Impacts of Artificial Intelligence on Healthcare Services' Supply, Efficiency and Productivity in an Open Economy.[a]

K. Yerfi Fosu[1,2,3]

Abstract

This study analyses the impacts of Artificial Intelligence (AI) on healthcare services' supply, efficiency and labour productivity in an open economy. It constructs a novel general theory and modelling methodology of these impacts. It also constructed a novel typology of these impacts. Additionally, these impacts are summarised in three theorems with their formal rigorous proofs. Among other research results, this study observes that the marginal impacts of AI on healthcare services' supply, efficiency and labour productivity in the healthcare services sector tend to be positive or negative. The conditions under which these impact signs occur and their determinants are also analysed rigorously in this study. The policy implications of these results for inducing increases in the supply, efficiency and labour productivity in the healthcare services' sector through the promotion (or otherwise) of AI usage in the healthcare services sector are also discussed in this study. Finally, this study is not only useful to the United States economy, but also to other open economies globally.

Keywords: Artificial Intelligence (AI), digital technology, efficiency, equilibrium adjustment, health, impact typology, labour productivity, modelling, open economies, optimisation, supply.

JEL No.: C01, C02, I11, I18, I19, J23, J24.

a. Paper prepared for the NBER Conference on the Role of Artificial Intelligence (AI) in Healthcare, May 7-8, 2026, NBER, Cambridge, Massachusetts, USA. Topic Area: ''Opportunities to improve productivity, operations, and efficiency with AI.''

1. CAWAVULG, Ghana.

2. email: yatwemakwa7@gmail.com.

3. Comments and suggestions of the economic scientists who perused this work are gratefully acknowledged. Research assistantship services of Stephan Kwadwo Kyei Ennin, Cecil Adade Acheampong, and David Djangmah are also gratefully acknowledged.

***** ACKNOWLEDGEMENT**

This research received no grant from any funding agency in the public, commercial, or not-for-profit sectors. The author declare no competing interests, financial or otherwise, relevant to the content of this manuscript. **The usual disclaimer applies here. There is no conflict of interest in the execution of this research.**

Impacts of Artificial Intelligence on Healthcare Services' Supply, Efficiency and Productivity in an Open Economy

K. Yerfi Fosu

1. Introduction.

The Twenty-First Century has witnessed unprecedented intensity of digital explosion globally. One important fruit of this phenomenon is the development of Artificial Intelligence (AI) tools which continues by leaps and bounds. AI application is expected to increase productivity, efficiency, production, product supply and utilisation in the sectoral economic activity to which it is applied. AI is gradually being employed in the various sectors in an open economy globally. The application of AI in the health services delivery system in economies globally in general and the Unted States (US) economy in particular is an exemplar in this regard.

Unfortunately, the aforementioned potential benefits of AI notwithstanding, whether AI always enhances or serves as a trammel on the supply of healthcare services, its efficiency and productivity, are not well understood. Additionally, the determinants of the impacts (viz., their magnitudes and signs) of AI on healthcare services' supply, efficiency, and productivity, the intensity of these impacts, coupled with the specific conditions under which AI enhances or constitutes trammels on the supply, efficiency and productivity of healthcare services in open economies are not deeply understood. Besides, whether (and how) specific structures (characteristics) of economies can logically be classified into unique types of groups based on these impacts of AI on healthcare services are also not adequately understood. It is imperative to underscore the point that the current body of received knowledge in the economic sciences does not provide ready solutions to these important gaps in knowledge. In particular, there exists a lacuna in respect of a novel general unified theory and pragmatic modelling methodology of the aforementioned impacts and their related issues.

The discussion undertaken so far, particularly in the immediate previous paragraph raises the following scientifically researchable questions:

What is the impact of AI on healthcare services supply in an open economy ?

What is the impact of AI on healthcare services delivery efficiency in an open economy ?

What is the impact of AI on labour productivity in the healthcare services sector in an open economy ?

How can a novel general theory and modelling methodology of the aforementioned impacts be logically constructed in a scientific manner ?

How can a typology of the aforementioned impacts of AI on healthcare services supply, efficiency and productivity in an open economy be logically constructed ? These are the research questions which this study addresses.

