DO EFFICIENCY AND PRODUCTIVITY PAY OFF FOR CAPITAL AND LABOR?

A Note Using Data Envelopment Analysis

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Abstract: Data envelopment analysis (DEA) is a linear programming technique that can be used to evaluate or benchmark the performance of different businesses, non-profit organizations, public sector agencies, and even national economies. DEA can compare these or any set of entities called decision-making units (DMUs) according to how well they minimize inputs in order to maximize output(s), or, in other words, evaluate the DMUs according to how efficient they are. This article uses DEA to compare and contrast 15 Organization for Economic Co-operation and Development (OECD) nations according to how efficiently they attained their national output levels through capital and labor inputs minimization at the peak of the last business cycle in 2007. Next, these efficiency scores as well as other measures of the income shares or returns to labor and capital for each economy are used in order to see if there is some type of support for an aggregate, economy-wide productivity theory of distribution. Although different measures of productivity have been used at aggregate levels to one degree or another to predict payments to factor inputs in order to assess marginal and average productivity theory, the research done for this article has not found any other works that have used DEA, and so this article seeks to make a new and perhaps unique empirical contribution to the literature on aggregate productivity theories of labor and capital income distribution.

Key words: data envelopment analysis; efficiency; productivity

1. Introduction

The concepts of diminishing returns, average productivity and marginal productivity in microeconomics have been debated by both heterodox and neoclassical

economists (Keen 2011). It is when these concepts, especially the concept of the marginal productivity of capital, are used by macroeconomists to describe income shares at aggregate levels, that the debate becomes even more contentious. According to Blaug (1975), Moseley (2012), and Cohen and Harcourt (2003), the use of marginal productivity to explain factor rewards in a macroeconomy comes more or less from an attempt by mainstream economists to respond to Marx's claim that profits or rewards to capital come from the exploitation of workers and from the capitalist taking the surplus value of the workers' efforts. Using a production function where $Q = f(K, L)$, essentially and simply stated, marginal productivity of capital and labor puts forth that

$$\frac{\delta \cdot Q}{\delta \cdot K} = r \tag{1}$$

and

$$\frac{\delta \cdot Q}{\delta \cdot L} = w, \tag{2}$$

where Q = output, K = capital, L = labor, w = real wage rate, and r = real rate of interest (Branson 1989; Jones 2002; Romer 2012). These concepts lead to the concepts of downward sloping demand curves for labor and capital (Cohen and Harcourt 2003), and according to Cobb and Douglas (1928) and Solow (1956, 1957) using a Cobb-Douglas production function and applying regression, aggregate labor and capital estimates "fit" very well the aggregate factors shares or payments over several decades. The shares are fairly constant—in the US, around one quarter to one third of national income goes to capital, and approximately two-thirds to 70% of it goes to labor (Jones 2002, 14).

Various econometric models have been developed at both the microeconomic and macroeconomic level to demonstrate factor productivities and their linkages with factor payments (Felipe and McCombie 2013),[1] although heterodox economists disagree that capital can be aggregated into a national factor input and point out that most of the econometric models yield excellent fits of the data because the models are mostly based on the accounting identity of $Q = rK + wL$, where the variables and their values come from national income accounting (Felipe and McCombie 2013). The purpose of this research note is to try to evaluate national, macroeconomic productivity and factor input payments using a method that has not been detected in the literature reviews for this article. Although it does not provide a measure of marginal productivity, data envelopment analysis (DEA) can assess how efficiently an entity uses its inputs in maximizing its output. DEA is based on linear programming and is a non-parametric technique that

ranks different entities (called decision-making units—DMUs) according to how efficiently they combine inputs to attain their respective levels of output(s). Since it is non-parametric, no a priori assumptions about production techniques (Cobb-Douglas, linear, fixed factors, etc.) are necessary. From a list of the DMUs' inputs and outputs, DEA essentially creates a production possibility frontier (PPF) that approximates the minimum use of inputs or resources to get a maximum output level. Each DMU is assigned an efficiency score based on how close it is to the PPF, and those DMUs which match PPF efficiency or have a combination of inputs and outputs which would place them on the PPF receive a score of 1.0.[2] Those DMUs which score below 1.0 fall below PPF efficiency and are deemed "inefficient."[3] In addition, for those DMUs performing inefficiently, target input and output levels for each DMU can be pinpointed and estimated so that DMUs can be advised on how to adjust their input usage and output production.

DEA has been used in the past to measure the performance of different nations with regard to efficiency, whether efficiency in labor productivity (Maudos, Pastor, and Serrano 2000), in the delivery of social services (Golany and Thore 1997), or efficiency in GDP production (Lambert 2011). It has been proposed as a useful tool for economists because of its ability to highlight "x-inefficiency" in production or any economic system (Leibenstein and Maital 1992).

