Appendix:
The Impact of Cheap Natural Gas on Marginal Emissions from Electricity Generation and Implications for Energy Policy

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This appendix provides robustness checks on the natural gas price regime definitions and identification strategy. We present results identifying marginal emissions off differences in natural gas and coal prices, rather than using regime definitions. We the present a robustness check that drops six months of the sample on either side of the the regime change date we use in the main text. Finally we present suggestive evidence that the costs of complying with the requirements of the Clean Air Act to purchase pollution permits does not have a significant impact on the changes in marginal emissions rates presented in the main text. In these robustness checks we present results for each NERC region pooled across the entire year, rather than for any particular month to save space.

1 Identification from input price levels

In this section we identify the impact of changes in natural gas prices on marginal emissions by including fuel prices directly in the estimation rather than separating the sample into fuel price regimes. While this specification is useful we do not prefer for economic reasons: the implicit economic assumption with this specification is that coal and natural gas prices used by firms in their bidding behavior in the wholesale market reflect spot prices. However, it is well known that coal contracts especially are long lived so that prices paid by electricity generators may not reflect spot prices on commodity markets. Further, the pass through of natural gas prices in electricity markets is an open question in the economics literature. For these reasons, we are not confident in the point estimates of these specifications but the qualitative findings are instructive.

Despite these concerns, we estimate the following econometric model:

$$E_{h,n} = \beta_{h,n}(load_{h,n} * hour_h * (P_c - P_g)) + \gamma_{n,m,y,h,d}(month * year * hour * dow) + \epsilon_{h,n}, \qquad (1)$$

where P_c is the coal price and P_g is the natural gas price. Both prices are collected from Bloomberg data reported daily in dollars per mmBTU. All control variables are identical to the control variables which we use in the econometric specifications in the main body of the paper. The coefficient of interest in this specification is $\beta_{h,n}$ where h represents the hour of the day and

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n represents the NERC region. Using relative prices in this way eliminates the need to break the sample into natural gas price regimes. The proper interpretation of this coefficient is that for a one dollar increase in relative prices between coal and natural gas (e.g., the price of coal increases by one dollar or the price of natural gas decreases by one dollar) the estimated coefficient is the change in the emissions rate for a particular hour in a particular NERC region. As a result, a negative coefficient implies that marginal emissions rates decrease when the price of coal increases or the price of natural gas decreases.

The results are summarized in figure A1. Constant across all regions is that decreases in the price of natural gas affect marginal emissions significantly more during the nighttime hours. This is consistent with natural gas more frequently being used as a marginal fuel during night hours as the price of natural gas decreases (e.g. Figure 9 in the main document). To some extent, the results from this econometric model reflect the relative share of coal as the marginal fuel during each hour of the day in Figure 9.

The results are also consistent with the qualitative findings in the main regression specification in which we estimate marginal emissions for the high and low natural gas price regimes. Specifically, the estimated difference in marginal emissions in the "regimes" specification decreased the most during night hours and either increased or stayed constant during daytime hours. The exception to this trend is Florida (FRCC) which, as explained in the main text, never satisfied load using a significant amount of coal to begin with (10-30%) and was building significant natural gas capacity over the sample period.

2 Gas price regime definitions

The Markov Switching Model presented in the text identifies January 8, 2009 as the most likely date of a regime shift. In this section we test the robustness of the estimated marginal emissions rates across NERC regions. We redefine our regime dates to exclude the six months on either side of January 2009. The new high natural gas price regie is defined as January 1st, 2005 through June 20th, 2008. The low natural gas price regime is defined at July 1st, 2009 through December 31st, 2011. We then re-estimate the marginal emissions specification using the new natural gas price regime definition:

