Economics Bulletin

Volume 34, Issue 1

Technological progress and employment

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Abstract

Since the days of David Ricardo economists have discussed the effects of technological progress on employment. Due to a theorem which can be traced back at least to Neisser (1942), these effects can be related to the elasticity of product demand. In this paper we prove the theorem formally in a modern framework and generalize it to the case of many products. This theorem is relevant in many different regards. In particular it may contribute to a better understanding of regional and national (un-) employment.

Oliver Ludewig, Johannes Ludsteck, Ronald Schettkat, and Karola Schmitt are thanked for very helpful suggestions. All responsibility for the analysis, however, remains with the authors.
Citation: Uwe Blien and Helge Sanner, (2014) "Technological progress and employment", *Economics Bulletin*, Vol. 34 No. 1 pp. 245-251.
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Submitted: August 05, 2013. **Published:** February 11, 2014.

1. Introduction

In a very influential paper, Autor, Levy and Murnane (2003) analyzed the effects of technological progress on the skill composition on employment. They showed that the so-called "skill biased technical change" was mainly the product of an increased "computerization" of production, which altered skill demands. The implementation of computer technology enhanced the relative demand for skilled labor and for low skilled service jobs (Autor and Dorn 2012). In this paper we address an even more basic question: What is the effect of technological progress on employment, without regard of skill levels?

The relation between technological progress and employment is a point of debate since the times of David Ricardo. In the chapter "On Machinery" in his "Principles", Ricardo described the process of productivity increases as one of substitution of labor by machinery. His special concern was "that the substitution of machinery for human labor is often very injurious to the interest of the class of laborers" (Ricardo 1817, p. 270). Later, economists described two effects of technological progress on employment, one labor saving and one compensating effect. The former effect arises because, due to productivity gains, less labor is required, ceteris paribus, to produce the same amount of the commodity. The latter effect means that increased productivity brings about lower prices, which has a positive effect on demand ("compensating effect"). Hence, more labor is needed to produce a larger quantity of the commodity. The conditions that decide which effect predominates, the labor-saving or the compensating effect, are at issue in this paper.

Obviously, the elasticity of aggregate demand plays an important role for the question, which effect prevails (see already Neisser 1942). Yet, a formal analysis of the issue has only been done many years later for some special cases. Most importantly, it has been shown for a macro-model of a one-product economy, that the limiting value for the labor market effect is a direct demand elasticity of minus one (see Appelbaum and Schettkat 1993). Labor demand increases with productivity gains if product demand is elastic and it falls if product demand is inelastic. This is the basic theorem on the overall effect of technological progress on employment, and in recognition of his work we call it also "Neisser's Theorem".

More recently a version of the theorem was included in a paper by Combes, Magnac and Robin (2004). It was also derived *en passant* by Cingano and Schivardi (2004) in a simple model structure with only one production factor. Cingano and Schivardi showed that agglomeration forces regarding productivity and employment might work in opposite directions. In the case of inelastic product demand these forces might increase productivity but decrease employment, and vice versa. Cingano and Schivardi also presented empirical evidence in support of their results.

As can easily be seen, the issue of the employment effects of technological progress is important for a better understanding of how regions and countries perform in terms of employment, although this relationship has not attracted much attention from theorists in the recent past. In our view, this might be a consequence of the assumptions regarding product demand in the analytical frameworks that are most frequently used today. In the many papers that employ the formalization of monopolistic competition suggested by Dixit and Stiglitz (1977), all firms producing the differentiated commodities operate in the elastic part of the product demand curve. This applies to the prevailing approaches in trade theory and new economic geography. In another strand of the literature, unit elastic demand is assumed, when the effects of structural change are at issue (see e.g. Duranton 2007). In these cases, the – positive –

compensating effect always at least offsets the labor saving effect. Also, papers that build up upon the contribution of Autor, Levy and Murnane (2003) do not consider a global employment effect. Their model structure usually abstracts from labor demand effect at the aggregate level, since they focus on the shift between skill groups (see also Autor and Dorn 2012).

In this paper we prove the basic theorem in a modern framework and generalize it to the case of a multi-product economy. This model and the included theorem can be used in various contexts. It permits a detailed analysis of the complex relationship between technological progress and employment. In particular, the theorem is able to explain diverging employment performances of nations that are rather similar with respect to their institutional arrangements. In these cases, the predominant approach, which takes labor market institutions to be at the bottom of these differences (see Layard, Nickell, and Jackman 2005), cannot explain the existing large differences in employment. The same accounts within economies, where the theorem might explain why some regions perform better than others in spite of identical institutional arrangements.

