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Labor-Eliminating Technology, Wage Inequality and Trade Protectionism

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Abstract: Rapid automation in manufacturing has raised pressing questions in public and policy discourse regarding the effects of a labor-eliminating technical progress in an industry. We address the implications of a labor-eliminating technology adopted in manufacturing for factor price changes, for skilled and unskilled wage gap, and for trade policies intending to protect workers. Using an otherwise traditional multi-sector general equilibrium model, we derive the conditions under which a labor-eliminating technology will be adopted in manufacturing, and show that such a technical change in manufacturing will increase the rate of return on capital, and decrease both skilled and unskilled labor wages. We derive conditions under which wage inequality increases, and most importantly, we show that implementing protectionist trade policies in the industry experiencing a labor-eliminating technical progress will paradoxically hurt the workers that the policy is meant to protect.

Keywords: Automation; Skilled-Unskilled Wage Gap; Trade Policy

JEL Classifications: D51; F13; J23; O14

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Abstract

Rapid automation in manufacturing has raised pressing questions in public and policy discourse regarding the effects of a labor-eliminating technical progress in an industry. We address the implications of a labor-eliminating technology adopted in manufacturing for factor price changes, for skilled and unskilled wage gap, and for trade policies intending to protect workers. Using an otherwise traditional multi-sector general equilibrium model, we derive the conditions under which a labor-eliminating technology will be adopted in manufacturing, and show that such a technical change in manufacturing will increase the rate of return on capital, and decrease both skilled and unskilled labor wages. We derive conditions under which wage inequality increases, and most importantly, we show that implementing protectionist trade policies in the industry experiencing a labor-eliminating technical progress will paradoxically hurt the workers that the policy is meant to protect.

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1 Introduction

Statistical evidence points to a clear trend of stagnant/decreasing wages, a decreasing labor share and increasing wage inequality; see, among others, Acemoglu and Restrepo (2019a). The literature on labor wages and in particular the skilled-unskilled wage gap is extensive. Motivated by the well-documented wage inequality between skilled and unskilled labor, and the widening gap between the two, many scholars have emphasized the growth in international trade and technical progress as potential driving forces (e.g., Tower and Pursell, 1987; Bound and Johnson, 1989; Katz and Murphy, 1992; Jones, 1996; Cline, 1997; Baldwin and Cain, 2000; and Oladi and Beladi, 2008). The theoretical foundations for the branch of the literature that claims that increased international trade is the driving force behind the observed wage changes mostly rely on the Stolper-Samuelson theorem. The literature that deals with effects of technical progress on wage changes, however, has assumed a factor-augmenting (or a factor-neutral) technical change. Given rapid automation in production (especially in the form of the introduction of industrial robots), while it may be tempting to use such canonical models relying on capital-augmenting technical changes, it is also well-known that such a capital-augmenting technical progress would not be able to explain wage/labor demand declines; see, for example, Acemoglu and Restrepo (2018b).[1] In particular, a capital-augmenting technical progress would always increase labor demand and wages, and would not be able to capture the fact that physical capital (in the case of automation in manufacturing) has been displacing labor.[2]

There is clear evidence that automation has been directly substituting blue-collar workers contributing to lower wages of unskilled labor and to wage inequality, see, among others, Acemoglu and Restrepo (2021), Autor et al. (2003), Goos and Manning (2007), and Michaels etal. (2014). Although a factor-eliminating technical progress, introduced by Seater (2005), has been used in the macroeconomics literature in the context of economic growth (see also Zuleta, 2008 and more recently Seater and Yenokyan, 2019), its implications have not yet been well established in a multi-sector general equilibrium model that looks into also protectionist trade policy outcomes. In a series of influential papers, Acemoglu and Restrepo have introduced and employed a task-based approach so as to explain the implications of automation for the labor market; see, among others, Acemoglu and Restrepo (2018a), Acemoglu and Restrepo (2018b), Acemoglu and Restrepo (2019a), Acemoglu and Restrepo (2021), and Acemoglu and Restrepo (2020).

[1] For evidence on wage declines in areas especially exposed mostly to the introduction of industrial robots, see Acemoglu and Restrepo (2020).

[2] For several historical and recent examples of such labor-eliminating technical changes, see Acemoglu and Restrepo (2019a) and Acemoglu and Restrepo (2019b).