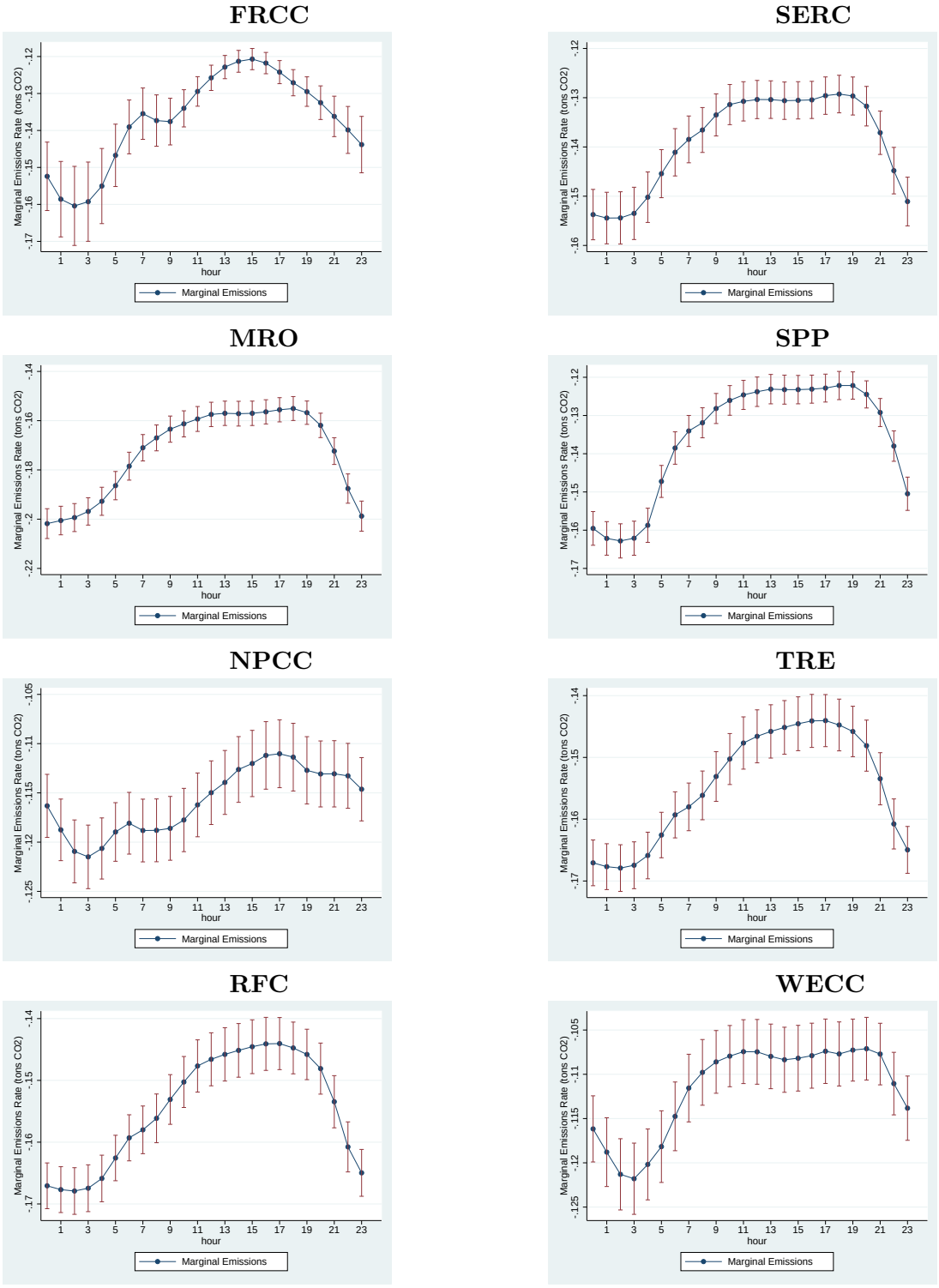
$$E_{h,n} = \beta_{h,r,n}(load_{h,n} * hour_h * regime_r) + \gamma_n(month * year * hour * dow) + \epsilon_{h,n}, \qquad (2)$$

The resulting β coefficients are presented in figure A2. The results are almost identical to those presented in the text in our main specification. We take this as evidence that neither the transition period in natural gas prices between 2008 and 2009 nor the recession over that time period is driving our results. We also find the marginal emissions estimates to be robust to excluding 2008 and 2009 from the data set although, the coefficients in that case are somewhat less precisely estimated. These results are available upon request.