DEA can also estimate whether a DMU is experiencing decreasing, constant, or increasing returns to scale with regard to output production, although traditional marginal productivity theory assumes an economy where "constant returns to production" and competitive markets exist, assumptions which some call parts of the "neo-classical fable" or a set of parables (Samuelson 1973). Therefore, this article will mostly focus on evaluating constant returns to scale (CRS) production with regard to production to see if there is some type of support for neoclassical theory. A DEA score represents an elasticity which measures "the relative change in output compared to the relative change in input" according to Cooper, Seiford, and Tone (2006, 119–21). Therefore, a DEA score is a way of assessing productivity that is similar to although not exactly the same as the marginal productivity concept.[4]

This article gives the neoclassical economists the "benefit of the doubt" with regard to being able to define capital so as to test hypotheses explaining factor shares by using a productivity concept such as DEA. Therefore, this article does not focus on the debate of whether capital can be aggregated and is mostly interested in testing whether a productivity measure such as that provided by DEA can determine whether factor shares are paid according to their productivity. This article proceeds as follows. The next section (Methods) outlines the variables and methods used to evaluate national economic productivity for labor and capital for different Organization for Economic Co-operation and Development (OECD

Statistics, various years) nations during the year 2007, the peak of the last business cycle before the Great Recession of 2008–2009. This year should be one in which most of these economies should have been operating at peak capacity with relatively low unemployment rates. After this section, a results and discussion section summarizes the main findings of the model developed and used to predict the measurements of *w* and *r*. Finally, a conclusion section reviews the major findings in light of their implications for economic theory.

2. Methods

Data from 15 OECD member nations[5] as shown in Table 1 from the year 2007 (all data are in US dollars and adjusted for purchasing-power-parity) were analyzed in two steps:

2.1. DEA

Using a CRS, slack-based model, efficiency scores that were input and output oriented as well as efficient input and output targets for each nation were calculated for the combined inputs of labor and capital in producing real GDP as output. For those nations producing inefficiently, the efficient input targets show the appropriate input levels needed to produce a nation's actual output whereas the efficient output target shows how much output a nation should produce using its actual inputs. Labor input used was 2007 total hours worked in thousands, the capital input used was 2007 consumption of fixed capital[6] (CFC) in 2005 prices, and output was GDP in millions of dollars (2005 prices). Using these categories for inputs, there were therefore three variables which were flow concepts, not

Table 1 Nations Used in DEA and Correlation Analysis

Austria
Belgium
Czech Republic
Denmark
Estonia
Finland
France
Germany
Italy
Netherlands
Norway
Spain
Sweden
United Kingdom
United States

stock concepts. These were used so as to relate 2007 real GDP production to inputs or resources used that year.

Percentages, per capita estimates, and ratios were not used in the DEA since it is a technique which does not assume a priori relationships among the inputs and outputs, and the avoidance of using ratios and instead using absolute amounts is considered appropriate in order to make the production frontier linear (unless the Banker, Charnes, and Cooper (BCC; 1984) formulation of DEA is used for analysis; Hollingsworth and Smith 2003). When used, with or without the ratio data, the BCC method is very good for capturing increasing and decreasing returns to scale in production whereas the Charnes, Cooper, and Rhodes (CCR; 1978) method is good for measuring CRS efficiency (Cooper, Seiford, and Tone 2006). Since this article is interested in assessing CRS efficiency, the CCR method is used, and this is another reason for not using ratio-based data. Finally, the number of inputs and outputs used (a total of three) in developing the efficiency scores are allowable given the number of cases (15) according to Cooper, Seiford, and Tone (2006, 106).

2.2. Pearson *r* Correlation Matrix

The efficiency scores, the ratio of efficient to actual input levels, and the ratio of efficient to actual output levels using CRS obtained from the DEA analysis were used in a correlation matrix with the following variables:[7]

a. Net Operating Surplus as a Percentage of a Nation's Fixed Assets or Net Capital Stock (NOS / Fixed Assets Pct.). This is used as a proxy for *r* or a return on a capital. NOS is Gross Operating Surplus less capital consumption allowances and less the net of business subsidies and taxes. Fixed assets or net capital include assets lasting over more than one year, including machinery, tools, commercial property, and "intangible assets."[8]
b. NOS as a percentage of GDP (NOS / GDP Pct.). In the literature cited above, this is the usual way of looking at capital's payment for its services at a macroeconomic level and is considered a share of GDP or National Income.
c. Total Wages and Salaries as a Percentage of GDP (Labor Income Share). This is used as a proxy for labor's share of national income and is commonly cited as a constant proportion over time when the Cobb-Douglas production function is employed to predict factor incomes shares.
d. Annual Average Pay per Employed (Labor Comp per Employed). This is used as a proxy for the wage level in each nation, which is hypothesized to be related to labor productivity. That is, the higher a nation's labor productivity, the higher its annual average pay per employed person.

