains only statistically significant variables.

In addition, the benchmarking provided with the two sensitivity analyses (Table 2 and Table 3) provide added confidence that the "base" model accurately captures system quality and that the three omitted dummy variables are of no importance. There is no dimension against which the Company's model is preferable.

Q. Are the results of the model described above and in Table 1 preferable to your original model sponsored in Exhibit AG-BWG-2 p1?

A. Yes. The original model that I sponsored corrects for the demand variable specification problem but did not include the system-quality related terms recommended by the Company. The system size/quality related terms are now included in Exh. AG-BWG-Sur-2 p1.

Q. What are your conclusions about the "base" model for marginal cost of capacity-related distribution plant?

A. My revised model for distribution plant offered in this surrebuttal testimony should be adopted. Looking at the results of the "base" model, the most salient point is this: the Company's model understates the marginal cost of capacity-related distribution plant. The Company proposes a value of $1,177/Dth, while AG-BWG-2 results in $2,186/Dth, and the "base" model regressions herein (Table 1) suggest it is actually $3,567/Dth. The new "base" model also demonstrates that sendout-related marginal costs are about $1/Dth (compared to the Company's zero). These alternative regressions demonstrate that the

Company's modeling inappropriately and inaccurately suppresses the true marginal cost values.

4. Marginal Cost of Capacity-Related Distribution Operations Expense

Q. What analysis did the Company use to calculate the marginal cost capacity-related distribution operations expense and the Company's specific estimate of the marginal cost of capacity-related operations expense?

A. As discussed in Exhibit NG-MFB-3 p1 and Exhibit NG-MFB-Rebuttal-1, at 23-24, the Company created a regression which relates annual distribution operations expense to seven independent variables:

(a) Actual Peak Demand;

(b) Interactive term for Feet of Main for years 2001-2019;

(c) Dummy variables for the periods 2018, 2019, 2013-14, and 2001-2019;

(d) Autoregressive Term with lag 4.

Using this equation, the Company proposes that the marginal cost of distribution plant equals $13.29/Dth. Exh. NG-MFB-3 p1. The Company's model has an R squared measurement of 0.9921.

Q. Please remind me of the analysis that you conducted to calculate the marginal cost capacity-related distribution operations expense and your specific estimate of the marginal cost of capacity-related operations expense.

A. My proposed model related operations expense to peak demand, a dummy variable for 2018 and a dummy variable for 2019. I excluded the feet-of-main term given the lack of justification offered by the Company in the pre-filed testimony and the thitherto unsubstantiated dummy variables which lacked causal explanations. As noted in Exhibit AG-BWG-3 p1, I estimated marginal cost of operations expense with respect to demand at $10.27/Dth.

Q. What are the Company's concerns with how you modeled operations expense?

A. The Company believes that the operations expense model should include a variable for feet-of-main on the system and explained that the 2001 period was:

> Consistent with the time period immediately after Keyspan Energy acquired the former Eastern Enterprises in 2000. As discussed in Exhibit NG-MFB-1 at 10, it is expected that changes in management could have affected various decisions related to costs that could cause structural shifts, so it is reasonable that the relationship between operations expense and total feet of main is significant during this period.
>
> Exh. NG-MFB-Rebuttal-1, at 26.

Q. Do you accept this explanation for the "Dummy Years 2001-After" and "Feet of Main Years 2001-After" variables?

Q. Yes. The Company's discussion of these variables is helpful and it appears to have a reasonable causal explanation for their inclusion. I propose to adopt the Company's marginal cost estimate of $13.29/Dth set out in Exhibit NG-MFB-3 p1.

5. Marginal Cost of Capacity-Related Distribution Maintenance Expense

Q. What analysis did the Company conduct to calculate the marginal cost capacity-related distribution maintenance expense and the Company's specific estimate of the marginal cost of capacity-related maintenance expense?

A. As discussed in Exhibit NG-MFB-3 p2 and Exhibit NG-MFB-Rebuttal-1, at 23-24, the Company created a regression which relates distribution maintenance expense to seven independent variables:

(a) Actual Peak Demand;

(b) Interactive term for Feet of Cast Iron Main, years 2005-2019;

(c) Dummy variables for the periods 2008, 2009, 2010, 2016, and 2018-9.

Using this equation, the Company proposes that the marginal cost of distribution maintenance expense equals $19.53/Dth. Exh. NG-MFB-3 p2. The Company's model has an R squared measurement of 0.9475.

Q. Please describe the analysis that you conducted to calculate the marginal cost capacity-related distribution maintenance expense and your specific estimate of the marginal cost of capacity-related maintenance expense.

A. The model offered in Exhibit AG-BWG-3 p2 is simpler than the Company's proposal and relates maintenance expense to peak demand, sendout, and dummy variables for the years 2018 and 2019. This model has an R squared value of 0.9270 and indicates the marginal cost of maintenance expense with respect to demand equals $25.1345/Dth-peak and that the marginal cost of maintenance expense with respect to sendout equals $0.2316/Dth.