3 Emissions trading programs

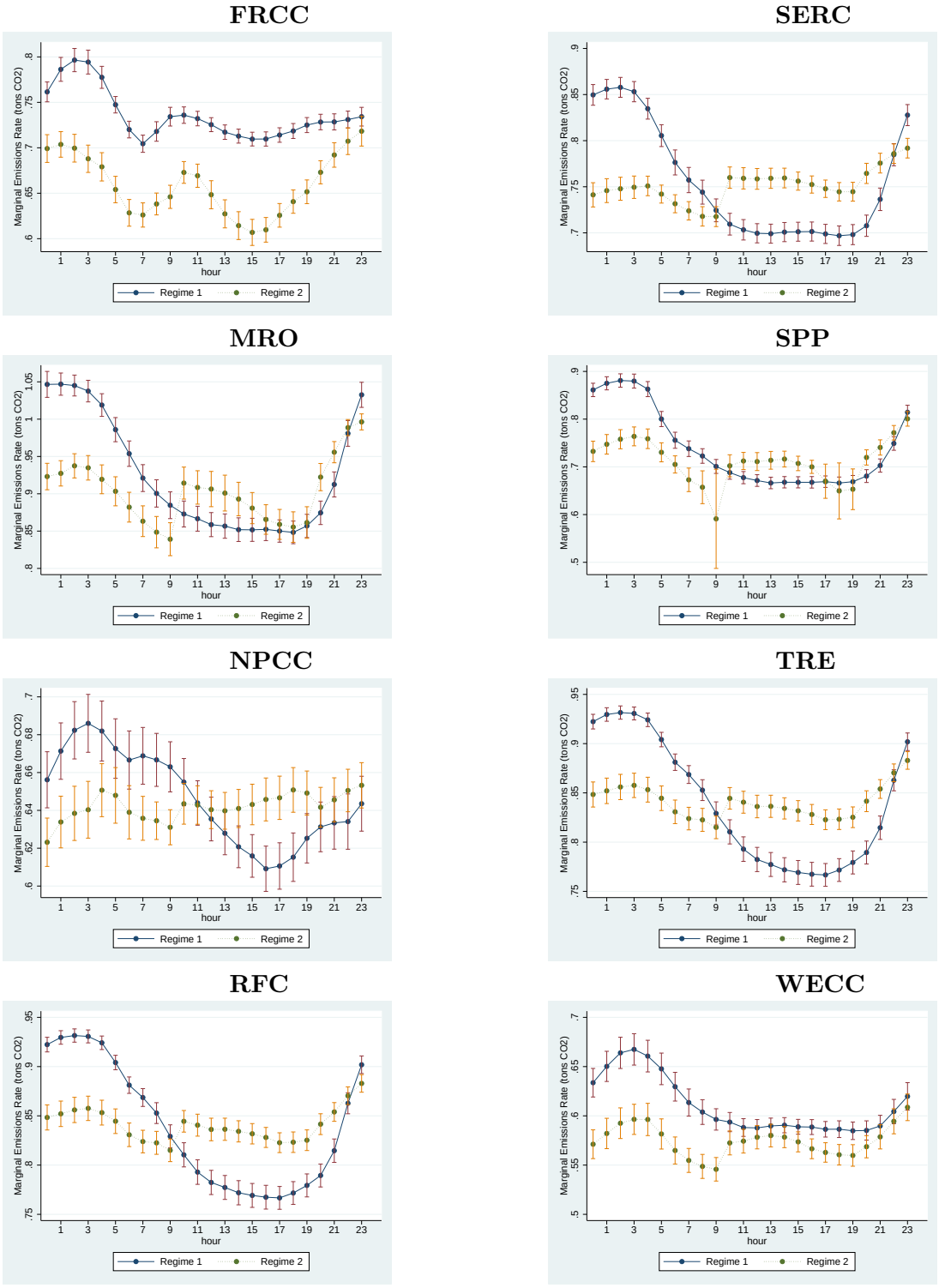
Changes in environmental regulation intensity could also shift the electricity fuel type mix by making natural gas fired generation relatively more attractive. If increases in environmental regulation stringency coincided with changes in natural gas prices we could mistakenly attribute the observed