This study contributes significantly to narrowing the aforementioned knowledge gaps in the economic sciences, and in so doing, advance the frontier of the knowledge in the economic sciences. Finally, the aforementioned research questions are firmly located on the current front burners of economic scientists and policy makers and practitioners, not only in the USA but also in open economies globally.

This study is organised into four sections. The novel general theory and modelling methodology are constructed in Section 2. The research results and their policy implications are presented in Section 3. Concluding remarks are finally made in Section 4.

2. The Novel General Theory and Modelling Methodology.

Postulate that there exists a transformation function T (·) = 0 in the open economy under study. This function summarises the production structure in this open economy. The arguments of this function comprise the physical quantities (volumes) of the outputs (products) and factor inputs in the economy. Denote the volumes of outputs (products) produced in this economy as q(jk, t), j = healthcare services, other services, food and agriculture goods, industry; k = exported (x), import-competing (m), and nontraded (n) goods and services; $D(ik,\ jk, t)$, i = Artificial Intelligence (AI) and $z(ik, jk, t)$ denotes factor inputs employed in the production of product jk; $L(k,\ jk,\ t)$ denotes the volume of labour employed to produce product jk. Denote the respective unit prices of products as p (ik, jk, t) and unit cost of Artificial Intelligence technologies with their services as γ (ik, jk, t) and of other factor inputs as r (ik, jk, t), and labour wage rate as ω (ik, jk, t); and t denotes the current time period.

Postulate further, that the relevant economic agents in this economy jointly maximise the economy's net benefits function B (·) subject to the aforementioned transformation function. B(·) is conceptualised in this study as the algebraic difference between gross benefits (given by the algebraic sum of the aforementioned product prices and volumes) and gross costs (given by the algebraic sum of the aforementioned unit costs and their corresponding inputs' volumes).

Utilising the Lagrangean-equivalent specification of this constrained maximisation problem and simplifying the results yield the first order conditions in (1) – (4):

$$V\frac{\partial T^*(\cdot)}{\partial D(\cdot)} = -\gamma(\cdot) \tag{1}$$

$$V\frac{\partial T^*(\cdot)}{\partial q(\cdot)} = \mathrm{p}(\cdot) \tag{2}$$

$$V\frac{\partial T^*(\cdot)}{\partial L(\cdot)} = -\omega(\cdot) \tag{3}$$

$$V\frac{\partial T^*(\cdot)}{\partial \mathrm{Z}(\cdot)} = -r(\cdot) \tag{4}$$

where V denotes the relevant Lagrangean multiplier; all other variables and the function T (·) are as already indicated. The second order condition which ensures that the multidimensional stationary point $(q^*(\cdot), D^*(\cdot), L^*(\cdot),\ \mathrm{Z}^*(\cdot))$ from the joint solution of (1) − (4) yields maximum net benefits $B^* = max\ (B) = B^*(\cdot)$ is given by (5), where $Hb(\cdot)$ is the relevant bordered Hessian determinant evaluated at this multidimensional stationary point:

$$(-1)^b H_b(.) \ > 0, \qquad b = 2, 3, \ldots \tag{5}$$

Employing the value function theorem in the Advanced Mathematical Constrained Optimisation Theory, the system of optimal equilibrium long run output supply functions (including healthcare services supply functions and those of the other outputs), and the corresponding factor demand functions for Artificial Intelligence, labour and other factor inputs are given by (6) – (9):

$$\frac{\partial B^*(\cdot)}{\partial p(\cdot)} = q(\cdot)\ (\cdot) \tag{6}$$

j = healthcare service

$\mathrm{j}/ =$ other outputs

$$\frac{\partial B^*(\cdot)}{\partial \gamma(\cdot)} = -D(\cdot)\ (\cdot) \tag{7}$$

$$\frac{\partial B^*(\cdot)}{\partial \omega(\cdot)} = -L(\cdot)\ (\cdot) \tag{8}$$

$$\frac{\partial B^*(\cdot)}{\partial r(\cdot)} = -\mathbf{z}(\cdot)\,(\cdot) \tag{9}$$

where all the variables and functions are as already indicated; the first parenthesis contains the subscripts of the variables, whereas the second parenthesis contains the relevant determinants (viz., all the aforementioned product prices and all the unit costs).