Q. What are the Company's concerns with how you modeled maintenance expense?

A. The Company believes that the operations expense model should include a variable for feet-of-main for the 2005–2019 period, noting:

> The feet of cast-iron main variable is included in the Company's maintenance expense regression because it is important to attempt to capture the condition of the Company's distribution system… It is reasonable to hypothesize that capacity-related distribution maintenance expense would be related to the amount of cast-iron main being maintained by the Company.
>
> Exh. NG-MFB-Rebuttal-1, at 36.

The Company also suggests that each of the dummy variables should be included because—in various ways—their removal makes the Company's model "inferior." Exh. NG-MFB-Rebuttal-1, at 37-38. The Company does not comment on my inclusion of a sendout related term. In other instances, however, the Company noted that it was not "conceptually" opposed to the addition of a sendout term. Exh. NG-MFB-Rebuttal-1, at 15.

Q. Do you have any concerns with any of the Company's independent variables in this regression?

A. Yes. As discussed above, I am not conceptually opposed to a pipe-related variable. Unfortunately, the Company's actual variable does not comport with its explanation of its variable. In my direct testimony, I criticized the Company's cast-iron feet variable for

REDACTED

the years 2005–2019, suggesting that from an interpretation standpoint, this "variable posits that there is something germane about the total amount of cast-iron main on the system – but only for the past 15 years; before then, the total amount of cast-iron main on the system is assumed to have no effect." Exh. AG-BWG-1, at 14-15. If, as the Company claims, "it is reasonable to hypothesize that capacity-related distribution maintenance expense would be related to the amount of cast-iron main being maintained by the Company" (Exh. NG-MFB-Rebuttal-1, at 36), then the Company should be looking at the length of cast-ion pipe on the system across time—not just the past 15 years.

In a milquetoast effort to justify the 2005–2019 timeframe, the Company states that the most recent 15-year period is reasonable because:

> It appears that the Company began replacing cast-iron pipe at a much higher rate starting in 2005 compared to the period prior to 2005, which may explain why there was a statistically significant relationship between the feet of cast iron main and maintenance expense for the period starting in 2005. For example, from 1986-2004, the Company's feet of cast-iron main declined an average of approximately 100,000 feet per year. From 2005-2019, the Company's feet of cast-iron main declined an average of over 215,000 feet per year.
>
> Exh. NG-MFB-Rebuttal-1, at 37.

This explanation, unfortunately, does not appear accurate. Figure 4 shows cast iron pipe length on the Company's system from 1986 through 2019.[10] In the 1986–2010 period (before TIRF or GSEP) cast iron pipe declined at an incredibly stable rate (so stable that a simple line accounts for 99.6% of variability). Starting in 2010, cast-iron pipe started to

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[10] Variable "CI_ft" offered by Company in "AG-8-2-5 Attachment CONFIDENTIAL.sav."

come off the system at a faster (but still incredibly stable) rate. These rates of reduction are so stable that it is hard to even see the superimposed trend-lines on each segment because the trend line and the observations are so in sync.

Figure 4: Feet of Cast Iron Pipe on the System, By Year

[redacted]

Even though Witness Bartos states that "[i]t appears that the Company began replacing cast-iron pipe at a much higher rate starting in 2005" (Exh. NG-MFB-Rebuttal-1, at 37), it is clear that the accelerated pipe removal did not start until 2010. Pipe replacement (or removal) in the 2005–2009 period is directly in line with the longer 1986–2009 trend. The true start for accelerated pipe replacement comports with the start of the TIRF/GSEP era. To that end, Witness Bartos is inappropriately controlling for time she should not control for. This variable is misspecified and should be removed or reformulated to align with actual system trends.

Q. Are the Company's concerns about your removal of dummy variables from this regression justified?

A. No. First, given the aforementioned problems with the cast-iron pipe variable discussed above, any assessment of whether I should have removed dummy variables is misguided from the start. The Company's assessments across Exhibit NG-MFB-Rebuttal-1, pages 37-41 would only maybe be potentially relevant if the Company had corrected its model and *then* checked the dummy variables that I excluded. Second, the Department has cautioned against the inclusion of non-causal dummy variables, and the Company does not try to justify its inclusion on any theoretical grounds (*e.g.*, D.P.U. 10-114 at 355*; see also* Exh. NG-MFB-Rebuttal-1, at 37-38). As discussed in my direct testimony, the inclusion of these variables has a trivial effect on model fit, suggesting that (while they may be significant) they have no meaningful explanatory power. They should not be included.

Q. What happens if you align the cast-iron variable with meaningful time periods such as 1986–2019 or 2010–2019?

A. I made efforts to modify the Company's regression model to account for the long-term trend in "system condition" as the Company apparently desired (*e.g.*, Exh. NG-MFB-Rebuttal-1, at 33, 36); the conditions in the 2010–2019 to account for the TIRF/GSEP programs (*i.e.*, the increased rate of iron-pipe replacement); or both the long-term trend in system size/condition and the conditions in the 2010–2019 timeframe. The Company made this analysis easier because it had already developed all of these variables.

First, if you modify the Company's regression to replace the "CI_ftx2005_After" variable with the non-time specific "CI_ft" variable and rerun the Company's model, then the cast-iron main variable's coefficient is not significant. (For regression output, *see* Appendix A, §4.c (Confidential)).

