

The HMLV Pivot: Digital Convergence, Energy-Inclusive TFP, and the Substitution Threshold of AI in Advanced Manufacturing

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Abstract: This paper investigates the shifting structural relationship among human labor, adaptive robotics, and energy inputs within High-Mix Low-Volume (HMLV) manufacturing. While neoclassical frameworks often attribute unexplained output growth to a “Solow Residual,” this study argues that such “innovation” is largely a manifestation of energy-capital synergies. Utilizing a nested Constant Elasticity of Substitution production function and Houthakker’s (1955) distributional approach, we identify a “Substitution Regime” where the elasticity of substitution (σ) surpasses critical thresholds, triggering wage stagnation. A key methodological contribution is our high-resolution analysis of 6-digit NAICS industrial data (1949–2023), which allows for the isolation of specific technological shifts in the Aerospace and Medical Instruments sectors granularity that is typically obscured in aggregate 3-digit sectoral studies. Utilizing a quasi-causal Difference-in-Differences design, our results demonstrate that the Energy-Inclusive Physical Production model significantly outperforms the traditional Capital-Labor baseline, achieving an $R^2 = 0.72$ and reducing residual variance into non-systematic white noise. We find that a 10% increase in real energy prices is associated with a 1.29 percentage point contraction in the labor share, indicating that modern autonomous systems act as a capital-energy composite that directly absorbs the “human premium” for flexibility.

Keywords: Total Factor Productivity, HMLV Manufacturing, Energy Synergy, Substitution Thresholds, Universal Basic Capital

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