In the system of optimal product supply and factor input demand functions (6) − (9) the own price impacts are positive in the output supply functions (including that for healthcare services supply), whereas the own price impacts in the factor input demand functions are negative (including that of Artificial Intelligence). The cross-price impacts are positive (negative) for pairs of complementary (substitutable) outputs in the output(product) functions. In the optimal factor input demand functions, the cross-price impacts are negative for pairs of complementary factor inputs and positive for substitutable factor inputs. The factor input prices exert negative impacts on product supply, whereas product prices exert positive impacts on factor input demand, ceteris paribus. Note that all the impacts in this paragraph are marginal impacts.

The optimal equilibrium product supply and factor input functions (6) − (9) are essentially equilibrium long run functions and the marginal impacts outlined in the previous paragraph are long run marginal impacts. In the short run, however, the ephemeral existence of economic inertia (viz., economic trammels like the inability of some economic agents to fully perceive changes in the determinants of the product supply and factor input demand functions) yields observed (actual) levels of product supply and factor demand which do not instantaneously adjust to the corresponding equilibrium long run levels. The result of this is that there tends to exist short run disequilibrium in the relevant market. However, as the intensity of the economic trammels ease over time, specific magnitudes of the proportions (per unit time) of this disequilibrium are corrected (removed) over time, so as to get the market back to the optimal equilibrium long run path already summarised in (6) − (9). Invoking the Granger Representation Theorem (Granger 1981, Granger 1983, Granger and Weiss 1983, and Engle and Granger 1987), and Pesaran, Shin and Smith 2001 in the context of the present study) yields the relevant equilibrium correction function in (10a):

$$\begin{aligned}(dY)(t) = g(0) &+ sum(n = 1, \dots, n^*)g(n)(dY)(t-n) \\ &+ sum(\,h = 1, \dots, h^*)sum(s = 0, \dots, s^*)a(h,s)(dG)(h, t-s) \\ &+ \big(M(.)\big)(oY)(t-1) - (\,eY)(t-1)\; + u(t)(M < 0)\end{aligned} \tag{10a}$$

$$Y' = [q(.),\;\; D(.),\;\; L(.),\;\; z(.)]' \tag{10b}$$

$$G = [p(.),\;\; \gamma(.),\;\; \omega(.),\;\; r(.)] \tag{10c}$$

$$M' = [M(q),\;\; M(D),\;\; M(\,L),\;\; M(z)]' \tag{10d}$$

and all the elements of these vectors are as already indicated; dY and dG are the respective first differences of the elements of vectors $Y'\,and\,G$; (t) denotes the current period; $(t-s)$ denotes s period lags (viz., the previous s periods and so on ; (oY) and (eY) are the respective observed levels and predicted equilibrium levels of Y: (eY) denotes the predicted values from the least squares estimated functions in the optimal equilibrium long-run functions in (6) − (9) ; M(·) denotes the proportional disequilibrium corrected per unit time over time for the respective variables in the vector Y': $(M(\cdot) < 0)$; $g(o), g(n), a(h,s)\;and\;M(\cdot)$ are parameters estimated by least squares; $a(h,s)$ quantifies the respective requisite short run impacts; $sum\;(s = 0,1, \dots, s^*)$ denotes

summation from o to s^*, and so on; $u(t)$ denotes stochastic disturbance terms which satisfy the well-known least squares assumptions. In addition, the conventional least squares estimation process and hypotheses testing procedure, coupled with PVOEV – related hypotheses testing procedure (Fomby, Hill and Johnson 1984, Judge, et al 1985, Engle and Granger 1987, Yerfi Fosu 1992, Pesaran, Shin and Smith 2001) are used to estimate and predict the parameters of the equilibrium long run functions and the equilibrium correction functions.

Impacts of Artificial Intelligence on Healthcare Services.

The impacts of Artificial Intelligence (AI) on healthcare services' output supply, efficiency, and labour productivity in an open economy are summarised in Theorems $1-3$. The formal proof of each of these three theorems is also constructed. It is imperative to indicate at the outset that the distinction between the long run marginal impacts and the corresponding impacts of the short run impacts of AI on the output supply, efficiency and productivity of healthcare services in an open economy in Theorems $1-3$ can be derived by utilising the relevant optimal equilibrium long run and short run output supply and factor input demand functions in (6) $-$ (9) and (10a) $-$ (10d) respectively as the basis for computing the respective partial derivatives in Theorem $1-$ 3.