Second, if you change the cast-iron main variable's period from 2005–2019 to 2010–2019 (*i.e.*, replace variable ""CI_ftx2005_After" with "CI_ftx2010_After"), to account for the actual increase in cast-iron pipe replacement after the TIRF/GSEP programs began (Figure 4) and rerun the Company's model, then the cast-iron main variable's coefficient is not significant. (For regression output, *see* Appendix A, §4.d (Confidential)).

Third, if, analogous to the main-related formulation offered in Section 3, above, you add (a) the long-term cast iron variable ("CI_ft"), (b) the dummy variable for the 2010-2019 period ("D_2010_After"), and (c) the 2010–2019 cast iron variable ("CI_ftx2010_After"), various variables are, again, not significant. (For regression output, *see* Appendix A, §4.e (Confidential)).

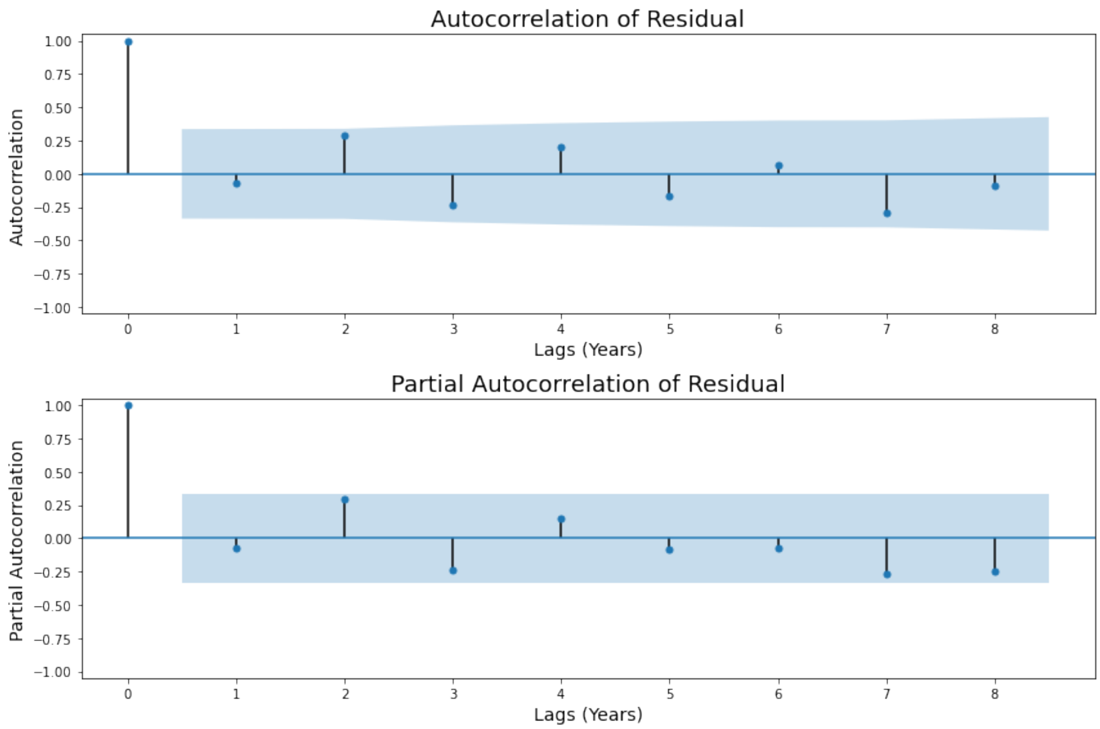
Fourth, if, as before, you add the "CI_ft", "D_2010_After", and "CI_ftx2010_After" variables, but also add an auto-regressive lag 1 or "AR(1)" variable, then the expanded model *does* compute, and all variables are significant. (For regression output of this expanded, autocorrelation-adjusted model, *see* Appendix A, §4.f (Confidential)).

This fourth regression has an R squared of 0.946, suggesting that it can account for 94.6% of maintenance expense variability. This model indicates that the marginal cost of maintenance expense with respect to demand equals $25.7/Dth. While a sendout term was investigated, it was not significant. Thus, the marginal cost of maintenance expense with respect to demand equals $0/Dth. Table 4 summarizes the coefficients and statistical significance of variables included in the modified model. Figure 5 plots the ACF/PACF for this modified model.

Table 4: Regression Results Modifying NG-MFB-3 p2 to Account for System Quality

Full Name	Variable Name	Coefficient Value	T Test	P Value
Constant	Const	132,709,175	4.57E+13	0.0000
Actual Peak Demand	A_pk	25.7049	2.0635	0.0391
Feet of Cast Iron Main	CI_ft	-8.6162	-10.2280	0.0000
Interactive: Feet of CI Main, 2010-2019	I_CI_ftx2010_After	16.4061	33.5538	0.0000
Dummy: 2010-2019	D_2010_After	-214,528,658	1.42E+14	0.0000
Dummy: 2008	d_2008	23,125,740	7.55E+12	0.0000
Dummy: 2009	d_2009	26,888,787	3.46E+14	0.0000
Dummy: 2010	d_2010	21,809,341	6.90E+12	0.0000
Dummy: 2016	d_2016	-8,197,732	-5.25E+13	0.0000
Dummy: 2018-2019	d_2018_2019	90,351,438	1.60E+13	0.0000
Autoregressive Var (Lag 1)	ar.L1	0.4403	2.8962	0.0038

