A Day late and a Dollar short: Intertemporal Revenue Cap Regulation considering Stranded Assets

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Overview

The transition toward carbon neutrality by 2050 has introduced substantial challenges for natural gas distribution grids in the European Union (EU). These networks, traditionally amortized over extended periods, now face risks of underutilization and stranded assets due to declining demand. This decline is driven by several factors, including the rising adoption of low-carbon technologies like heat pumps, increased carbon pricing through mechanisms such as the EU Emissions Trading System II (ETS II), and the introduction of subsidies for retrofitting buildings and alternative heating systems. The central focus of this research lies in analyzing how revenue cap regulations—predominantly used in many European countries—affect the ability to recover fixed infrastructure costs in the face of accelerating decarbonization timelines. Utilizing an intertemporal equilibrium model, we evaluate the dynamic interactions between network tariffs, household behavior, and welfare outcomes under varying regulatory frameworks. In doing so, we provide an analytical foundation for understanding the structural inefficiencies and potential solutions inherent in existing regulatory approaches.

Methods

The methodology centers on constructing a mathematical equilibrium model that captures the interdependencies among three core decision-making entities: households, network operators, and regulators. Households are modeled as rational agents seeking to minimize their heating costs by either remaining connected to the gas grid or defecting to alternative heating technologies. Their defection decisions depend on a cost-benefit analysis incorporating the relative costs of gas and electricity, investment costs for switching, and anticipated savings. Heterogeneity among households is explicitly modeled by differentiating them based on their heating demand and the one-time costs associated with transitioning to alternative technologies.

Network operators, constrained by revenue caps set by regulators, aim to maximize profits. These revenue caps are structured to recover the fixed costs of grid infrastructure over time. The interplay between household defection and network tariffs creates a feedback loop: rising tariffs incentivize more defections, reducing the user base and further exacerbating cost-recovery challenges. Regulators, as the third stakeholder, set revenue caps to balance multiple objectives, such as achieving efficient household decisions, ensuring fairness in cost recovery, and minimizing overall social costs. The model examines three regulatory scenarios: (1) (optimal) degressive front-loading, where higher tariffs are imposed in earlier periods to recover costs while the user base is still large; (2) traditional linear depreciation, which spreads cost recovery evenly over the asset's intended lifetime; and (3) unregulated profit-maximization by operators, constrained only by household defection. Welfare implications are assessed through two dimensions: internal welfare effects, which reflect outcomes within the regulated grid, and external welfare effects, which account for broader societal impacts of incomplete cost recovery.

Results

The model's results highlight degressive front-loading as the most effective strategy for reconciling cost recovery and minimizing welfare losses in declining gas networks. By concentrating cost recovery in the initial years, when household defections are fewer, degressive front-loading mitigates the financial strain on remaining users in later periods. This strategy contrasts sharply with traditional linear depreciation, which fails to adapt to declining demand and results in incomplete cost recovery, particularly when the operational horizon of the grid is shortened to align with decarbonization goals.

The analysis reveals that under degressive front-loading, tariffs decline over time, reducing the likelihood of a "death spiral" in which rising tariffs trigger accelerated defections. In contrast, linear depreciation schemes result in escalating tariffs as the user base diminishes, disproportionately burdening late-defecting households. These households, often characterized by higher costs of switching to alternatives, face significant financial strain, exacerbating social inequities. Additionally, the results underscore that under unregulated scenarios, operators prioritize profit maximization, setting tariffs at levels that accelerate household defections. Degressive front-loading also addresses the dynamic interactions between tariffs and household defection. The study finds that higher initial tariffs incentivize households with lower switching costs to defect early, leaving a relatively stable base of users who are less price-sensitive. This stabilizing effect enables more predictable cost recovery and reduces the social costs associated with stranded assets. The findings suggest that incorporating household heterogeneity and dynamic decision-making into regulatory frameworks is essential for achieving sustainable outcomes.

Internal welfare effects, measured as the combined consumer and producer surplus within the regulated grid, vary significantly across the regulatory scenarios. Degressive front-loading aligns tariff trajectories with the household cost-benefit considerations. By doing so, it maximizes the consumer surplus associated with efficient household decisions. Producer surplus is also preserved under this approach, as cost recovery occurs during periods when the user base remains sufficiently large to support higher tariffs. Linear depreciation, in contrast, results in substantial internal welfare losses. The even distribution of cost recovery over time does not account for the accelerated decline in demand, leading to inefficiencies in household decision-making. Households with medium switching costs are incentivized to defect prematurely, while those with higher costs face rising tariffs and diminishing consumer surplus. Producer surplus is also negatively impacted, as incomplete cost recovery leaves operators unable to recoup their investments. The unregulated scenario produces the most severe internal welfare losses. Operators, unconstrained by revenue caps, set tariffs at levels that maximize short-term profits but induce widespread household defections. The resulting collapse of the user base exacerbates inefficiencies in household decision-making, as many households are forced to switch prematurely to avoid unsustainable tariff burdens.

The study also evaluates external welfare effects, defined as the societal costs associated with incomplete cost recovery. These costs include increased capital costs for future investments in infrastructure, reduced investor confidence in regulated industries, and potential disruptions to essential services. Degressive front-loading proves effective in minimizing these external costs by achieving a higher degree of cost recovery than linear depreciation scenarios. The model demonstrates that under front-loading, cost recovery may approach full amortization of the asset base, ensuring financial stability without overburdening households. Depending on the setting, linear depreciation may only achieve partial cost recovery, and fails to amortize infrastructure investments fully even within a shortened depreciation timeframe. This gap in cost recovery may impose significant external costs on society, as operators may require public subsidies or higher risk premia for future projects. These findings underscore the importance of regulatory intervention in balancing financial sustainability with social equity.

The distributional impacts of different regulatory scenarios are a critical dimension of the analysis. Under degressive front-loading, the cost burden is distributed more equitably across households. Early defectors, who face lower switching costs, absorb a higher share of the initial tariffs, while late defectors benefit from declining tariffs in later periods. This approach reduces the financial strain on households with limited flexibility to switch, ensuring a more balanced allocation of costs. In contrast, linear depreciation disproportionately impacts late defectors, who bear the brunt of rising tariffs as the user base diminishes. These households, often characterized by structural barriers to adopting alternative technologies, face significant economic hardships under this regulatory framework.

Conclusions

This study provides a rigorous analysis of the challenges associated with cost recovery in declining natural gas networks under different regulatory frameworks. By examining the dynamic interactions between network tariffs, household defection, and welfare outcomes, it identifies degressive front-loading as the optimal strategy for balancing efficiency, fairness, and financial sustainability. The findings underscore the importance of incorporating household heterogeneity and behavioral dynamics into regulatory designs, as well as the need for proactive measures to address the risks of stranded assets and incomplete cost recovery. While the focus of this research is on analytical insights, the implications extend to broader debates on the role of regulation in supporting the energy transition and ensuring equitable outcomes for all stakeholders.