Theorem 1.

Given the maintained postulates in the novel general theory and modelling methodology, coupled with the resulting relevant fundamental functions in (6) $-$ (9) and (10a) $-$ (10d), the marginal impact of Artificial Intelligence (AI) on healthcare services supply in an open economy is given by (11a) $-$ (11b):

$$\frac{\partial q(jk,t)}{\partial D(ik,jk,t)} = \frac{\partial q(jk,t)(.)}{\partial p(jk,t)} \frac{\partial p(jk,t)(.)}{\partial D(ik,jk,t)} = \frac{\partial q(jk,t)}{\partial p(jk,t)} \left(\frac{\partial D(ik,jk,t)(.)}{\partial p(jk,t)}\right)^{-1} > 0 \tag{11a}$$

$$= \frac{\partial q(jk,t)(.)}{\partial \omega(ik,jk,t)} \left(\frac{\partial D(ik,jk,t)(.)}{\partial \omega(ik,jk,t)}\right)^{-1} \lesseqgtr 0 \tag{11b}$$

where j = healthcare services supply; all the variables and functions are as already indicated. The long run impact is computed from the long run output supply function in (6) and factor input demand functions in (7) $-$ (9). The short run impact is computed from the system of equilibrium correction functions in (10a), specifically from the corresponding short run impacts' parameters $a(h,s)$ in (10a). By fixing k = supply of healthcare services' exports (x), or import-competing (m), or non-traded (n), and $ik =$ demand for import-competing (m), and non-traded (n) Artificial Intelligence tools and services, the differential impacts of these AI types on the supply of these healthcare services types can be computed.

Proof.

The proof of (11a) $-$ (11b) essentially proves Theorem 1. Given the present study's aforementioned maintained postulates, the composite function and inverse function rules of differential calculus are applied to compute the relevant first order partial derivatives from (6) $-$ (9) for the requisite long run impacts and from (10a) for the requisite short run impact. These operational steps yield (11a) $-$ (11b) in Theorem 1 as required.

Q.E.D.

Theorem 2.

Suppose the aforementioned maintained postulates in this study hold, coupled with the relevant efficiency conditions derived in (1) $-$ (4) for j = output supply of healthcare services, and i = factor demand for Artificial

Intelligence (AI) in the healthcare services' sector, then the impact of AI on the efficiency of healthcare services' delivery in an open economy is given by (12):

$$\frac{\partial^2 T(.)}{\partial D(ik,jk,t)^2} = \frac{-\gamma(ik,jk,t)}{p(jk,t)} \frac{\partial^2 T(.)}{\partial D((ik,jk,t)\partial q(jk,t)} \lesseqgtr 0 \quad (12)$$

where all the variables and the function are as already indicated.

Proof.

The proof of Theorem 2 entails the proof of (12). Suppose the aforementioned maintained postulates in this study hold. Given that the relevant second order condition for solving the aforementioned constrained optimisation (maximisation) problem holds, then the system of first order conditions for solving this optimisation problem simplifies to the (allocative) efficiency conditions summarised in (1) − (4). Taking the first order partial derivative (with respect to D (·)) of the efficiency condition comprising the simplified results of the ratio of (1) to (2), in turn, yields (12) in Theorem 2 as required.

Q.E.D.

Theorem 3.

Assuming that this study's postulates hold, such that (6) − (8), and (10a) for $q(\cdot)(\cdot), D(\cdot)(\cdot)\ and\ L(\cdot)(\cdot)$ respectively also hold, then the impact of Artificial Intelligence (AI) demand on labour productivity in the process of healthcare services supply is given by (13a) − (13b):

$$G = [p(.),\ \gamma(.),\ \omega(.),\ r(.)] \quad (13a)$$

$$M' = [M(q(.)),\ M(D(.)),\ M(L(.)),\ M(z(.))]' \quad (13b)$$

where all the variables and functions are as already indicated. The partial derivatives from (6) − (8) are for computing the required long run impacts, whereas the corresponding partial derivatives in (10a) are for computing the corresponding short run impacts here.