Figure 5: ACF / PACF Plot for the Modified" Model



Q. What are your opinions of this final "modified" version of the Company's Exhibit NG-MFB-3 p2 model?

A. This "modified" version of Exhibit NG-MFB-3 p2 is superior to the Company's uncorrected version, but is not superior to the model that I offered in Exhibit AG-BWG-3 p2. Compared to the Company's proposed model (Exh. NG-MFB-3 p2), the modified model described in Table 4 meets all of the technical criteria discussed previously—it captures the long-run effect of system size/quality using the "CI_ft" variable, captures the structural change on the system at the start of the TIRG/GSEP era using the "I_CI_ftx2010_After" and "D_2010_After" variables, corrects for the misspecified cast-iron pipe term offered by the Company, and has approximately the same explanatory power as the Company's model.

That said, the relative complexity the modified model leaves something to be desired. The modified model requires 10 variables compared to my model's 5 variables (Exh. AG-BWG-3 p2). Moreover, 4 of those incremental variables are dummies that still lack theoretical justification. The modified model also offers little improvement in overall goodness of fit compared to my model (R Squared of 0.946 versus my R Squared of 0.927).

Q. What do you conclude from this investigation of maintenance costs?

A. I conclude that the Company, by luck (or trial and error), found a period for a cast-iron related variable that happened to be significant—ignoring that the 2005–2019 timeframe does not map to any underlying change on the system. While the inclusion of a system-size/quality related terms is not a bad idea, it is most likely not reasonable *in this instance.*

Moreover, it appears that the Company found four years to control for using dummy variables that are not based on any piece of theory. The Company makes no effort to justify its inclusion of various dummy variables (*e.g.*, Years 2008, 2009, 2010, and 2016). These variables reduce model power and, in line with Department guidance, I eliminated these variables because they are non-causal and do not appear to help with model fit.

Because the Company does not substantiate its use of four dummy variables, omits the logically relevant sendout variable, and includes a flawed and difficult to remedy cast-iron pipe variable, the Department should reject the Company's proposed model. Instead, the Department should adopt my model offered in Exhibit AG-BWG-3 p2 for maintenance expense because it has high explanatory power, is parsimonious, includes a sendout related term, and largely aligns with the outcomes of the "modified" Company model.

6. Conclusion

Q. Please summarize your final marginal cost estimates and compare them to the Company's values and the values you sponsored in direct testimony.

A. In summary, I conclude that:

- For marginal cost of distribution plant additions: The "base" model estimating marginal distribution plant addition cost, offered in this surrebuttal testimony, is superior in every way to what the Company proposes *or* what I proposed in direct testimony because Exhibit AG-BWG-Sur-2 actually calculates marginal costs, offers increased explanatory power, explicitly accounts for accelerated main replacement programs, is more parsimonious, and lacks any non-causal dummy variables. **The Department should adopt my updated model for distribution plant, offered in this surrebuttal testimony;**

- For marginal cost of distribution operations expense: The Company offered a reasonable theoretical justification for its model estimating marginal distribution operations expense in rebuttal testimony. **I do not object to use of the Company's model for operations expense, offered in Exhibit NG-MFB-3 p1;**

- For <u>marginal cost of distribution maintenance expense</u>: The Company's justification for their model estimating marginal distribution maintenance expense is not reasonable, and my proposed model in Exhibit AG-BWG-3 p2 offers similar explanatory power, is more parsimonious, and does not include an obviously misspecified variable. Moreover, my estimate has also been favorably benchmarked to a modified version of the Company's model which more appropriately accounts for system size/quality dynamics. **I recommend that the Department adopt the AGO model offered for maintenance expense in Exhibit AG-BWG-3 p2.**

Q. Based on your revised marginal cost estimates, please summarize your estimate of marginal cost per Dth delivered.

A. As shown on Exhibit AG-BWG-Sur-4 p2, I have estimated that the annual loss-adjusted marginal distribution capacity-related cost of service at a customer's meter is $380.64 per Dth of Design Day Demand, and $0.3620 per Dth of delivery quantities.

The marginal capacity cost per Dth of Delivery Quantities by rate category, as tabulated in Exhibit AG-BWG-Sur-4 p2, is shown in Table 5, below:

Table 5: Marginal Capacity Cost per Dth of Delivery Quantity, by Rate Category

	R1/R2	R3/R4	G&T 41/42/43/44	G&T 51/52/53/54
Normalized Usage - Annual Total (Dth)	1,387,315	70,691,370	42,276,860	20,179,114
Normalized Peak Day Demand	10,692	801,149	509,483	136,261
Marginal Capacity cost per Dth of Delivery Quantity	$3.30	$4.68	$4.95	$2.93

Q. How do your suggestions differ from the Company's current proposal and your initial proposal?

A. My revised estimates indicate that marginal costs are higher than the Company's estimates offered in Exhibit NG-MFB-6 p2, and higher than what I sponsored in Exhibit AG-BWG-4 p2. The Company's estimated annual loss-adjusted marginal distribution capacity-related cost of service at a customer's meter is $148.47 per Dth of Design Day Demand, and $0.00 per Dth of delivery quantities. My initial estimate for annual loss-adjusted marginal distribution capacity-related cost of service at a customer's meter was $240.05 per Dth of Design Day Demand, and $0.2983 per Dth of delivery quantities.