3. Results and Discussion

Table 2 shows the actual 2007 data and overall efficiency scores for the 15 nations examined in this article. Norway and the UK scored the best relative to the other nations as far as utilizing their inputs to attain their levels of real GDP. In Table 3, the results of an input-oriented, CRS, slack-based model of data envelopment are shown, and these values give the target or optimal amount of input that each nation should be using to attain its actual level of GDP output, whereas Table 4 gives the target real GDP output possible for each nation given its inputs. Norway and the UK are the only two nations whose actual and target input and output levels match because they are deemed efficient and have scores of 1.0 under input- and output-oriented DEA.

The targeted input levels for each nation were divided by their actual input levels to obtain the efficient input level that each nation should have had for labor and capital, and the targeted level of real GDP was divided by the actual real GDP level for each nation to arrive at the efficient real output level that each nation should have had. Ratios for the former were all below one except for Norway and the UK, which both scored 1.0, and this indicates too much input usage among most nations. For the latter, all ratios were above one, indicating a real GDP gap or, in other words, most nations fell short of target real GDP, except for Norway and the UK, whose scores were 1.0 each. These ratios in turn were correlated with the four variables listed above that represent factor payments, and the Pearson *r* coefficients are shown in Table 5.

In examining the results of Table 5 and in looking at those correlations which show statistical significance, the efficiency measurement for labor (Efficient Input Target to Actual Hours Worked) is strongly correlated with labor compensation per employed and moderately correlated with labor income share. Both show statistical significance at 0.05 or below. The efficiency measurement for capital (Efficient Input Target to Actual CFC) has a statistically significant correlation with NOS as a percentage of net capital stock with which it has a moderate degree of correlation. The two measures of capital rewards, NOS / GDP percent and NOS as a percentage of net capital stock also appear to be measuring close to the same thing—the higher the return on capital in a nation, the higher capital's share of national income. Both efficiency measurements for capital and labor are linked to efficient output (the greater these ratios, the lower the real GDP gaps), but this is to be expected since these were the inputs used to create the output. Also, both capital efficiency and annual labor compensation are moderately correlated (r = 0.516), which shows that more efficient capital usage leads to greater labor productivity. Next, the table shows that a lower GDP gap (= efficient level / actual

Table 2 Actual Values for Inputs and Output and Efficiency Scores

Nation	*2007 CFC in 2005 US $ Values*	*2007 Total Hours Worked*	*2007 Real GDP in Million US $ (2005 Prices)*
Austria	44,814,469,106.0	7,133,410,900.00	305,681.0
Belgium	57,391,835,316.0	6,984,973,871.00	365,624.3
Czech Republic	41,420,217,222.0	8,825,146,000.00	256,669.2
Denmark	31,268,752,376.0	4,070,551,775.00	193,286.9
Estonia	3,267,590,776.0	1,324,537,400.00	26,724.0
Finland	27,731,858,001.0	4,287,178,000.00	184,113.9
France	267,508,855,929.0	39,603,749,525.00	2,011,083.0
Germany	408,383,741,767.0	54,020,358,000.00	2,838,921.0
Italy	281,060,209,226.0	42,171,152,000.00	1,780,109.0
Netherlands	90,433,444,552.0	11,800,359,600.00	652,668.9
Norway	31,422,093,970.0	3,485,144,000.00	231,227.8
Spain	269,780,734,889.0	34,123,132,200.00	1,315,115.0
Sweden	40,946,067,381.0	7,254,000,000.00	335,590.1
United Kingdom	45,678,355,949.0	48,793,992,000.00	2,203,731.0
United States	1,701,000,000,000.0	264,705,000,000.00	13,681,971.0

DMU No.	*DMU Name*	*Input-Oriented CRS Efficiency*	*Output-Oriented CRS Efficiency*
1	Austria	0.724	1.381
2	Belgium	0.815	1.227
3	Czech Republic	0.529	1.892
4	Denmark	0.756	1.324
5	Estonia	0.410	2.437
6	Finland	0.720	1.389
7	France	0.840	1.190
8	Germany	0.840	1.190
9	Italy	0.701	1.426
10	Netherlands	0.881	1.135
11	Norway	1.000	1.000
12	Spain	0.608	1.646
13	Sweden	0.804	1.243
14	United Kingdom	1.000	1.000
15	United States	0.868	1.152

Note: CFC = consumption of fixed capital; DMU = decision making unit; CRS = constant returns to scale.

level) is associated with greater annual labor compensation ($r = –0.857$). Finally, there is a moderate, inverse relationship displayed between capital and labor income shares ($r = –0.594$), which illustrates the tradeoffs in factor payments between capital and labor.

