INDIAN INSTITUTE OF FOREIGN TRADE

WPS No. EC-22-59

WORKING PAPER

TECHNOLOGICAL CHANGE AND DEMOGRAPHICS IN A MODEL WHERE CONSUMPTION IS TIME-CONSTRAINED

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Printed and published by
Indian Institute of Foreign Trade
Delhi Centre | IIFT Bhawan, B-21, Qutab Institutional Area, New Delhi 110016
Kolkata Centre | 1583 Madurdaha, Chowbagha Road, Borough XII, Kolkata 700107

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Technological Change and Demographics in a model where consumption is time-constrained

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ABSTRACT

This study demonstrates why traditional 'cost-saving' technical progress fails in an economy where consumption is time-constrained. In such a case, introducing 'time-saving' technical progress establishes a new consumption-production equilibrium characterized by higher per-capita consumption and real income, lower prices, and, a higher scale of production for surviving producers. Nonetheless, since there is a limit to how much time can be saved by technological advances, the model also suggests an alternative solution in the form of a rising labor force (via immigration) to close the production-consumption gap. This solution echoes the empirical reality illustrating why Emerging Market Economies matter.

Key Words: Cost-saving technical progress, Time-saving technical progress, Consumption-time, General Equilibrium model, Demographics, Immigration

JEL Codes: O14, D50, D11, D21

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1. Introduction

One notable feature of the decades since the 1980s has been the growing popularity of household appliances and other utility items, which help consumers in saving their time. Devices such as vacuum cleaners, dishwashers, among others, had become common in North American and West-European households in the early 1980s, and gradually gained traction in the global market. The rapidly growing E-commerce industry offers another illustration to explain the critical role assumed by 'time' in determining consumer preferences today. In a recent article by Hari (2022), it has been explained how among the many unicorns that were set up in the last few years, only a few of them which applied the right strategy of distinguishing between 'money-rich and time-poor' and 'money-poor and time-rich' consumers, could fare well, while others have been losing because of overestimation of their potential market sizes. While the former set of consumers (which are in large proportion in developed markets, and comparatively lesser in number in developing and emerging economies) value time-saving devices, the latter, are usually the ones with less income and an abundance of time. This difference in the availability of time (on the consumption side) was established theoretically in a study by Marjit et al. (2020), which shows how outsourcing of unproductive household tasks from skilled professionals to unskilled domestic workers enhances the welfare of both the types of individuals in a two-sector, two-factor economy. The authors utilize such a framework to explain the pattern of votes in London against BREXIT based on a pure economic reason that the availability of domestic workers enables the white-collared professionals to free up their labour (and, hence, time) by hiring them for performing domestic chores such as cleaning, washing dishes, cooking, etc. Thus, the model clearly establishes the role of time on the demand side. However, it does so by introducing the two classes of workers and incorporating the disutility obtained by doing such activities in the utility function of skilled individuals. Further, this disutility arises because of two reasons – (a). the irksomeness of such activities, (b). the opportunity cost of performing such tasks for skilled workers, vis-à-vis the possibility of outsourcing these activities to domestic laborers at a relatively lower cost. Hence, the freed-up time, given the model setup, was utilized in performing more work in the production sector to earn a higher income, and not for ensuring higher consumption directly. The importance of time, more specifically the constraint on consumption due to unavailability of time, was, thus, not modelled in the framework. In fact, in micro models of technology and trade as well, time has no role to play on the demand side.[3] It is always assumed that consumption is only constrained by income.

A related issue that has gathered a lot of attention in the recent decade relates to the relationship between a country's demography and its economic growth. Empirical economists have been stressing that only countries which have a reasonable growth of working-age population have experienced positive growth in recent years (Sharma 2016, Basch 2020). The notable examples of emerging market economies (EMEs) like India and China are often discussed in this context. Due to their favorable demographics, these economies have now become the most appealing destinations for the majority of the world's large industrial companies (Tanchua and Shand 2016; Mancini et al. 2017; Jamrisko, Nag and Teso 2019; among others). The reason why population dynamics are linked to the availability of time on the demand side is that in countries where the population is stagnant (for instance, the USA, Japan, or even Germany), consumption time and hence, demand, automatically becomes limited. Thus, the demand growth in such economies depends on the extent to which technology could be time-saving, or the improvement in the rate of growth of labor force (say via flexible immigration policies).