Q. Does this conclude your surrebuttal testimony?

A. Yes

AG-BWG-Surrebuttal-1 Appendix A

2021-04-30

These workpapers calculate marginal costs of capacity-related distribution plant and capacity-related maintenance expense based on NG timeseries data and support regression analyses discussed on surrebuttal.

Section 1 Libraries for Analysis

Section 2 Functions for statistical analysis

Section 3 Regressions for Distribution Plant

Section 4 Regressions for Distribution Maintenance Expense

THE ENTIRETY OF APPENDIX A HAS BEEN REDACTED.

MA AGO (Based on Exhibit NG-MFB-2-GRID p1 & AG-BWG-2 p1)

MARGINAL COST STUDY

Summary of Marginal Distribution Plant-Related Costs

Selected Model:

***N.b.**, all values changed from the AGO original (AG-BWG-2p1) are highlighted in yellow*

Line						
1	Dependent Variable					
2	Total **Cumulative** Distribution Capacity Additions 2019$ (1988 - 2019)					
3	Explanatory Variables		Data base variable name	Coefficient value	t test	Significance
4		Constant	const	-3,018,341,765	-45,425,370,684,426	0.0000
5		Normalized Peak Demand (Dth)	Combined_Norm_pk	3,567.2294	55.2030	0.0000
6		Interactive: Feet of Plastic Main, 2010-2019	Plas_2010_2019	163.6493	66.0416	0.0000
7		Dummy: Years 2010-2019	D_2010_After	-3,641,957,360	-3,076,643,298,688,130	0.0000
8		Total Sendout (Dth)	Tot_send	1.0522	2.5961	0.0094
9		Autoregessive Var (Lag 1)	ar.L1	0.7286	3.6624	0.0002
10						
11						
12	Model Statistics					
13		R_Squared	0.9982			
14		Adjusted R_Squared	Not Calculated			
15		Mean Absolute % Error (MAPE)	Not Calculated			
16		Passes ACF/PACF	Yes			
17						
18	Marginal Cost Calculation					
19		Cumulative Distribution Plant = -$ 3,018,341,765 + $ 3,567.23 x Combined_Norm_pk + $ 163.65 x Plas_2010_2019 + -$ 3,641,957,360 x D_2010_After + $ 1.05 x Tot_send + $ 0.73 x ar.L1				
20						
21		∂ Distribution Plant / ∂ Peak Demand = $ 3,567 per Dth	3567.22940			
22		∂ Distribution Plant / ∂ Sendout = $ 1.052 per Dth	1.05220			

National Grid
MARGINAL COST STUDY
Summary of Marginal Distribution Operations Expense

Selected Model:

***N.b.**, Company original replaces AG-BWG-3p1. All values from the Company original NG-MFB-3p1. Presented for completeness only.*

Line					
1	Dependent Variable				
2	Distribution Operations Expense 2019$ (1986 - 2019)				
3	Explanatory Variables	Data base variable name	Coefficient value	t test	Significance
4	Constant	Constant	8,498,277	1.82	0.0795
5	Actual Peak Demand	A_pk	13.29	2.31	0.0290
6	Dummy: Year 2001 and after	d_2001_After	(35,609,303)	(2.60)	0.0148
7	Dummy: Year 2018	d_2018	182,984,740	49.49	0.0000
8	Dummy: Year 2019	d_2019	25,990,568	7.09	0.0000
9	Dummy: Years 2013 to 2014	d_2013_2014	9,767,899	3.73	0.0009
10	Interactive: Feet of Main, years 2001 and after	I_Sum_Main_ftx2001_After	0.5406	2.11	0.0445
11	Model Statistics				
12	R_Squared	0.9921			
13	Adjusted R_Squared	0.9903			
14	Mean Absolute % Error (MAPE)	12.3269			
15	Passes ACF/PACF	Yes			

16

17 Marginal Cost Calculation

18 Distribution Non-Customer Operations Expense = \$ 8,498,277 + \$ 13.29 x A_pk + - \$ 35,609,303 x d_2001_After + \$ 182,984,740 x d_2018 + \$ 25,990,568 x d_2019 + \$ 9,767,899 x d_2013_2014 + \$ 0.5406 x I_Sum_Main_ftx2001_After

19

20 ∂ Distribution Operations Expense / ∂ Peak Demand = \$ 13.29 per Dth

MA AGO (Based on Exhibit NG-MFB-3-GRID p2)
MARGINAL COST STUDY
Summary of Marginal Distribution Maintenance Expense

Selected Model:

N.b., *Identical to AG-BWG-3p2; Presented for Completeness Only.*

Line	Item	Data base variable name	Coefficient value	t test	Significance
1	Dependent Variable				
2	Distribution Maintenance Expense 2019$ (1986 - 2019)				
3	Explanatory Variables	Data base variable name	Coefficient value	t test	Significance
4	Constant	Constant	(21,150,000)	-5.66E+12	-
5	Dummy: Year 2018	d_2018	82,330,000	3.45E+13	-
6	Dummy: Year 2019	d_2019	73,070,000	3.67E+15	-
7	Actual Peak Demand	A_pk	25.13	1.82228	0.0680
8	Total Sendout	Tot_send	0.2316	2.353395	0.0190
9	Autoregressive Term: Lag 1	ar.L1	0.75	6.19752	-
10					
11					
12	Model Statistics				
13	R_Squared	0.9270			
14	Adjusted R_Squared	Not Calculated			
15	Mean Absolute % Error (MAPE)	Not Calculated			
16	Passes ACF/PACF	Yes			

17

18 Marginal Cost Calculation

19 Distribution Non-Customer Maintenance Expense = - $ 21,150,000 + $ 82330000.00 x d_2018 + $ 73,070,000 x d_2019 + $ 00,025 x A_pk + $ 0.2316 x Tot_send + $ 0,000,001 x ar.L1

20

21 ∂ Distribution Maintenance Expense / ∂ Peak Demand = $ 25.13 per Dth

22 ∂ Distribution Plant / ∂ Sendout = $ 0.232 per Dth

MA AGO (Based on Exhibit NG-MFB-6-GRID p1 and AG-BWG-4 p1)
MARGINAL COST STUDY
Summary of Marginal Capacity Costs

N.b., all input values changed from the Company original are highlighted in yellow with red text.

Line		Demand	Source	Sendout	Source
1	Plant Investment				
2	Marginal Distribution Capacity Costs	$3,567.23	Exhibit AG-BWG-Sur-2, Page 1 Line 21	$1.0522	Exhibit AG-BWG-Sur-2, Page 1 Line 22
3	Marginal General Plant Loading Factor	2.43%	Exhibit NG-MFB-4, Page 3 Line 21	2.43%	Exhibit NG-MFB-4, Page 3 Line 21
4					
5	Total Marginal Plant Investment	$3,653.79	Line 2 * (1 + Line 3)	$1.0777	Line 2 * (1 + Line 3)
6					
7	Fixed Carrying Charge Rate	6.92%	Exhibit NG-MFB-5, Page 1 Line 20	6.92%	Exhibit NG-MFB-5, Page 1 Line 20
8					
9	Levelized, Annualized Cost of Marginal Plant Investment	$252.89	Line 5 x Line 7	$0.0746	Line 5 x Line 7
10					
11	Operations and Maintenance Expenses				
12	Marginal Operating Expense	$13.2897	Exhibit NG-MFB-3, Page 1 Line 20	$0.0000	Exhibit NG-MFB-3, Page 1 Line 21
13	Marginal Maintenance Expense	$25.1345	Exhibit AG-BWG-3, Page 2 Line 21	$0.2316	Exhibit AG-BWG-3, Page 2 Line 22
14					
15	Total Marginal O&M Expense	$38.42	Line 12 + Line 13	$0.2316	Line 12 + Line 13
16					
17	Administrative and General Expenses				
18	Marginal Plant related A&G per $ of Marginal Plant Investment	1.64%	Exhibit NG-MFB-4, Page 1 Line 21	1.64%	Exhibit NG-MFB-4, Page 1 Line 21
19	Plant related A&G Expense	$60.03	Line 18 x Line 5	$0.0177	Line 18 x Line 5
20					
21	Marginal Non-Plant related A&G per $ of Marginal O&M	5.03%	Exhibit NG-MFB-4, Page 1 Line 24	5.03%	Exhibit NG-MFB-4, Page 1 Line 24
22	Non-Plant related A&G Expense	$1.93	Line 21 x Line 15	$0.0117	Line 21 x Line 15
23					
24	Total A&G Expense	$61.96	Line 19 + Line 22	$0.0294	Line 19 + Line 22
25					
26	Marginal Working Capital Calculations				
27	Marginal M&S per $ of Marginal Plant Investment	0.79%	Exhibit NG-MFB-4, Page 2 Line 20	0.79%	Exhibit NG-MFB-4, Page 2 Line 20
28	M&S Cost	$28.98	Line 27 x Line 5	$0.0085	Line 27 x Line 5
29					
30	Cash Working Capital Allowance Rate	11.87%	43.31 Days	11.87%	43.31 Days
31	Working Cash O&M Allowance	$4.56	Line 30 x Line 15	$0.0275	Line 30 x Line 15
32	Revenue Requirement for Working Capital	$3.19	(Line 31 + Line 28) x Tax Effected Cost of Capital, Exhibit NG-MFB-5, Page 3 Line 21	$0.0034	(Line 31 + Line 28) x Tax Effected Cost of Capital, Exhibit NG-MFB-5, Page 3 Line 21
33					
34	Total Marginal Cost per Dth	$356.47	∑ Lines 9, 15, 24, 32	$0.3390	∑ Lines 9, 15, 24, 32
35	Escalator to Adjust to Rate Year	0.0390	Exhibit NG-MFB-5, page 3, Line 34	0.0390	Exhibit NG-MFB-5, page 3, Line 34
36	Total Adjusted Marginal cost per Dth	**$370.37**	Line 34 * (1 + Line 35)	**$0.3522**	Line 34 * (1 + Line 35)