Their modeling approach is that automation leads to the expansion of the set of tasks that can be produced by machines (industrial robots) directly replacing labor. That is, there is substitution of capital for labor (so long as the cost savings are positive), which is referred to as the displacement effect (or automation at the extensive margin). They show that such technological improvements reduce wages. In particular, they distinguish between a displacement effect that reduces labor demand, and a range of other effects that increase demand for labor such that a productivity effect (that works through product markets decreasing real prices, increasing real incomes and demand); a capital accumulation effect (increasing capital intensity of production); and the effect of automation at the intensive margin (so-called deepening of automation that increases the productivity of capital in tasks that are already automated).

This paper is closely related to Gilbert and Oladi (2021) (which focuses on automation in developing economies) and complements the task-based framework introduced by Acemoglu and Restrepo (as summarized in Acemoglu and Restrepo, 2019b). Specifically, we show how labor-eliminating technical progress influences skilled and unskilled wages, factor income shares, wage inequality and protectionist trade policy implications in an otherwise traditional multi-sector general equilibrium model. In order to do so, we construct a three-sector general equilibrium model in which a high-tech sector uses skilled labor, and the remaining sectors (which we interpret as manufactures and services) employ unskilled labor. Capital is also used as a mobile input in all three sectors. Our main result is that, under fairly general conditions, labor-eliminating technical change lowers both skilled and unskilled wages but increases the skilled-unskilled wage gap. Our paper is also related to Pi and Zhang (2018) who show the effect on wage inequality of what they term an exogenous structural change. In their setup, Pi and Zhang (2018) assume that the government changes the production technology directly by altering the production parameters of Cobb-Douglas production functions. In addition to the restrictive nature of the technology, which we relax in this paper, in their setup the important question of firm's choice of whether or not to adopt a labor-eliminating technology is not present.

The recent revival of protectionist sentiments among the public in the United States, the United Kingdom and elsewhere, and the concomitant imposition of protectionist policies, raise important questions as to the effects of such policies on wages in an economy that is experiencing a labor-eliminating technical progress. We show that a tariff increase on manufactures can easily exacerbate the effects of a labor-eliminating technical change on labor markets. Hence, in contrast to public expectations, protectionist trade policies may hurt the unskilled workers that they are intended to protect.

The remainder of the paper is organized as follows. In Section 2 we introduce the model. In Sections 3 and 4 we solve the model for the effects of a labor-eliminating technical progress on the changes in factor prices, in factor income shares, in wage inequality, and in sector-specific outputs. Section 5 discusses the implications of protectionist trade policies in the case of a labor-eliminating technical change. Finally, Section 6 offers some concluding remarks.

2 The Model

We consider a small open economy that produces three goods, a high tech good, a manufactured good, and a service, denoted by h, m and s, respectively. All three sectors use capital as an input. In addition, the high tech sector uses skilled labor, while the manufacturing and service sectors use unskilled labor. To keep the model as simple as possible, we assume competitive product and factor markets, and neoclassical production technologies for all sectors with the usual assumptions.

In order to cleanly isolate the impact of factor-eliminating technical change on factor prices, we let production technology be represented by a CES function:

$$Q_i = [\delta_i K_i^{\rho_i} + I(1-\delta_i) H_i^{\rho_i} + (1-I)(1-\delta_i) U_i^{\rho_i}]^{\frac{1}{\rho_i}}, \quad i \in \{h, m, s\}, \tag{1}$$

where Q, K, H and U represent output, capital, skilled labor and unskilled labor, respectively, and $\rho < 1$, $\rho \neq 0$.[3] I is the indicator variable that takes the value of one if it is the high-tech sector (i.e., $I = 1$ if $i = h$), or zero otherwise (i.e., $I = 0$ if $i \neq h$).

Following Gilbert and Oladi (2021), we model a labor-eliminating technical change as a capital-augmenting technical change that is combined with a labor-disaugmenting technical change, which effectively moves the unit value isoquant diagonally away from the factor being eliminated.[4] That is, we consider an increase in the distribution parameter, denoted by δ_m, in (1), so as to capture a labor-eliminating technical change that takes place in the manufacturing industry.[5]

[3]In particular, our results will still hold true even if we relax the CES-assumption for the service and high-tech sectors.

[4]The way we model a factor-eliminating technical change thus generates both an inward (outward) movement along horizontal vectors and an opposite outward (inward) movement along vertical vectors above the unit vector. It is worth noting the total contrast to neutral technical improvements generating a proportional inward movement of the unit value isoquant along all vectors from the origin, and to factor augmenting technical improvements generating a proportional inward movement along all vertical (or horizontal) vectors.