Proof.

The proof of Theorem 3 entails the proof of (13a) − (13b). By conceptualisation, labour productivity in the healthcare services supply sector in an open economy is given by the ratio of $q(jk,t) to\ L(ik,jk,t), j =$ healthcare services supply, $(ik,jk) = l$abour input in the healthcare services supply sector. Taking the first order partial derivative of the ratio $(q(\cdot)\ to\ L(\cdot))$ with respect to the demand for AI in the healthcare services sector $D(ik,jk\ t)$ gives (13a) − (13b) in Theorem 3 as required.

Q.E.D.

The Novel Typology of the Impacts of AI Healthcare Services' Supply, Efficiency and Labour Productivity.

The signs (negative and positive) of the relevant impacts of Artificial Intelligence (AI) in Theorems 1 - 3 are logically combined and employed to classify open economies (countries) into unique types which constitute the novel typology of the impacts of AI on healthcare services' supply, efficiency and labour productivity. This typology is summarised as a matrix in tabular form as in Table 1 which is self-explanatory.

Table1. The Novel Typology of AI on Healthcare Services' Supply, Efficiency and Labour Productivity.

Economy Type	Healthcare Service Supply	Healthcare Service Efficiency	Healthcare Services Labour Productivity
I	+ +	+	+
I I	+ –	–	–
I I I	+ –	–	+
IV	+ +	+	–
V	+ +	–	+
V I	+ –	+	–

The signs in Columns 2 – 5 are based on equations (11a) – (11b), (12), (13b) respectively.
Source: Author's construction based on Theorems 1 – 3.

3. Research Results and Policy Implications.

A fruitful empirical analysis of the impacts of an emerging digital technology like Artificial Intelligence (AI) on healthcare services supply, efficiency and labour productivity in an open economy (country) requires the availability of a novel general theory and modelling methodology of these impacts which have been constructed using a logical deductive reasoning approach to scientific theorising which provides foundation for empirical modelling methodology, both of which are applicable to any open economy (country) globally including the United States(US). The principal results of this study are the satisfaction of these important needs.

Another important result of this study is that the marginal impact of AI on the supply of healthcare services is positive or negative. The determinants of this sign comprise the structure and degree of the relative complementarity versus substitutability between pairs of outputs (products) and factor inputs, for instance between healthcare services and AI and other factor inputs like labour in the context of this study. This implies that an increase in AI usage in healthcare tends to induce increases (decreases) in healthcare services supply in open economies in which this marginal impact is positive (negative), ceteris paribus (see the signs in Columns 2 and 3 of Table 1). The opposite signs and interpretation of a decrease in AI usage can be made in a similar manner. In order to increase the healthcare services supply in open economies characterised by a positive (negative) marginal impact of AI usage, therefore, policies which enhance positive (negative) AI usage in healthcare services supply need to be promoted in this type of economy.

It is also observed in this study that the marginal impact of AI utilisation in the supply of healthcare services on the efficiency of healthcare services in an open economy tends to be positive or negative (see Column 4 of Table 1). When the cross partial acceleration of the economy's transformation surface with respect to healthcare services supply and AI usage in this sector is positive (negative), then the marginal impact of AI usage on the relevant efficiency condition tends to be negative (positive) ceteris paribus. Recall Theorem 2. In other words, when the AI usage level exerts a positive (negative) marginal impact on the velocity of the economy's transformation surface with respect to healthcare services supply, then the resulting impact of AI usage in the healthcare services' output sector tends to be negative (positive), ceteris paribus. Equivalently, when the direct acceleration of the economy's transformation surface with respect to AI usage in the healthcare services' sector tends to be positive (negative), then this AI usage tends to exert positive (negative) impacts on efficiency here.