MA AGO (Based on Exhibit NG-MFB-6-GRID p2 and AG-BWG-4 p2)
MARGINAL COST STUDY
Calculation of Loss-Adjusted Marginal Costs
by Class

N.b., all input values changed from the Company original are highlighted in yellow

Line		Peak Demand	Sendout	
1	Lost and Unaccounted for			
2	Distribution	2.70%	2.70%	Company records
3				
4	Marginal Distribution Capacity Cost ($/Dth)	$370.37	$0.3522	Exhibit AG-BWG-Sur-4, Page 1 Line 36
5				
6	Loss-Adjusted Marginal Capacity Cost	$380.64	$0.3620	Line 4 /(1 - Line 2)

Line		R1/R2	R3/R4	G&T 41/42/43/44	G&T 51/52/53/54	
7						
8						
9	Normalized Usage - Annual Total (Dth)	1,387,315	70,691,370	42,276,860	20,179,114	Company records
10						
12	Normalized Peak Day Demand	10,692	801,149	509,483	136,261	Company records
13						
14	Marginal Capacity cost per Dth of Delivery Quantity	$3.30	$4.68	$4.95	$2.93	(Line 13 x Line 6 PeakDemand) / Line 9 + Line 6 Sendout
15						

MA AGO (Based on Exhibit NG-MFB-6-GRID p3 and AG-BWG-4 p3)
MARGINAL COST STUDY
Summary of Marginal Capacity Cost Detail

N.b., all input values changed from the Company original are highlighted in yellow

Line		Peak Demand			Source
			Growth		
		Total	Expansion	Core: Reinforce	
		(A)	(B)	(C)	
A1	Growth-related Allocation	100.00%	18.48%	81.52%	Company Provided
	Plant Investment				
A2	Marginal Distribution Capacity Costs	$3,567.23	$659.29	$2,907.94	Exhibit AG-BWG-Sur-4, Page 1 Line 2
A3	Marginal General Plant Loading Factor	2.43%	2.43%	2.43%	Exhibit NG-MFB-4, Page 3 Line 21
A4	Total Marginal Plant Investment	$3,653.79	$675.29	$2,978.50	(1+Line A3) x Line A2
A5	Fixed Carrying Charge Rate	6.92%	6.92%	6.92%	Exhibit NG-MFB-5, Page 1 Line 20
A6	Levelized, Annualized Cost of Marginal Plant Investment	$252.89	$46.74	$206.15	Line A5 x Line A4
	Operations and Maintenance Expenses				
A7	Marginal Operating Expense	$13.29	$2.46	$10.83	Exhibit AG-BWG-Sur-4, Page 1 Line 6
A8	Marginal Maintenance Expense	$25.13	$4.65	$20.49	Exhibit AG-BWG-Sur-4, Page 1 Line 7
A9	Total Marginal O&M Expense	$38.42	$7.10	$31.32	Line A7 + Line A8
	Administrative and General Expenses				
A10	Marginal Plant related A&G per $ of Marginal Plant Investment	1.64%	1.64%	1.64%	Exhibit NG-MFB-4, Page 1 Line 21
A11	Plant related A&G Expense	$60.03	$11.09	$48.93	Line A10 x Line A4
A12	Marginal Non-Plant related A&G per $ of Marginal O&M	5.03%	5.03%	5.03%	Exhibit NG-MFB-4, Page 1 Line 24
A13	Non-Plant related A&G Expense	$1.93	$0.36	$1.58	Line A12 x Line A9
A14	Total A&G Expense	$61.96	$11.45	$50.51	Line A13 + Line A11
	Marginal Working Capital Calculations				
A15	Marginal M&S per $ of Marginal Plant Investment	0.79%	0.79%	0.79%	Exhibit NG-MFB-4, Page 2 Line 20
A16	M&S Cost	$ 28.98	$ 5.36	$ 23.63	Line A15 x Line A4
A17	M&S Rev Req	$2.76	$0.51	$2.25	Line A16 x (Sched NG-MFB-5 p3 Line 21)
A18	Cash Working Capital Allowance Rate	11.87%	11.87%	11.87%	43.31 Days
A19	Working Cash O&M Allowance	$4.56	$0.84	$3.72	Line A18 x Line A9
A20	Working Cash Revenue Requirement	$0.43	$0.08	$0.35	Line A19 x (Sched NG-MFB-5 p3 Line 21)
	Marginal Cost-based Rate Calculations				
A21	Total Marginal Cost per Dth	$356.47	$65.88	$290.58	∑ Lines A6, A9, A14, A17, A20
A22	Escalator to Adjust to Rate Year	3.90%	3.90%	3.90%	Exhibit NG-MFB-6, Page 1 Line 35
A23	Total Marginal Cost per Dth, adjusted for Rate Year	$370.37	$68.45	$301.92	Line A21 * (1 + Line A22)
A24	Loss Factor	2.70%	2.70%	2.70%	Company Provided
A25	Total Marginal Cost per Dth, adj for Rate Year and losses	$380.64	$70.35	$310.29	Line A23 / (1 - Line A24)
A26	Plant-related Marginal Cost per Dth	$272.99	$50.45	$222.53	(∑ Lines A6, A17) * (1+Line A22) / (1 - Line A24)
A27	Expense-related Marginal cost per Dth	$107.66	$19.90	$87.76	(∑ Lines A9, A14, A20) * (1+Line A22) / (1 - Line A24)
A28	Contract Floor price (Capacity Constrained)	$380.64	$70.35	$310.29	Line A27 + Line A26
A29	Contract Floor Price (Capacity not Constrained)	$107.66	$19.90	$87.76	Line A27
	Rate per Dth for 100% Load Factor Customer				
A30	Contract Floor price per Dth (Capacity Constrained)	$1.4048	$0.2596	$1.1452	Line A28 / 365 + Line B28
A31	Contract Floor Price per Dth (Capacity not Constrained)	$0.5764	$0.1065	$0.4699	Line A29 / 365 + Line B29
	Rate per Dth for Average High Load Factor (G-50s) Customer				
A32	Contract Floor price per Dth (Capacity Constrained)	$2.9323	$0.5419	$2.3904	Line A28 x Sched NG-MFB-6 p2 Line 12/ Sched NG-MFB-6 p2 Line 9 + Line B28
A33	Contract Floor Price per Dth (Capacity not Constrained)	$1.0084	$0.1864	$0.8220	Line A29 x Sched NG-MFB-6 p2 Line 12/ Sched NG-MFB-6 p2 Line 9 + Line B29