[5]It goes without saying that a decrease in δ_i would then imply a capital-eliminating technical change in sector i, in our context. Also note the similarities between our approach and the task-based framework introduced by Acemoglu and Restrepo (as summarized in Acemoglu and Restrepo, 2019b): while we do not explicitly model tasks that are automated in production, both this paper and the papers by Acemoglu and Restrepo employing a task-based framework model automation such that it leads to (directly or indirectly) a simultaneous change in the distribution shares of factors employed in the automated sector.

Given that the markets are competitive, the price should be equal to unit cost in each sector:

$$p_m = c_m(w_U, r), \tag{2}$$

$$1 = c_s(w_U, r), \tag{3}$$

$$p_h = c_h(w_H, r), \tag{4}$$

where r, w_U and w_H represent the return on capital, and unskilled and skilled labor wage, respectively, and the price in the service sector plays the role of the numéraire (i.e., $p_s = 1$). Given the production technology in manufacturing, we can solve for the minimum cost of producing a single unit of output, holding factor prices fixed, and can express the unit cost function in sector m as $c_m = [\delta_m^{\sigma_m} r^{1-\sigma_m} + (1-\delta_m)^{\sigma_m} w_U^{1-\sigma_m}]^{\frac{1}{1-\sigma_m}}$, where $\sigma_m = 1/(1-\rho_m)$ is the elasticity of substitution between capital and unskilled labor in manufacturing.

In the context of general equilibrium models, it is well known that both neutral and factor-augmenting technical improvements always reduce costs, and thus, once such technologies are available and affordable, there is no doubt that they will be adopted by profit-maximizing firms. A similar remark, however, cannot be made in the case of a labor-eliminating technology as is modeled in this paper. It is straightforward to show that, under constant factor prices, differentiating the unit cost function given above with respect to δ_m leads to (in a percentage change form) $\hat{c}_m = -\zeta_m \hat{\delta}_m$, where $\zeta_m \equiv (\theta_m - \delta_m)/(1-\delta_m)\rho_m$ is the cost elasticity of the labor-eliminating technical progress and θ_m is the cost share of capital in sector m. We can now show that, in our model, competitive firms will adopt the labor-eliminating technology in sector m if (and only if) it will reduce the unit production costs at the prevailing factor prices, that is, iff $\zeta_m > 0$. Using the (initial) cost share of capital in sector m, $\theta_m = rK_m/(rK_m + w_U U_m)$ and the initial (calibrated) value of the distribution parameter $\delta_m = rK_m^{1-\rho_m}/(rK_m^{1-\rho_m} + w_U U_m^{1-\rho_m})$, it is straightforward to show that $\zeta_m > 0 \iff K_m/U_m > 1$, which we refer to as the *adoption rule*.[6] We will assume this adoption rule holds true throughout the paper, that is, manufacturing in our model, uses at least as much capital as labor in production, irrespective of the degree of capital-labor substitutability.[7]

Condition 1 (Adoption Rule). $k_m = K_m/U_m > 1$.

Using factor demands, we can also show that the adoption rule given in Condition 1 implies $w_U\delta_m/r(1-\delta_m) > 1$, which is intuitive: a labor-eliminating technology will be adopted by firms insofar as the cost of labor relative to capital is not too low.[8] In addition to Condition 1, we assume the following:

Assumption 1. $k_m > k_s = K_s/U_s$.

That is, throughout the paper, we assume that manufacturing is capital intensive relative to the service sector.

We are now ready to establish the equilibrium conditions for the factor markets. We can write the equilibrium conditions, respectively, for the aggregate capital market, for the aggregate unskilled labor market, and for the aggregate skilled labor market as follows:

$$a_{Km}Q_m + a_{Ks}Q_s + a_{Kh}Q_h = \overline{K}, \tag{5}$$

[6]Note that the initial (calibrated) value of the distribution parameter is implied by the tangency of the isoquant and isocost at the prevailing factor prices.

[7]This does not preclude the fact that when capital and labor are greatly substitutable so that switching between labor and capital is rather very easy to begin with, a labor-eliminating technology will have less to offer in terms of cost savings. This is rather easy to see as the cost elasticity of a labor-eliminating technology is decreasing with an increase in the elasticity of substitution between capital and labor.

[8]Condition 1 is consistent with the adoption rule employed in a task-based framework by Acemoglu and Restrepo (2018c) and Acemoglu and Restrepo (2019a).

$$a_{Um}Q_m + a_{Us}Q_s = \overline{U}, \tag{6}$$

$$a_{Hh}Q_h = \overline{H}, \tag{7}$$

where a_{ji}, $j \in \{K, U, H\}$, $i \in \{m, s, h\}$, is the per-unit demand for factor j in sector i, and $\overline{K}$, $\overline{U}$ and $\overline{H}$ are the constant levels of capital, unskilled labor, and skilled labor endowment, respectively.