Against this backdrop, the present paper attempts to bridge the gap in the literature by reworking a general equilibrium closed-economy model (with wide applicability in the trade literature) by incorporating the role of *constrained* time on the consumption side. It is worth pointing out that such inclusion of time assumes the role that capital often plays in a two-factor framework, where capital and labour could act as substitutes for each other on the production side. However, no such possibility exists on the demand side of these frameworks. What technology does is that it increases the production capacity of firms by raising the productivity of factors of production (displaces jobs), and hence, reduces the prices of goods and services to which it is applied (Rodrik 2018). Further, increased R&D and innovation often lead to new (and better) product varieties. While capital and technology are combined with labour inputs to produce output – it is only labour that can consume goods. And, this is where the role of time becomes critical. An increase in income is necessary to ensure increased consumption, but it is not sufficient for a consumer must also have

[3] A thorough literature review revealed that few studies have attempted to establish the role of time in constructing a household's production function, and assessing its impact on demand for energy-intensive devices (see, Binswanger 2004, Brenčič & Young 2009).

the time available for physical consumption/use of commodities. It is in this context we explain the role that time plays in eliminating the asymmetry in the treatment of labor on the demand and supply side of micro models.

Using our simple micro model, we show why in an economy with time-constrained consumption, a traditional 'cost-saving' technical progress fails in establishing equilibrium on the consumption and production side. Rather, if the technical progress is time-saving, not just the equilibrium gets established, in fact under certain circumstances, such kind of advancements could also lead to improved welfare. Further, we also establish the link between time-saving technical progress and the growth of labor force in explaining the role of EMEs today.

The rest of the paper is structured as follows. The next section outlines the theoretical framework. Section 3 examines the effect of cost-saving technical progress, vis-à-vis time-saving technical progress, and identifies the role of demographics in an economy where consumption is time-constrained. Finally, the last section concludes the study.

2. The Model

We build on the simple model of imperfect competition developed by Dixit and Stiglitz (1977) and Krugman (1980) by adding the role of time on the demand side. The economy is endowed with only one factor of production, labor, which is utilized in producing a large number of goods, indexed by $i \in [1, n]$. All these goods enter symmetrically into demand. The utility function of a representative individual is given by:

$$U = \sum_{i=1}^{n} c_i^{\theta} \qquad \text{where} \qquad 0 < \theta < 1 \tag{1}$$

Here, n represents the number of goods, and c_i is the consumption of any good i, which not only depends on the income of the consumer and per-unit price of the good, but is also constrained by the total available time for consumption (T) as well as the time required (t_i) for consuming each variety (c_i). Assuming $t_i = t \ \forall \ i$, this time constraint is given by:

$$T = \sum_{i=1}^{n} t c_i \tag{2}$$

such that if L represents the total number of individuals or laborers in this economy, then the economy-wide time-constraint can be represented as:

$$\bar{T} = LT \tag{3}$$

Equation (3) explicitly highlights that given T remains fixed, the only way to increase $\bar{T}$ is by expanding the size of the total labor force. This has important policy implications, which we'll discuss later in this paper.

As in general equilibrium models of imperfect competition with external economies of scale (see Krugman *op.cit.*), the relevant production function is given by

$$l_i = \alpha + \beta x_i \qquad \alpha, \beta > 0 \tag{4}$$

where x_i refers to the scale of production of good i, and l_i represents the amount of labor for production, such that

$$x_i = Lc_i \tag{5}$$

Equation (5) implies that the supply of any variety i should equal the individual demand times the total labor force, L.

Finally, the assumption of full employment of labor requires that

$$L = \sum_{i=1}^{n} l_i \tag{6}$$

Thus, the baseline model has three unknowns viz. the price of each variety (p_i), x_i, and n, i.e., the number of varieties. As in Krugman (*op. cit.*), it is clear that for each variety, there will be a symmetric equilibrium with $p_i = p$ and $x_i = x \; \forall \; i$. The model proceeds in 3 stages. The first stage identifies the demand curve facing a consumer given the new time-constraint that we have introduced apart from the income constraint. The second stage derives the profit-maximizing behavior of firms, followed by the determination of the number of firms in equilibrium.