Line		Sendout			Source
			Growth		
		Total	Expansion	Core: Reinforce	
		(E)	(F)	(G)	
B1		100.00%	18.48%	81.52%	Company Provided
	Plant Investment				
B2		$1.0522	$0.1945	$0.8577	Exhibit AG-BWG-Sur-4, Page 1 Line 2
B3		2.43%	2.43%	2.43%	Exhibit NG-MFB-4, Page 3 Line 21
B4		$1.08	$0.1992	$0.8785	(1+Line B3) x Line B2
B5		6.92%	6.92%	6.92%	Exhibit NG-MFB-5, Page 1 Line 20
B6		$0.0746	$0.0138	$0.0608	Line B5 x Line B4
	Operations and Maintenance Expenses				
B7		$0.0000	$0.0000	$0.0000	Exhibit AG-BWG-Sur-4, Page 1 Line 6
B8		$0.2316	$0.0428	$0.1888	Exhibit AG-BWG-Sur-4, Page 1 Line 7
B9		$0.2316	$0.0428	$0.1888	Line B7 + Line B8
	Administrative and General Expenses				
B10		1.64%	1.64%	1.64%	Exhibit NG-MFB-4, Page 1 Line 21
B11		$0.02	$0.0033	$0.0144	Line B10 x Line B4
B12		5.03%	5.03%	5.03%	Exhibit NG-MFB-4, Page 1 Line 24
B13		$0.0117	$0.00	$0.01	Line B12 x Line B9
B14		$0.0294	$0.01	$0.02	Line B13 + Line B11
	Marginal Working Capital Calculations				
B15		0.79%	0.79%	0.79%	Exhibit NG-MFB-4, Page 2 Line 20
B16		$0.0085	$ 0.0016	$ 0.0070	Line B15 x Line B4
B17		$0.00	$0.00	$0.00	Line B16 x (Sched NG-MFB-5 p3 Line 21)
B18		11.87%	11.87%	11.87%	43.31 Days
B19		$0.0275	$0.0051	$0.0224	Line B18 x Line B9
B20		$0.0026	$0.0005	$0.0021	Line B19 x (Sched NG-MFB-5 p3 Line 21)
	Marginal Cost-based Rate Calculations				
B21		$0.3390	$0.0627	$0.2763	∑ Lines B6, B9, B14, B17, B20
B22		3.90%	3.90%	3.90%	Exhibit NG-MFB-6, Page 1 Line 35
B23		$0.3522	$0.0651	$0.2871	Line B21 * (1 + Line B22)
B24		2.70%	2.70%	2.70%	Company Provided
B25		$0.3620	$0.0669	$0.2951	Line B23 / (1 - Line B24)
B26		$0.0805	$0.0149	$0.0656	(∑ Lines B6, B17) * (1+Line B22) / (1 - Line B24)
B27		$0.2815	$0.0520	$0.2294	(∑ Lines B9, B14, B20) * (1+Line B22) / (1 - Line B24)
B28		$0.3620	$0.0669	$0.2951	Line B27 + Line B26
B29		$0.2815	$0.0520	$0.2294	Line B27

COMMONWEALTH OF MASSACHUSETTS
DEPARTMENT OF PUBLIC UTILITIES

Boston Gas Company d/b/a National Grid	))))	**DPU 20-120**

AFFIDAVIT OF BENJAMIN GRIFFITHS

Benjamin Griffiths does hereby depose and say as follows:

I, Benjamin Griffiths, on behalf of the Massachusetts Attorney General's Office, certify that the testimony, including information responses, which bear my name was prepared by me or under my supervision and is true and accurate to the best of my knowledge and belief.

Signed under the pains and penalties of perjury this 30th day of April, 2021.

Benjamin Griffiths