It is well-known in such traditional general equilibrium models that capital intensity of a sector is an increasing function of per-unit capital demand, such that $k_m = a_{Km}/a_{Um}$, $k_s = a_{Ks}/a_{Us}$, and $k_h = a_{Kh}/a_{Hh}$, where $a_{Ki} = (\delta_i c_i/r)^{\sigma_i}$, $i \in \{m, s, h\}$, $a_{Ui} = ((1-\delta_i)c_i/w_U)^{\sigma_i}$, $i \in \{m, s\}$, and $a_{Hh} = ((1-\delta_h)c_h/w_H)^{\sigma_h}$. To see, however, how capital intensity changes in each sector in response to a labor-eliminating technology adopted in manufacturing, we first need to establish the changes in per-unit factor demands. Using the per-unit factor demand expressions we can show the proportional changes as follows:

$$\hat{a}_{Km} = \sigma_m((1-\theta_m)(\hat{w}_U - \hat{r}) + (1-\zeta_m)\hat{\delta}_m), \tag{8}$$

$$\hat{a}_{Ks} = \sigma_s(1-\theta_s)(\hat{w}_U - \hat{r}), \tag{9}$$

$$\hat{a}_{Kh} = \sigma_h(1-\theta_h)(\hat{w}_H - \hat{r}), \tag{10}$$

$$\hat{a}_{Um} = -\sigma_m(\theta_m(\hat{w}_U - \hat{r}) + (\delta_m/(1-\delta_m) + \zeta_m)\hat{\delta}_m), \tag{11}$$

$$\hat{a}_{Us} = -\sigma_s\theta_s(\hat{w}_U - \hat{r}), \tag{12}$$

$$\hat{a}_{Hh} = -\sigma_h\theta_h(\hat{w}_H - \hat{r}), \tag{13}$$

where θ_i is the cost share of capital in sector $i \in \{m, s, h\}$ and a circumflex denotes a proportional change. As might be expected, a labor-eliminating technical progress adopted in manufacturing affects per-unit factor demands through changes in factor prices. In addition, there is a direct effect only in manufacturing. The direct effect on per-unit capital demand in manufacturing is determined by the proportional change in the value of marginal product of capital and is equivalent to $\sigma_m(1-\zeta_m)\hat{\delta}_m$. The sign of this expression is ambiguous and depends on how strong the cost saving is (i.e., depends on the cost elasticity of the labor-eliminating technology). The proportional change in the value of marginal product of capital will be positive (negative) if the labor-eliminating technical progress reduces costs less-than-proportionately (more-than-proportionately) and thus per-unit capital demand will decrease (increase) at constant factor prices. By the same token, a proportionate cost reduction generates no proportional change in per-unit capital demand at constant factor prices as the value of the marginal product of capital stays intact. In contrast, the direct effect of a labor-eliminating technical change on per-unit unskilled labor demand in manufacturing (as is determined by the proportional change in the value of marginal product of unskilled labor in manufacturing) is always negative $-\sigma_m(\delta_m/(1-\delta_m)+\zeta_m)\hat{\delta}_m$ and thus reduces per-unit unskilled labor demand. As for the indirect effects through changes in factor prices and as for the overall effects, we need to establish first how factor prices change with a labor-eliminating technology adopted in manufacturing, which we do in the next section.

3 Factor Price Changes and Wage Inequality

To address how factor prices change with a labor-eliminating technology, we can differentiate Eqs.(2), (3) and (4), so as to obtain the following expressions:

$$\hat{p}_m = \theta_m \hat{r} + (1-\theta_m)\hat{w}_U - \zeta_m \hat{\delta}_m, \tag{14}$$

$$0 = \theta_s \hat{r} + (1-\theta_s)\hat{w}_U, \tag{15}$$

$$\hat{p}_h = \theta_h \hat{r} + (1-\theta_h)\hat{w}_H, \tag{16}$$

Holding all good prices constant, we can solve the system of equations (14), (15) and (16) to obtain:

$$\hat{r} = \frac{\zeta_m(1-\theta_s)}{\Theta}\hat{\delta}_m, \tag{17}$$

$$\hat{w}_U = -\frac{\zeta_m\theta_s}{\Theta}\hat{\delta}_m, \tag{18}$$

$$\hat{w}_H = -\frac{\zeta_m\theta_h(1-\theta_s)}{\Theta(1-\theta_h)}\hat{\delta}_m, \tag{19}$$

where $\Theta \equiv \theta_m - \theta_s > 0$, given Assumption 1. It is immediate from Eqs. (17), (18) and (19) that, so long as a labor-eliminating technology is adopted in manufacturing (see the adoption rule in Condition 1), $\hat{r} > 0$, $\hat{w}_U < 0$, and $\hat{w}_H < 0$:

Proposition 1. *A labor-eliminating technical change in manufacturing increases the return on capital, and decreases both unskilled and skilled labor wages.*

An immediate result that follows Eqs.(17), (18) and (19) is that the percentage changes in factor prices in response to a labor-eliminating technical progress can be related also to the elasticity of substitution between capital and labor.

Proposition 2. *For a given proportional labor-eliminating technical change, the percentage changes in factor prices given in Eqs.*(17), (18) *and* (19) *will be less the higher is the initial substitutability between capital and labor in a sector's production process (ceteris paribus).*

Note that it is rather straightforward to show that the cost elasticity of a labor eliminating technology decreases with an increase in the elasticity of substitution between capital and labor in production. That is, higher substitutability would imply lower cost savings upon a labor-eliminating technical change, with which the magnitudes of the changes given in Eqs.(17), (18) and (19) would be smaller. Moreover, it follows directly from Eqs. (18) and (19) that a labor-eliminating technology adopted in manufacturing leads to a greater skilled-unskilled wage gap under a certain condition:

Proposition 3. *A labor-eliminating technical change in manufacturing leads to a greater skilled-unskilled wage gap if (and only if) the (initial) cost share of capital in the service sector is greater than that in the high-tech sector, such that* $\theta_s > \theta_h$.

Using the cost share definitions, the condition for the increasing wage gap in Proposition 3 can be expressed in terms of capital intensities corrected by the respective factor prices, such that $\theta_s > \theta_h \iff k_s/w_U > k_h/w_H$. This is intuitive as it suggests a labor-eliminating technology adopted in manufacturing widens the wage gap between unskilled and skilled labor if the cost of labor relative to capital in the service sector (vis-à-vis that in the high-tech sector) is sufficiently high. Note that this condition does not necessarily require a higher capital intensity in the service sector relative to the high-tech sector.

Also, given the percentage changes in factor prices with a labor-eliminating technical change in manufacturing in Eqs.(17), (18) and (19), it is now clear from Eqs.(9), (10), (12) and (13) that per-unit capital demand decreases in both the service and high-tech sectors, while per-unit unskilled (skilled) labor demand increases in the service (high-tech) sector. Moreover, the proportional change in per-unit capital (labor) demand in both sectors is smaller (greater) the higher (lower) is the cost share of capital in each sector (ceteris paribus). As for manufacturing, the overall percentage changes in per-unit factor demands are ambiguous. In particular, the indirect effects through the changes in factor prices in response to a labor-eliminating technical change decrease (increase) per-unit capital (unskilled labor) demand in manufacturing. This is not surprising, as we have already shown a labor-eliminating technical progress in manufacturing makes capital (labor) more (less) costly. The ambiguity is, however, due to the direct effects in manufacturing as is already discussed (i.e., the changes in the value of the marginal factor products with a labor-eliminating technical change).

Using Eqs.(17) and (18), we can show that per-unit capital demand in manufacturing, given in (8), increases with a labor-eliminating technical progress if (and only if) the percentage change in the distribution parameter of capital in production increases the rate of return on capital less-than-proportionately, such that $\hat{r}/\hat{\delta}_m < 1$, which would require a sufficiently low cost elasticity of a labor-eliminating technology (i.e., $\zeta_m < \zeta'_m$). Similarly, we can show that per-unit unskilled labor demand in manufacturing, given in (11), decreases with a labor-eliminating technical progress if (and only if) the percentage decrease in the unskilled wage with a percentage increase in the distribution parameter of capital in production is sufficiently low, such that $-\hat{w_U}/\hat{\delta}_m < \delta_m/(1-\delta_m)$, which also would require a sufficiently low cost elasticity of a labor-eliminating technology (i.e., $\zeta_m < \zeta''_m$).[9] Having established the changes in per-unit factor demands with a labor-eliminating technology in manufacturing, we are now ready to address the question how capital intensity changes in each sector in response to a labor-eliminating technical progress in manufacturing. Using the percentage changes in per-unit factor demands given in Eqs.(8)-(13), and the percentage changes in factor prices given in Eqs.(17), (18) and (19), we can show that the following result should hold.