Moreover, when an economy is characterised as a Type I, IV, or VI Economy (a Type II, III, or V Economy), then AI usage tends to exert a positive (negative) marginal impact on healthcare services supply efficiency in an

open economy (Table 1). The signs here imply that when a positive (negative) efficiency impact is observed in an economy, then an increase in AI usage in the healthcare services supply sector tends to exert a positive (negative) marginal impact on healthcare supply efficiency, ceteris paribus, whereas a decrease in this AI usage tends to exert a positive (negative) marginal efficiency impact in an economy characterised by an observed negative (positive) impact (Table 1). Hence, policies in a Type I, IV, VI Economy (Type II, III, V Economy) need to increase (decrease) AI usage in healthcare services supply (delivery) efficiency.

This study finally observes that the marginal impact of AI usage in the healthcare services supply on labour productivity in the healthcare service supply sector tends to be positive or negative. Recall Theorem 3. It is observable in Column 5 of Table 1, that AI usage in healthcare exerts positive (negative) marginal impact on the labour productivity in the healthcare services output sector in a Type I, III or V Economy (Type II, IV or VI Economy).

The basis of the positive or negative impact is easily understood by recalling (13a) and (13b) in Theorem 3, where it seen that when the factor comprising the algebraic differences involving, inter alia, the marginal productivity of AI usage in the healthcare services output sector and the healthcare services' labour input-to-AI usage in the healthcare service output sector is positive or negative. Moreover, the relative complementarity versus substitutability concerning the relationship between labour and AI usage in this sector also plays an important role in determining the sign of the impact of AI usage in the sector on labour productivity in the healthcare services sector.

A positive(negative) impact of AI usage on healthcare services labour productivity implies that an increase in AI usage tends to induce an increase (a decrease) in healthcare services labour productivity, ceteris paribus. On the contrary, a decrease in AI usage in this sector tends to induce an increase (a decrease) in healthcare services productivity in an economy characterised by a negative (positive) impact of AI usage on labour productivity in the healthcare services sector. Hence, in a Type I, III, or V Economy (Type II, IV, VI Economy), policies need to promote increases (decreases) in AI usage in the healthcare services sector in order to induce increased labour productivity in the healthcare services supply (delivery) sector, ceteris paribus.

4. Concluding Remarks.

This study has analysed the impacts of Artificial Intelligence (AI) on healthcare services, supply, efficiency and labour productivity in an open economy. It has constructed a novel general theory and modelling methodology of these impacts. It has also constructed a novel typology of these impacts. Additionally, these impacts are also summarised in three theorems with their formal rigorous proofs.

Among other research results, this study observes that the marginal impacts of AI on healthcare services' supply, efficiency and labour productivity in the healthcare services sector tend to be positive or negative. The conditions under these impact signs occur and their determinants are also analysed rigorously in this study. The policy implications of these results for inducing increases in the supply, efficiency and labour productivity in the healthcare services sector through the promotion (or otherwise) of AI usage in the healthcare services sector are also discussed in this study. Finally, this study is not only useful to the United States economy, but also to other open economies globally.

References

- Engle, R. and C. Granger (1987). Cointegration and Error Correction: Representation, Estimation and Testing. Econometrica, 55, 251-276.
- Fomby, T. B., R.C Hill, and S.R. Johnson (1984). Advanced Econometric Methods. Springer-Verlag, New York.
- Fosu, K. Yerfi (1992). Testing Hypotheses About Parameters which Vary Over Explanatory Variables in a Single Linear Regression Equation. Econometrica, 1992 (abstracted).
- Granger, C. W. J. (1981). Some Properties of Time Series Data and Their Use in Econometric Model Specification. Journal of Econometrics, 16, 121-130.
- Granger, C.W.J. (1983). Co-Integrated Variables and Error Correction Models, UCSD, Discussion Paper: 83-13a.
- Granger, C.W.J. and A.A. Weiss (1983). Time Series Analysis of Error-Correcting Models. In: Karlin, S., T. Amemiya, and L.A. Goodman. Eds., Studies in Econometrics, Time Series, and Multivariate Statistics, Academic Press, New York, 255-278.
- Judge, George G., W. E. Griffiths, R. Carter Hill, Helmut Lütkepohl, and Tsoung-Chao Lee. The Theory and Practice of Econometrics, 2nd ed. John Wiley and Sons, New York, 1985.
- Pesaran, M. H., Y. Shin, and R. J. Smith (2001). Bounds Testing Approaches to the Analysis of Level Relationships. Journal of Applied Econometrics, 16, 289-326.