2. Product demand and employment

In the following we derive a generalization of the basic theorem on the employment effects of technical progress in a simple model. Compared to previous versions of the theorem our model includes more than only one product. It starts from generalized assumptions about the production function. Assume an economy with n perfectly competitive industries. Each firm within the same industry exhibits the same linear-homogenous production function.[1] Aggregation at the industry level yields the industry-wide production functions $\mathrm{Q_j(t) = A_j(t) \cdot F(K_j, L_j)}$, where Kand L denote the amount of capital and labor employed in industry j, respectively. The prices of these factors, denoted r and w, are assumed to be constant. $\mathrm{A_j(t) = A_j e^{\gamma_j t}}$ is a scaling factor, which increases over time t with the exogenous industry-specific rate of technological progress, γ_j. Labor productivity is $\mathrm{\pi_j(t) = Q_j(t)/L_j(t) = A_j(t) \cdot f(k_j)}$, where $\mathrm{k_j}$ denotes capital intensity, $\mathrm{k \equiv K/L}$. Note that k is time-invariant, since production functions are homothetic.

Demand at the industry level for industry κ's product is $Q_\kappa(p_1, \dots, p_\kappa, \dots, p_n)$, where p_j denote prices that must be equal for all firms within the same industry j. More specifically, these prices coincide with the marginal costs of production, of which labor costs make up a constant share. Put differently, prices are proportional to labor input per unit produced, $L_j/Q_j = 1/\pi_j$, i.e. $p_j(t) = \theta_j/\pi_j(t)$, where θ_j is an industry-specific parameter which depends on factor prices and the technology employed, but not on time.[2] This is to say that prices only change over time in this model because they depend on productivity, ceteris paribus.

Now we are in the position to analyze the development of employment over time. The functional relationships needed for this exercise are:

[1] This assumption is more than necessarily restrictive, and has primarily been made to ease the presentation. For our results to become effective, any production function that leads to a constant capital intensity would suffice, e.g. the Leontief and every homothetic production function.

[2] In the case of a Cobb-Douglas production function, $Q_j(t) = A_j(t) K_j^{\beta_1} L_j^{\beta_2}$, with $\beta_1 + \beta_2 \gtreqless 1$, it is straightforward to show that $\theta_j = w/\beta_2$.

$$\pi_j(t) = \frac{Q_j(t)}{L_j(t)} = A_j(t) \cdot f(k_j) \tag{A}$$

$$A_j(t) = A_j e^{\gamma_j t} \tag{B}$$

$$p_j(t) = \frac{\theta_j}{\pi_j(t)} \tag{C}$$

$$Q_j(t) = Q_j(p_1(t), \dots, p_j(t), \dots, p_n(t)) \tag{D}$$

Note that equations (A)–(D) are either definitional, or based on fairly weak and standard pre-conditions.

Building the derivative of the price-setting equation (C) with respect to π_j yields

$$\frac{\partial p_j}{\partial \pi_j} = \frac{-\theta_j}{\pi_j(t)^2} = \frac{-p_j}{\pi_j(t)} \tag{1}$$

The evolution of employment over time can be inferred by building the total derivative of $L_\kappa = Q_\kappa(p_1, \dots, p_\kappa, \dots, p_n)/\pi_\kappa$ with respect to t:

$$\frac{dL_\kappa}{dt} = \frac{1}{{\pi_\kappa}^2} \cdot \left[\sum_{j=1}^{n} \left(\frac{\partial Q_\kappa(\cdot)}{\partial p_j} \frac{\partial p_j}{\partial \pi_j} \frac{\partial \pi_j}{\partial t} \right) \pi_\kappa - Q_\kappa(\cdot) \frac{\partial \pi_\kappa}{\partial t} \right] \tag{2}$$

Making use of eq. (1) and $\partial \pi_j / \partial t = \gamma_j \, \pi_j$, the derivative becomes

$$\begin{aligned} \frac{dL_\kappa}{dt} &= \frac{-1}{{\pi_\kappa}^2} \cdot \left[\sum_{j=1}^{n} \left(\frac{\partial Q_\kappa(\cdot)}{\partial p_j} \frac{p_j}{\pi_j} \gamma_j \pi_j \right) \pi_\kappa + Q_\kappa(\cdot) \gamma_\kappa \pi_\kappa \right] \\ &= \frac{-1}{{\pi_\kappa}^2} \cdot \left[\sum_{j=1}^{n} \left(\frac{\partial Q_\kappa(\cdot)}{\partial p_j} \frac{p_j}{Q_\kappa(\cdot)} \gamma_j Q_\kappa(\cdot) \right) + Q_\kappa(\cdot) \gamma_\kappa \right] \\ &= -\gamma_\kappa L_\kappa \cdot \left[\sum_{j \neq \kappa}^{n} \left(\eta_{Q_\kappa, p_j} \frac{\gamma_j}{\gamma_\kappa} \right) + \eta_{Q_\kappa, p_\kappa} + 1 \right] \end{aligned} \tag{3}$$

where η_{Q_κ, p_j} denotes the elasticity of aggregate demand for commodity κ with respect to the price of commodity j. While we can safely assume that the direct price elasticity is negative, the signs of the cross-price elasticities depend on whether the goods are substitutes $\eta_{Q_\kappa, p_j} > 0$ or complements $\eta_{Q_\kappa, p_j} < 0$. If the rate of technological progress is zero in one specific industry $l \neq \kappa$, the degree of substitutability between goods l and κ has no effect on the evolution of employment in industry κ. If $\gamma_\kappa = 0$, the development of employment in the κ-industry hinges solely on the technological progress in other industries and the corresponding cross-price elasticities:

$$\frac{dL_\kappa}{dt}\Big|_{\gamma_\kappa = 0} = -L_\kappa \cdot \sum_{j \neq \kappa}^{n} \left(\eta_{Q_\kappa, p_j} \gamma_j \right)$$