Proposition 4. *While a labor-eliminating technical change in manufacturing unambiguously decreases capital intensity in both the service and high-tech sectors,*

[9] More precisely, we can show that $\hat{r}/\hat{\delta}_m < 1 \iff \zeta_m < \zeta'_m \equiv \Theta/(1-\theta_s) < 1$, and that $-\hat{w_U}/\hat{\delta}_m < \delta_m/(1-\delta_m) \iff \zeta_m < \zeta''_m \equiv \Theta\delta_m/\theta_s(1-\delta_m)$. Depending on the initial cost share of capital in the service sector and the initial (calibrated) distribution parameter of capital in manufacturing, we can show that $\zeta'_m < \zeta''_m \iff \theta_s < \delta_m$.

capital intensity in manufacturing (where a labor-eliminating technology is adopted) increases if (and only if) the cost elasticity of the labor-eliminating technology is sufficiently small, such that $\zeta_m < \Theta/(1-\delta_m)$.

Using the cost elasticity definition, we can show that $\zeta_m < \Theta/(1-\delta_m) \iff \Theta > (\theta_m - \delta_m)/\rho_m\theta_m$. This suggests that an increase in manufacturing capital intensity with a labor-eliminating technical change tends to occur when the difference in the cost share of capital across sectors is large. Assessing the RHS of the inequality is complicated by the interdependence of ρ_m and δ_m, which are both functions of σ_m. We can show that the lower is the elasticity of substitution between capital and labor to begin with, and the smaller is the initial (calibrated) distribution parameter of capital in manufacturing production, the more likely it will be that capital intensity in manufacturing will increase with a labor-eliminating technical progress.

4 Factor Income Shares and Sector-Specific Output

In this section, we look at the percentage changes in national income, factor shares in national income, and sector-specific outputs. To begin with, we can take the change in national income at constant prices, assuming the change in the value of aggregate consumption is equivalent to that of national income, such that $dY = p_m dQ_m + dQ_s + p_h dQ_h \equiv \overline{K}dr + \overline{U}dw_U + \overline{H}dw_H$. In a percentage change form, we can rewrite this as $\hat{Y} = s_K\hat{r} + s_U\hat{w}_U + s_H\hat{w}_H$, where $\hat{r}$, $\hat{w}_U$, and $\hat{w}_H$ are given in Eqs.(17), (18), and (19), respectively. Note that s_K, s_U, and s_H denote, respectively, the share of capital, unskilled labor, and skilled labor in national income. Denoting the employment shares by λ_{ji}, where $j \in \{K, U, H\}$ and $i \in \{m, s, h\}$, and using Eqs.(17), (18), and (19), we can show that $\hat{Y} = \hat{r}s_K(1 - \lambda_{Ks}/\lambda_{Us} - \lambda_{Kh})$. We have already shown that $\hat{r} > 0$ (see (17)). Also, given Assumption 1, it is straightforward to show that the expression in parenthesis is positive. That is, a labor-eliminating technical change in manufacturing increases national income. This immediately leads to the following (expected) result (especially given the percentage changes in factor prices in Eqs.(17), (18), and (19)):

Proposition 5. *A labor-eliminating technology in manufacturing increases both national income and the share of capital in national income, while the share of unskilled and skilled labor in national income both decrease.*

As for the percentage changes in sector-specific outputs in response to a labor-eliminating technical change in manufacturing, we can totally differentiate Eqs.(5), (6) and (7) and write the following equation system:

$$\begin{bmatrix} \lambda_{Km} & \lambda_{Ks} \\ \lambda_{Um} & \lambda_{Us} \end{bmatrix} + \begin{bmatrix} \hat{Q}_m \\ \hat{Q}_s \end{bmatrix} = \begin{bmatrix} -(\lambda_{Km}\hat{a}_{Km} + \lambda_{Ks}\hat{a}_{Ks} + \lambda_{Kh}(\hat{a}_{Kh} - \hat{a}_{Hh})) \\ -(\lambda_{Um}\hat{a}_{Um} + \lambda_{Us}\hat{a}_{Us}) \end{bmatrix} \tag{20}$$

where the percentage changes in unit factor demands, denoted $\hat{a}_{ji}$, $j \in \{K, U, H\}$, $i \in \{m, s, h\}$, are given in Eqs.(8)-(13), the percentage factor price changes are given in Eqs.(17)-(19), and the percentage change in high-tech output can be derived as $\hat{Q}_h = -\hat{a}_{Hh} < 0$.[10] At constant prices, given the decrease in the high-tech sector output, and the increase in national income with a labor-eliminating technical change in manufacturing (see Proposition 5), the following result is immediate:

Proposition 6. *A labor-eliminating technology adopted in manufacturing either increases only the manufacturing output or only the service sector output, or increases outputs of both sectors.*

It is now clear that the unambiguous increase in national income and the

[10]Note that the determinant of the $2x2$-matrix on the LHS of the equality in (20) is positive given Assumption 1.

unambiguous decrease in the high-tech sector output with a labor-eliminating technical progress in manufacturing preclude the possibility that outputs of both the service and manufacturing sectors decrease.

The solution to the equation system given in (20) is

$$\hat{Q}_m = \frac{1}{\Delta_1}(\Delta_2 - \lambda_{Km}\lambda_{Us}\hat{a}_{Km} + \lambda_{Ks}\lambda_{Um}\hat{a}_{Um}) \tag{21}$$

$$\hat{Q}_s = \frac{1}{\Delta_1}(\Delta_3 + \lambda_{Km}\lambda_{Um}(\hat{a}_{Km} - \hat{a}_{Um})) \tag{22}$$

where, from Assumption 1: $\Delta_1 = \lambda_{Km}\lambda_{Us} - \lambda_{Ks}\lambda_{Um} > 0$; and from Eqs.(8)-(13) and (17)-(19): $\Delta_2 = -(\lambda_{Us}\lambda_{Ks}\hat{a}_{Ks} + \lambda_{Us}\lambda_{Kh}(\hat{a}_{Kh} - \hat{a}_{Hh}) - \lambda_{Ks}\lambda_{Us}\hat{a}_{Us}) > 0$, and $\Delta_3 = (\lambda_{Ks}\lambda_{Um}\hat{a}_{Ks} + \lambda_{Kh}\lambda_{Um}(\hat{a}_{Kh} - \hat{a}_{Hh}) - \lambda_{Km}\lambda_{Us}\hat{a}_{Us}) < 0$.

In general, the sign of the expressions in (21) and (22) is ambiguous and depends on different constellations of parameter values of the model. In particular, it is clear from the expression in (21) that $\hat{Q}_m > 0$ for $\hat{a}_{Km} < 0$ and $\hat{a}_{Um} > 0$, which are not necessary but sufficient conditions. We have already shown that $\hat{a}_{Km} < 0 \iff \zeta_m > \Theta/(1-\theta_s)$ and $\hat{a}_{Um} > 0 \iff \zeta_m > \Theta\delta_m/\theta_s(1-\delta_m)$ (see Eqs.(8) and (11), and footnote 9). Similarly, it is clear from the expression in (22) that a sufficient (but not necessary) condition for $\hat{Q}_s < 0$ to hold is that $\hat{a}_{Km} - \hat{a}_{Um} < 0$, which corresponds to a decreasing capital intensity in manufacturing. Proposition 4 has already shown that $\zeta_m > \Theta/(1-\delta_m)$ is required for capital intensity in manufacturing to decrease with a labor-eliminating technology. It is now clear that in the case that the cost elasticity of the labor-eliminating technical change is sufficiently high to begin with, such that $\zeta_m > \max\{\Theta/(1-\theta_s), \Theta/(1-\delta_m), \Theta\delta_m/\theta_s(1-\delta_m)\}$, manufacturing output increases, while output in the service sector decreases.[11]

[11] If capital intensity in the service sector is not too different from that in manufacturing, such that $k_s > k_m^{(1-\rho_m)}$, then we can show that $\max\{\Theta/(1-\theta_s), \Theta/(1-\delta_m), \Theta\delta_m/\theta_s(1-\delta_m)\} = \Theta/(1-\theta_s)$.

In particular, in such a case, a given percentage increase in the distribution parameter of capital in manufacturing production generates a sufficient increase in the rate of return on capital and a sufficient decrease in unskilled labor wage leading manufacturing to employ less capital and more unskilled labor per unit production. Although capital intensity in manufacturing decreases in such a case, its aggregate capital and unskilled labor demands both increase. As for the service sector, capital intensity also decreases as the changes in factor prices lead the service sector to employ less capital and more unskilled labor per unit production. That said, the service sector's aggregate capital and unskilled labor demands both decrease. In addition to capital and unskilled labor moving from the service sector to manufacturing, some capital from the high-tech sector will also move to manufacturing. Paradoxically, under this scenario labor-eliminating technical progress takes place in manufacturing, and yet aggregate labor employment of the manufacturing sector rises.