Equilibrium in a closed economy

The problem facing the consumer is now given by

$$\mathcal{L} = \sum_{i=1}^{n} c_i^{\theta} + \lambda\left(W - \sum_{i=1}^{n} p_i c_i\right) + \mu\left(T - \sum_{i=1}^{n} t c_i\right)$$

where, λ and μ represent the shadow price on the income constraint and time constraint, respectively.[4] Thus, the demand curve facing a consumer is given by:

$$p_i = \lambda^{-1}\theta(x_i/L)^{\theta-1} - \lambda^{-1}\mu t \quad (7)$$

such that

$$\varepsilon_i(t) = \frac{\theta - \mu t c_i^{1-\theta}}{\theta(1-\theta)} \quad (8)$$

Here, $\varepsilon_i(t)$ represents the price elasticity of demand of variety i, which is now a function of t. This is where the model differs from Krugman (1980), where elasticity turned out to be a parametric constant (depending only on the value of θ). Two key points emerge from Equation (8), viz. $\partial\varepsilon_i/\partial c_i < 0$ and $\partial\varepsilon_i/\partial t < 0$. Thus, when consumption is time-constrained, not only does demand become less elastic, but the elasticity also varies inversely with the amount of consumption of any variety i or time required to consume c_i. The implication is that the time-saving devices, which are becoming widely popular recently, also affect the price-sensitivity of demand, and hence, the pricing strategy of firms.

Next, we consider the profit-maximizing behavior of firms. Given that n is large, each firm's pricing decision will not affect the demand for other varieties. Thus, the first-order condition is given by:

$$p_i = \left[\frac{\theta - \mu t c_i^{1-\theta}}{\theta^2 - \mu t c_i^{1-\theta}}\right]\beta w \quad (9)$$

or, substituting the value from Equation (8),

$$p_i/w = \frac{1}{1 - 1/\varepsilon_i(t)}\beta \quad (10)$$

Using the zero-profit condition (given the nature of this market), we derive the second relationship between p_i/w and c_i or x_i, and find

$$(p_i/w - \beta)(Lc_i/\alpha) = 1 \quad \text{or} \quad x_i = (\varepsilon_i(t) - 1)\frac{\alpha}{\beta} \quad (11)$$

[4] These could also be interpreted in terms of marginal utility of income and time, and are considered as fixed by producers given that the number of varieties produced is large.

From Equations (9) to (11), it is clear that we cannot characterize the equilibrium using simple arithmetic operations. Hence, following Krugman (1979), we use graphical illustrations to obtain the equilibrium solution. Let Equation (10) represent the PP curve, depicting a direct relation between c_i and p_i/w, and Equation (11) symbolize a negative association between the two (represented by curve ZZ). Figure (1a) determines the production equilibrium (E), which also satisfies the time-constraint on the consumption-side as shown by the vertical line at $\left(c_i = \frac{T}{nt}\right)$.

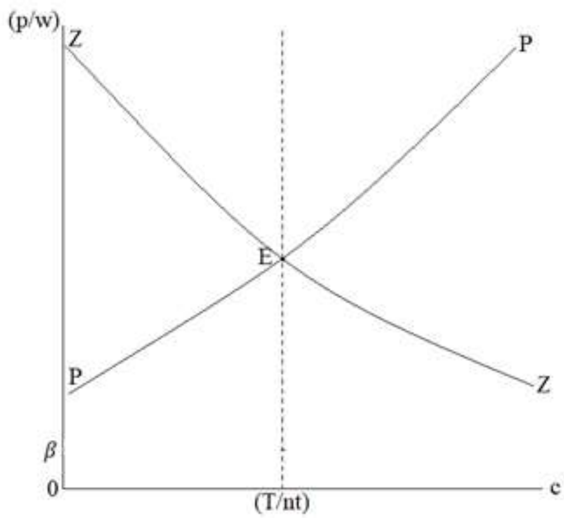

Figure 1a: Equilibrium in a closed economy

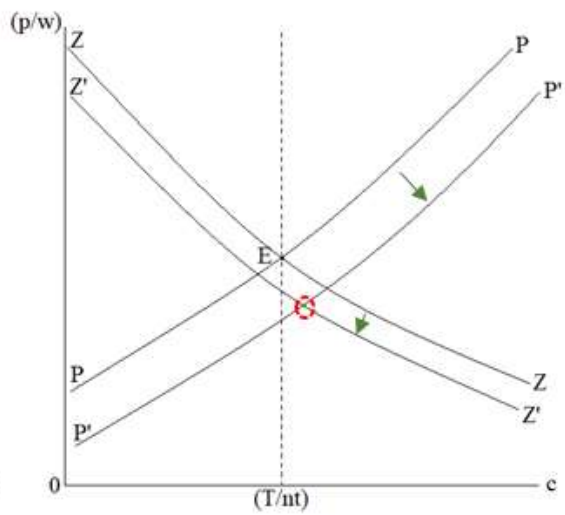

Figure 1b: Cost-saving technical progress, and production-consumption mismatch

Thus, using the equilibrium value of c_i, we determine the equilibrium number of firms based on Equations (2), (5), and (6), such that

$$n = \frac{L}{\alpha\varepsilon} = \frac{T}{c_i t} \tag{12}$$

This completes the determination of equilibrium in our model.[5] We now examine the consequences of cost-saving, vis-à-vis time-saving technical progress in the following section.