Figure A1: Marginal CO_2 emissions estimated from relative fuel prices



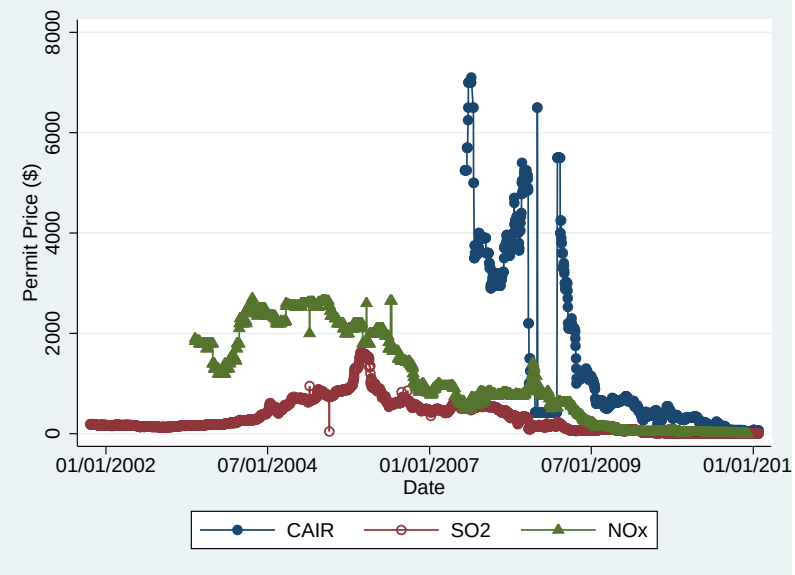
Note: Marginal emissions rates for CO_2 associated with a one unit increase in the natural gas-coal price ratio for each NERC region. Each panel displays estimates from a single regression with 61,296 hourly observations and robust standard errors.

Figure A2: Marginal CO_2 emissions across NERC region under alternate regime definitions



Note: Marginal emissions rates for CO_2 across alternate natural gas fuel price regimes for each NERC region. The high gas price regime is defined as the beginning of January 2005 through the end of June 2008. The low gas price regime is defined as July 2009 through the end of 2011. This eliminates the six months on either side of the regime change identified by the Markov Switching model. Each panel displays estimates from a single regression with 61,296 hourly observations and robust standard errors.

Figure A3: Pollution permit prices



Note: Pollution permit prices over the study period for three tradeable permit programs. CAIR is the Clean Air Interstate Act which began trading in 2007. SO2 and NOx prices are part of the Clean Air Act Amendments cost containment schemes. Permit prices have fallen in tandem with natural gas prices.

changes in marginal emissions rates to natural gas prices. There are three major cap-and-trade programs that electricity generators are subject to. Under the Clean Air Act and its amendments power plants must purchase emissions permits to cover their emissions of SO_2 and NO_x. During our study period the EPA introduced a new cap-and-trade program known as the Clean Air Interstate Rule. The regulation was officially promulgated in 2005, but permits did not begin trading till 2007. Several court challenges have threatened the validity of the program, but permits have continued to trade. Figure A3 describes the price of pollution permits under each program over the life of the markets.

Pollution permit prices have been strongly correlated with natural gas prices over the study period. As coal fired generation has been replaced by natural gas as baseload the price of permits have fallen. SO2 permits that consistently traded over $500 during peak natural gas prices are now trading for less than $5. This suggests that the costs of complying with environmental regulation has actually fallen during the low natural gas price regime. The reduction in permit prices has actually made coal fired generation relatively more attractive in regime 2 implying that the change in marginal emissions rates described above actually understates the changes that would be expected had the firm level cost of the environmental policy regime remained constant.