Impact of Automation on Employment and Productivity: A nonlinear Input – Output Model

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Abstract

Impacts of automation, digitalization, and artificial intelligence on economic and social development are at the forefront of contemporary academic and policy debates. These technologies offer both transformative opportunities and disruptive challenges. A central concern is their potential to substitute human labour, leading to structural shifts in the labour market. To what extent can productivity gains offset employment losses? Is the working society at risk of running out of jobs, or can demographic pressures—such as the declining working-age population in many EU countries—be mitigated through technological progress?

Recognizing that the performance of an economy arises from the complex relationships between individual industries rather than from the merely sum of their activities, we shall use a modified open input - output model where instead of explaining primary inputs by constant coefficients of Walras – Leontief production function substitution possibilities among three primary factors: labour, traditional physical capital (machines, production facilities, production halls etc.), and automation capital (robots, 3D printers, etc.), conceptualized as "programmable labour are admitted. Following Johansen (1960); Schumann (1968), Luptáčik (1977, 2010) we assume constant coefficients for current inputs and variable proportions between primary inputs by using a Cobb – Douglas production function for each industry. When an industry changes over to more automation capital intensive methods of producing goods to satisfy final demand, the structure of current inputs will not be affected very much but will alter the proportion in primary input requirements.

For simplicity but without loss of generality, we consider the two-sector economy and formulate a nonlinear optimization problem with the objective of minimizing total labour input for an exogenously given final demand (in other words,maximization of labour productivity) The constraints include sector-specific endowments of both physical and automation capital. This problem belongs to the class of geometric programming problems (Luptáčik, (1977), (2010), ch. 6), which allows for efficient solution and meaningful economic interpretation through the lens of duality theory.

The solution of the dual problem—characterized by a nonlinear objective function and linear constraints—reveals the dual variables as elasticity coefficients associated with each term of the primal objective function and constraints. These coefficients provide insight into how changes in capital stocks affect employment across sectors. From this dual structure, we derive a nonlinear employment multiplier, which estimates the lower bound on employment growth resulting from an increase in final demand and/or in automation capital endowment under primary factor substitution.

Several key propositions emerge from the model:

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- The employment elasticity of automation capital in a given sector cannot be higher than the ratio of the output elasticity of automation capital to that of labour in the same sector.
- If the output elasticity of automation capital in sector j exceeds that of labour, the constraint on automation capital is binding; i.e., automation capital is fully utilized.
- When the output elasticity of labour equals that of automation capital in a sector, the employment share in that sector equals the elasticity of automation capital.
- The employment share in sector 1 depends on the production function parameters of sector 2. An increase in the output elasticity of automation capital in sector 2 leads to a higher employment share in sector 1, while a higher output elasticity of labour in sector 2 reduces it.

To illustrate the interindustry implications of these results, we present an analytical two-sector version of the model. The framework shows how increased investment in automation in one sector affects employment not only locally, but throughout the economy due to input–output linkages. Moreover, dual variables linked to capital constraints quantify the percentage change in employment resulting from a 1% increase in the availability of physical or automation capital in a given sector.

In summary, the proposed model provides a flexible and theoretically sound framework for analyzing substitution processes between labour, physical capital, and automation capital. It supports policy design in addressing technological change by quantifying employment impacts and clarifying the structural conditions under which automation complements or substitutes labour.

References

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