3. Cost-saving *versus* time-saving technical progress

Suppose that the industry considered in our closed economy model experiences a 'traditional' cost-saving technical progress that leads to a fall in β (i.e., a fall in the marginal cost of production).

[5] Given the parametric space, it has been checked that equilibrium does exist in this stylised model.

The effects of such a change are shown in Figure 1b. This leads to a downward shift of both PP and ZZ curves, and hence, 'E' no longer remains the equilibrium. The following lemma is immediate.

Lemma 1: *In a closed-economy model with time-constrained consumption, any cost-saving technical progress of the 'traditional-type' will lead to a production-consumption disequilibrium.*

Proof With $\varepsilon_i > 1$, it is clear from Equations (10) and (11), that the shift in the PP curve will be more than the shift in the ZZ curve.[6] Thus, on the production side, there will be a tendency to expand the scale of production at lower prices. With no change in the size of the labor force, this implies that c should increase (Equation (5)). However, unlike Krugman (1980), consumption is also a function of time, and not just income. Since the total time available for consumption, the time required for consuming each variety, and the number of varieties (Equation (12)), do not change with a change in β, the vertical line representing the time-constraint doesn't shift. This implies that the consumers cannot increase their consumption of the existing varieties.[7]

Thus, cost-saving technical progress (which is usually defined in the literature in terms of factor-using, factor-saving, or neutral technical progress) leads to a consumption-production mismatch in an economy where consumption also needs time. Primarily this happens because while such a technology shift improves the real income of consumers by reducing the per-unit price of goods, it cannot affect the 'time' required for consuming more of each variety. Therefore, the question to ask is – *how can we correct this disequilibrium*?

Suppose now the technical progress is such that it saves consumption time. As discussed in the introductory section, starting 1980s, we have seen that many technological innovations were indeed time-saving. Automatic vacuum cleaners, interactive cameras, dishwashers, automated typing devices, etc. – are some of the well-known examples. The easiest way to show the effects of such a type of technological advancement in our framework is to reduce t, i.e., the time required for consuming any variety.

[6] From Equation (10), $\partial(\frac{p}{w})/\partial\beta = (\varepsilon/\varepsilon - 1) > 1$, and from Equation (11), $\partial(\frac{p}{w})/\partial\beta = 1$.

[7] Given that $\theta_i = \theta \; \forall \; i$, consumers will not increase the consumption of some varieties at the expense of other varieties. Hence, this possibility is completely ruled out in our framework.

Referring back to equations (10) and (11), we can observe that even a fall in t causes both the PP and ZZ curves to shift downward – similar to the effect of cost-saving technology. Given that the size of the labor force remains fixed, there will be a tendency for the scale of production to expand as well.[8] However, unlike in the previous scenario, now the time-constraint changes and the vertical line shifts towards the right to establish the new equilibrium at the intersection of PP', ZZ' and $c' = T/nt$, highlighted by the dotted red circle in Figure 1b.

Thus, armed with the lemma previously established, we derive our first proposition.

Proposition 1: *In an economy where consumption is time-constrained, technical progress needs to be time-saving to ensure production-consumption equilibrium.*

Proof Q.E.D. From Equations (10) – (12).

Thus, the new equilibrium will be characterized by higher per-capita consumption and real income, lower per-unit prices, and, a higher scale of production for every surviving producer. However, the number of varieties falls. Intuitively, this happens because a fall in t raises the demand as well as the price-elasticity of demand. Given the nature of the product market and the role of scale economies, consequently, price falls and the production scale expands. With no change in the size of the labor force or the production function, this implies that not all the varieties will be produced if the scale of production needs to be increased with a fall in t. It is, however, indeterminate which n varieties survive in the new equilibrium, but it is also trivial for our analysis.

There is one more important point that emerges from our analysis. Though the time-saving technical progress seems to rectify the issue of disequilibrium due to the traditional cost-saving technical progress and, at the same time, improves the welfare of a representative individual by raising her/his real income, it also leads to a reduction in the equilibrium number of varieties (while consumption of the surviving varieties increases). This suggests that the net welfare effect of such technical progress is ambiguous. Equally imperative is to note that while newer technologies that increasingly adopt the internet of things today, allow consumers to save their consumption time, these cannot increase the total time available in a day, which is fixed at 24 hours. An interesting alternative in that case, which caters to the issue of both 'time-constrained consumption' and

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[8] What this implies is that the new intersection of PP' and ZZ' should again lie on the right of the initial Equilibrium at E.