Table 3 Efficient Input Targets for Actual Output

DMU No.	*DMU Name*	*Efficient Input Targets*		*Actual Output*
		2007 CFC in 2005 US $ Values (Thousands)	*2007 Total Hours Worked (Thousands)*	*2007 Real GDP in Millions US $ (2005 Prices)*
1	Austria	6,336,075,285	6,768,247,245	305,681
2	Belgium	25,669,939,130	6,984,973,871	365,624
3	Czech Republic	5,320,171,599	5,683,050,650	256,669
4	Denmark	7,413,140,295	4,070,551,775	193,287
5	Estonia	553,928,036	591,710,441	26,724
6	Finland	3,816,264,444	4,076,564,773	184,114
7	France	121,914,043,411	39,603,749,525	2,011,083
8	Germany	202,820,081,212	54,020,358,000	2,838,921
9	Italy	36,897,630,668	39,414,349,712	1,780,109
10	Netherlands	56,711,570,670	11,800,359,600	652,669
11	Norway	31,422,093,970	3,485,144,000	231,228
12	Spain	27,259,357,464	29,118,667,745	1,315,115
13	Sweden	9,831,078,759	7,254,000,000	335,590
14	United Kingdom	45,678,355,949	48,793,992,000	2,203,731
15	United States	906,482,408,738	264,705,000,000	13,681,971

Note: DMU = decision making unit; CFC = consumption of fixed capital.

Table 4 Efficient Output Targets for Actual Inputs

DMU No.	*DMU Name*	*Actual Inputs*		*Efficient Output Target*
		2007 CFC in 2005 US $ Values (Thousands)	*2007 Total Hours Worked (Thousands)*	*2007 Real GDP Million US $ (2005 Prices)*
1	Austria	44,814,469,106	7,133,410,900	422,155
2	Belgium	57,391,835,316	6,984,973,871	448,789
3	Czech Republic	41,420,217,222	8,825,146,000	485,510
4	Denmark	31,268,752,376	4,070,551,775	255,828
5	Estonia	3,267,590,776	1,324,537,400	65,137
6	Finland	27,731,858,001	4,287,178,000	255,808
7	France	267,508,855,929	39,603,749,525	2,392,784
8	Germany	408,383,741,767	54,020,358,000	3,377,841
9	Italy	281,060,209,226	42,171,152,000	2,537,964
10	Netherlands	90,433,444,552	11,800,359,600	741,076
11	Norway	31,422,093,970	3,485,144,000	231,228
12	Spain	269,780,734,889	34,123,132,200	2,164,665
13	Sweden	40,946,067,381	7,254,000,000	417,163
14	United Kingdom	45,678,355,949	48,793,992,000	2,203,731
15	United States	1,701,000,000,000	264,705,000,000	15,764,932

Note: DMU = decision making unit; CFC = consumption of fixed capital.

Table 5 Pearson *r* Correlation Matrix

	NOS / GDP Pct.	*NOS / Fixed Assets Pct.*	*Efficient Input Target/ Actual CFC*	*Efficient Input Target / Actual Hours Worked*	*Labor Comp per Employed*	*Labor Income Share*	*Efficient Output Target / 2007 Real GDP*
NOS / GDP Pct.	1.000						
NOS / Fixed Assets Pct.	0.780**	1.000					
Efficient Input Target/Actual CFC	0.339	0.531*	1.000				
Efficient Input Target/Actual Hours Worked	–0.330	–0.285	0.438	1.000			
Labor Comp per Employed	–0.224	–0.175	0.516*	0.854**	1.000		
Labor Income Share	–0.594*	–0.493	–0.033	0.531*	0.481	1.000	
Efficient Output Target / 2007 Real GDP	0.148	0.091	–0.646**	–0.962**	–0.857**	–0.420	1.000

Note: NOS = Net Operating Surplus; CFC = consumption of fixed capital.

*$p < .05$. **$p < .01$.