The result expressed in eq. (3) is summarized in the following theorem:

Theorem 1 *Employment in one specific industry κ rises iff the sum of all cross-price elasticities of the commodity produced by this industry, weighted by the relative rates of technological progress, plus the direct price elasticity are below minus one.*

Two corollaries can be deduced from theorem 1.

Corollary 1 (Neisser's Theorem) For a given technology of all other industries ($\gamma_j = 0, \forall j \neq \kappa$), technological progress in industry κ leads to an increase in employment if the direct price elasticity is below minus one. If, however, the direct price elasticity is greater than minus one, *a higher rate of technological progress in this industry actually accelerates the decrease in employment* due to its labor-saving effect.

Corollary 2 The more industries produce close substitutes with a high rate of technological progress, the more likely it is that employment in industry κ decreases due to technological progress *even if the direct demand elasticity for the corresponding good is well below minus one.*

Dividing eq. (3) by L_κ we obtain the growth rate of employment in industry κ:

$$\hat{L}_\kappa = \frac{dL_\kappa/dt}{L_\kappa} = -\gamma_\kappa \cdot \left[\sum_{j\neq\kappa}^{n}\left(\eta_{Q_\kappa,p_j}\frac{\gamma_j}{\gamma_\kappa}\right) + \eta_{Q_\kappa,p_\kappa} + 1\right] \tag{4}$$

If the technological growth rates of all industries are equal, $\gamma_j = \gamma_\kappa, \forall j \in \{1, \dots, n\}$, we have

$$\hat{L}_\kappa = -\gamma_\kappa \cdot \left[\sum_{j\neq\kappa}^{n}\left(\eta_{Q_\kappa,p_j}\right) + 1\right]$$

and if the budget constraint $y_i = \sum_{j=1}^{n} p_j q_j$ is binding for all consumers i, the equation reduces to

$$\hat{L}_\kappa = \gamma_\kappa \cdot (\epsilon_{Q_{\kappa,y}} - 1) \tag{5}$$

where $\epsilon_{Q_{\kappa,y}}$ denotes the income elasticity of good κ[3]. (5) suggests that global technological progress boosts employment in a specific industry if the good produced by this industry is superior, i.e. characterized by a larger proportion of consumption as income rises. Since the income elasticity is one on average, the weighted average growth rate of employment in all industries is zero. In other words, global technological progress can only have a positive effect on employment in one region or country if its economy possesses a more than proportionate share of industries with superior goods. Employment gains in this region are accompanied by employment losses in other regions, however. Of course, all results are sensitive to our assumption that factor prices are not (fully) flexible.

3. Discussion

The theorem derived in the previous section explains that two economies, which are similar with respect to their institutions and the level of productivity, can show a completely different performance with respect to employment. Our analysis also provides an explanation for the empirical fact that the variation of regional unemployment is as large as the variation between nations, although institutions are similar if not identical within nations. Our findings suggest that in these cases the specialization of the economy or region could be the cause of differences regarding the development of employment. Of course the propositions we derive from

[3] For the relation between income and price elasticities see Henderson and Quandt (1980, p. 34).

the generalized form of the basic theorem depend on several assumptions. In fact, if wages would adjust completely flexibly according to the regional scarcity of labor, the industry mix of the economy would have no effect on unemployment. Recent literature, however, describes a limited adaptation process by a macroeconomic "wage setting curve" and a regional "wage curve". According to Blanchflower and Oswald (2005), the empirical elasticity of wages with respect to regional unemployment is -0.1. Therefore, regional wages are not completely flexible, and the proposed mechanism remains relevant.

The theorem can be integrated in a variety of economic models. The relationship between technological progress and employment is relevant for macroeconomic theory, regional economics, trade theory and the theory of structural change. The theorem is sufficiently simple to be integrated in models on the mentioned topics if the structural composition of the economy is at issue to account for effects of productivity changes.

It is only tentatively known how important the empirical consequences of the proposed mechanism are, since related econometric analyses are scarce. In an econometric paper with data on nations and industries Möller (2001) found that in the passing of time the demand elasticity decreased in all three countries he studied, the USA, the UK, and Germany. In parallel the economies showed increasing employment problems, which is in accordance with our theoretical analysis.

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