'reduction in the number of varieties' is to allow the labor force to grow (say, via immigration). Figure 2 analyses some of the effects of an increase in L, and helps us in establishing our final proposition.

Proposition 2: *In an economy where consumption is time-constrained, Immigration may turn out to be more welfare-enhancing than technical progress.*

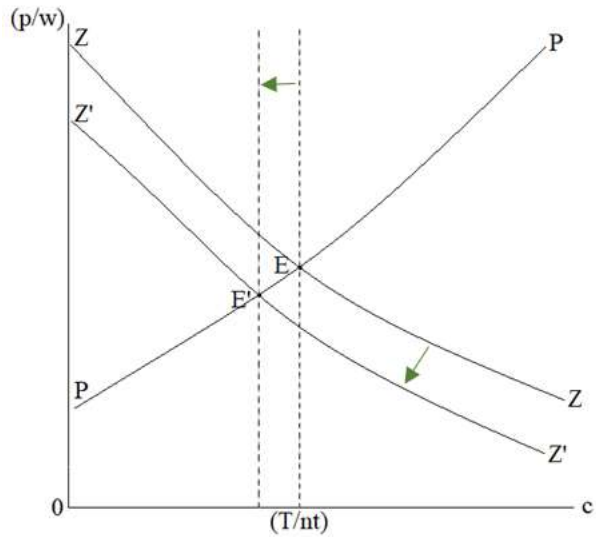

Figure 2: Growth in Labour force

Proof As observed from Equation (10), an increase in the size of the labor force doesn't affect the PP curve, however, both the ZZ curve (Equation 11) and the vertical line representing the time-constraint (Equation (12)) shift, establishing the new equilibrium at E′, with lower c and p/w than at E. Here, the nature of the utility function assumes a crucial role.[9] With an increase in L, n, i.e., the number of varieties tends to increase (unlike the case of time-saving technical progress), and hence, consumers reduce their per-capita consumption of each variety. Consequently, per-unit price also falls to restore the equilibrium on the production side. The important point to note here is that this newly established combination of c and p/w satisfy both the constraints on 'n' as identified in Equation (12). With L rising and c falling, Equation (5) implies that the scale of production of each variety, however, increases in the new equilibrium like in the case of time-saving technical progress.

[9] The existence of a 'love-for-variety' utility function implies that expanding the number of varieties consumed is more beneficial than increasing the consumption of existing varieties.

What about the welfare implications of such type of growth? – In this case, not only does the real income of a representative individual increase, the number of varieties also expands, and hence, the consumer welfare necessarily rises. This is essentially because large populations allow for a multiplication of time, and the economy-wide time constraint given by Equation (3) expands.

A corollary of the above established propositions is thus straightforward.

Corollary 1: *In an economy where technical progress is time-saving, Immigration improves consumer welfare unambiguously*.

4. Conclusions

This short paper demonstrates why traditional cost-saving technical progress fails in an economy where consumption requires physical time (apart from income) by leading to an excessive production of goods, since consumers do not have any additional time to consume them. In such a case, the introduction of a 'time-saving' technical progress facilitates establishing a new consumption-production equilibrium in the model. This novel theoretical result clearly explains why technological innovations since about the 80s or so have focused on time-saving advancements. However, it is surprising to note that such important characteristics have not yet been emphasized in formal models of technology (and in textbooks). Given the strong nexus between technology and trade, it is not trivial to assume that the so-called 'consumption-time' will also have a critical role to play in determining the pattern and geography of international trade. This is where demographics and hence, the role of emerging market economies, become imperative. Time becomes a constraint on consumption when populations dwindle, which is what is happening in the case of developed countries. Despite this, technology continues to produce goods at a rapid pace. As a result, many MNCs from the developed world are now targeting EMEs for their future production and growth. Our simple model incorporates this role of favorable demographics by showing how immigration turns out to be more welfare-enhancing than any type of technical progress in an economy where consumption is time-constrained. The importance of this novel discussion on immigration and technical progress stems from the fact that technology can help in saving consumption time only up to a certain limit, but it cannot increase the total time available to any consumer. Immigration, on the contrary, by expanding the size of the labor force, unambiguously enhances welfare in such a case.

Thus, by incorporating the reality that consumption requires not just income but time, we believe we have introduced a new dimension in a simple general equilibrium model.

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