5 Trade Protectionism

We now consider the implications of trade protectionism in the case of a labor-eliminating technical progress in manufacturing. Suppose that manufacturing is the import competing sector in our setup, and that it is protected by an ad valorem tariff rate of t. Equation (2) then becomes:

$$Tp_m^w = c_m(w_U, r), \tag{23}$$

where $T = 1 + t$. Totally differentiating (23) at constant world prices yields:

$$\hat{T} = \theta_m \hat{r} + (1 - \theta_m)\hat{w}_U - \zeta_m \hat{\delta}_m. \tag{24}$$

Holding all good prices constant, we can solve the system of equations (15), (16) and (24) to obtain:

$$\hat{r}^t = \hat{r} + \frac{(1-\theta_s)}{\Theta}\hat{T}, \tag{25}$$

$$\hat{w}_U^t = \hat{w}_U - \frac{\theta_s}{\Theta}\hat{T}, \tag{26}$$

$$\hat{w}_H^t = \hat{w}_H - \frac{(1-\theta_s)\theta_h}{\Theta(1-\theta_h)}\hat{T}, \tag{27}$$

where $\hat{r} > 0$, $\hat{w}_U < 0$ and $\hat{w}_H < 0$ are the percentage changes in the absence of a tariff, given in Eqs.(17), (18), and (19), respectively. It is evident from Eqs.(25), (26) and (27) that a protectionist policy reinforces the effects of a labor-eliminating technical change on factor prices leading to the following important trade policy result:

Proposition 7. *A protectionist trade policy in the form of increasing tariffs on manufacturing imports exacerbates the negative effects of a labor-eliminating technical progress on skilled and unskilled labor wages, and, so long as $\theta_s > \theta_h$, also on the wage gap.*

Proposition 7 suggests that, in the case of a labor-eliminating technical change in manufacturing, a protectionist trade policy can act counter to its intent, especially if the policymaker's objective is to protect (unskilled) workers. In particular, Eqs.(17)-(19) show that, all else being equal, the rate of return on capital (skilled-labor wage) increases (decreases) less if the initial cost share of capital in the service sector is high to begin with. That said, the decrease in unskilled-labor wage will be greater, given initially the high cost share of service capital. It is now clear from Eqs.(25)-(27) that the same argument holds also for the implications of a tariff increase on manufacturing imports for factor price changes: if the initial cost share of capital in the service sector is high to begin with, then a protectionist trade policy in the form of increasing tariffs on manufacturing imports exacerbates the negative effects of a labor-eliminating technical progress on unskilled-labor wage even more. That said, the negative (positive) impact of a tariff increase on the skilled-labor wage decrease (the rental increase) will be less should there be initially a high cost share of service capital. Also it follows from Eqs. (19) and (27) that, all else being equal, the skilled-labor wage decrease (resulting from both a labor-eliminating technology adopted in manufacturing and a protectionist trade policy directed at manufacturing) will be less if the capital intensity in the high-tech sector is low to begin with, and/or if the rental-to-skilled-labor-wage ratio is initially low.

6 Concluding Remarks

Anecdotal evidence of labor-eliminating technical progress is abundant. From the upsurge of automation in manufacturing in the last few decades to the current development of artificial intelligence and its application in the production processes, technical change has been as much of the labor-eliminating type as the more commonly studied labor-augmenting type. As we have mentioned in Section 1 that this paper aims at incorporating a labor-eliminating technical progress and the implications in an otherwise traditional, multi-sector general equilibrium model. Although we have not explicitly modeled the set of tasks changing the distribution share of capital in production, we believe our paper complements the task-based approach and provides the existing literature with further important insights on such a contentious topic and on its trade policy implications. We have shown that a labor-eliminating technical progress lowers both skilled and unskilled wages under fairly plausible conditions, and amplifies the skilled-unskilled wage gap. Moreover, a protectionist trade (tariff) policy will magnify the negative effects of a labor-eliminating technical change on both skilled and unskilled wages and on wage inequality.

The trade policy implications can hardly be understated, especially given the revival in protectionist sentiments that automation has provoked. A protectionist trade policy that is meant to protect workers may easily in fact hurt them. That is, if an economy is experiencing a labor-eliminating technical change and as a result wages are falling and wage inequality is rising, protecting local manufacturers by increasing tariffs would be precisely the wrong prescription under the circumstances highlighted in this paper.

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