4. Conclusion

The results of this article fail to show support for a strong theory of macroeconomic productivity and its link to capital rewards or shares of income. This of course allows for the leap of faith that capital or fixed assets can be aggregated, and in turn, a measurement of their consumption and depreciation can be measured as well. In spite of allowing for this assumption, this article finds only a moderate correlation between capital productivity/efficiency and its payment/reward in terms of return on capital (NOS / Fixed Assets).

There is stronger support for labor productivity being connected to higher income shares and pay, especially between efficient labor input and annual average pay per employed person ($r = 0.854$). In this analysis, labor productivity also appears to have a stronger relationship with efficient total output or a lower real GDP gap ($r = –0.857$) than does capital.

Although DEA is non-parametric and makes no a priori assumptions about whether a production function is Cobb-Douglas, or takes the Constant Elasticity of Substitution (CES) form, etc., it does evaluate DMUs on their relative efficiency in maximizing output while minimizing inputs. Using neoclassical assumptions of

greater productivity yielding higher factor payments, one would expect better results for the efficient use of capital measurement as a predictor of returns to capital or capital income shares. Yet the results are mixed at best in the simple model developed. Instead, it is pretty much labor efficiency that shows the better match with factor rewards.

The limits of this research note include the fact that a larger sample size of nations would have been preferred to the 15 nations studied. However, data limitations were present. The variables net operating surplus and the measurement of fixed assets or net capital stock were only available for these nations. Also, more years could have been examined and a panel data set could have been used for analysis. However, since 2007 was the peak of the last business cycle, it was felt that most if not all of the nations examined would be operating at either full capacity or close to full capacity with regard to resource utilization. That is, there was a desire to avoid possible cyclical effects and picking up any inefficiency in output due to (1) an economy having high levels of unemployment or underutilization of resources during recessionary periods or (2) an economy having low levels of input usage due to its experiencing an expansionary/post-recession period.

With labor performing better than capital in this analysis, some doubt is cast upon the argument that capital earns a factor payment for its productivity. This could be due to the problems of aggregating capital as discussed earlier, although aggregating heterogeneous labor is also difficult. Brown (2005) notes that many heterodox economists reject the idea of not only capital aggregation but also labor aggregation. The simple analysis performed in this article indicates that what determines factor payments or income shares is not necessarily productivity and efficiency, especially with regard to a capital measurement. If one allows for the assumption of capital aggregation, then the neoclassical argument of the productivity of capital only finds mixed results at best in this article.

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Notes

1. The most recent major article to weigh in on the controversy is one by Biewen and Weiser (2014), who in analyzing data from Chilean manufacturing plants, write “our article also seems to be the first one that considers deviations from marginal productivity theory for the different production factors capital, labour, and intermediate inputs at the same time” (997).

2. For output-oriented DEA, the scores are basically the reciprocal of the input-oriented DEA results where 1 is deemed efficient and scores greater than 1 are deemed inefficient.
3. Admittedly, this is a narrow definition of efficiency. Yet it is in the spirit of the neoclassical point of view that agents and markets seek to maximize profits and/or output through minimizing costs and/or inputs, and this article tries to give the neoclassical point of view the opportunity to show some validity since it has come under heavy criticism in the past. Hence, this narrow definition is used. Heterodox economists would probably disagree with such a narrow definition, or even that efficiency as a concept exists. For example, Simon (1947) argued that managers in organizations act in a way such that their behavior often is not oriented toward maximization but instead toward "satisficing" or obtaining satisfactory results.
4. Elasticity measures have a derivative embodied in them and are therefore not the same as a derivative. Price elasticity is often calculated as $(dQ / dP) \times (P / Q)$ where the first ratio is a derivative.
5. There are more than 15 OECD member nations, but because of data limitations, only 15 could be used for this article. The chief data limitation was finding values for net operating surplus and net capital stock for enough nations so as to increase sample size. Data source: http://stats.oecd.org/Index.aspx?#.
6. Consumption of fixed capital is defined by OECD as "the decline, during the course of the accounting period, in the current value of the stock of fixed assets owned and used by a producer as a result of physical deterioration, normal obsolescence or normal accidental damage." http://stats.oecd.org/glossary/detail.asp?ID=430.
7. Descriptive statistics for all variables can be provided by the author upon request. Data source: http://stats.oecd.org/Index.aspx?#.
8. More specifically, according to OECD:

   > Fixed assets are defined in national accounts as non-financial produced assets that are used repeatedly or continuously in production for more than one year. Fixed assets include not only dwellings, buildings, structures, machinery and equipment but also cultivated assets such as livestock for breeding and vineyards. They also include intangible assets such as computer software and entertainment, literary or artistic originals. (http://stats.oecd.org/glossary/detail.asp?ID=998)

   It is not entirely clear from this definition whether copyrights and patents are included.

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