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Productivity Growth in APEC Countries

by

Robert G. Chambers, Rolf Färe
and Shawna Grosskopf

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Robert G. Chambers*, Rolf Färe** and Shawna Grosskopf**

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In this paper, we introduce a new technique for measuring productivity growth, and apply it to a sample of APEC countries. The new technique is based on a version of Luenberger's shortage function which generalizes Shephard's input and output distance functions.

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This paper introduces a new technique for measuring productivity growth and applies it to a sample of APEC countries. The new technique is based on the directional technology distance function, a version of Luenberger's shortage function (Luenberger (1992, 1995)), which generalizes Shephard's input and output distance functions (Chambers, Chung and Färe (1996)). The directional technology distance function encompasses all known distance functions.

Recently, Färe, Grosskopf, Norris and Zhang (1994), used ratios of output distance functions to define and calculate productivity growth among OECD countries. They followed the nonparametric Malmquist productivity approach initiated by Färe, Grosskopf, Lindgren and Roos (1989). Here we also employ a nonparametric model of technology, but we develop new linear programming models suitable for calculating directional distance functions while basing our productivity measure upon Luenberger productivity indicators introduced by Chambers (1996).

The Productivity Model

This section introduces the directional technology distance function and the productivity indicator based on it. We follow Chambers (1996) and Diewert (1993) and use the term "indicator" for measures defined in terms of differences.

Let the technology be described by a set, $T \subseteq \mathbb{R}^N_+ x \mathbb{R}^M_+$, defined by

$$T = \{(x,y) : x \text{ can produce } y\}, \tag{1}$$

where $x \epsilon \mathbb{R}^N_+$ is a vector of inputs and $y \epsilon \mathbb{R}^M_+$ is a vector of outputs. The directional technology distance function denoted by $\vec{D}_T(\bullet)$, is defined as

$$\vec{D}_T(x,y;g_x,g_y) = \sup\{\beta : (x-\beta g_x, y+\beta g_y) \epsilon T\} \tag{2}$$

where (g_x,g_y) is a nonzero directional vector.

Figure 1. The Directional Technology and Output Distance Functions

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Figure 1 illustrates the directional distance function. We assume constant returns to scale so that T can be visualized as all input-output vectors below the ray from the origin and the input-output vector under consideration is the point (x,y). The direction in which this vector is "expanded" is given by (g_x,g_y). The minus sign in (2) follows from the subtraction from inputs in (2). The (x,y) vector is expanded in the (g_x,g_y) direction as much as is feasible. The maximal expansion is the value of $\vec{D}_T(x,y;g_x,g_y)$.

Under free disposability of inputs and outputs,[1] the directional distance function completely characterizes the technology. (Chambers, Chung, and Färe, 1996). In particular

$$\vec{D}_T(x,y;g_x,g_y) \geq 0 \text{ if and only if } (x,y)\epsilon T.^2 \tag{3}$$

To show how the directional distance function (2) is related to Shephard's output distance function, recall that the latter is defined as

$$D_o(x,y) = \sup\{\theta : (x,y/\theta)\epsilon T\} \tag{4}$$

and that

$$D_o(x,y) \leq 1 \text{ if and only if } (x,y)\epsilon T. \tag{5}$$

Now if we choose $g_x = 0$ and $g_y = y$, then we find

$$\vec{D}_T(x,y;0,y) = (1/D_o(x,y)) - 1. \tag{6}$$

Thus Shephard's output distance function is a special case of the directional technology distance function.[3]

---

[1]Inputs and outputs are freely disposable if $(x,y)\epsilon T$ and $(x',-y') \geq (x,-y)$ imply $(x',y')\epsilon T$.

[2]For additional properties of $\vec{D}_T(x,y;g_x,g_y)$ see Chambers, Chung and Färe (1996).

[3]One can also easily derive the relationship between $\vec{D}_T(\bullet)$ and the Shephard input distance function.

In Figure 1, we expand (x,y) due "North" (in the direction of y) to illustrate $D_o(x,y)$ or $\vec{D}_T(x,y;0,y)$. Moreover, if T exhibits constant returns to scale, i.e., $\lambda T = T$, $\lambda > 0$, then it follows for $\lambda > 0$ that

$$\vec{D}_T(\lambda x,\lambda y;g_x,g_y) = \lambda\vec{D}_T(x,y;g_x,g_y). \tag{7}$$

Next we introduce our productivity indicator based on the directional distance function. Following Chambers (1996), we define the Luenberger productivity indicator for periods t and t+1 as

$$\begin{aligned} L(x^t,y^t,x^{t+1},y^{t+1}) = {} & \tfrac{1}{2}(\vec{D}_{T^{t+1}}(x^t,y^t;g_x,g_y) - \vec{D}_{T^{t+1}}(x^{t+1},y^{t+1};g_x,g_y) \\ & + \vec{D}_{T^t}(x^t,y^t;g_x,g_y) - \vec{D}_{T^t}(x^{t+1},y^{t+1};g_x,g_y)) \end{aligned} \tag{8}$$

Productivity improvements are indicated by positive values and declines by negative values.

The Luenberger productivity indicator can be decomposed into two component measures, namely an efficiency change component.[4]

$$EFFCH = \vec{D}_{T^t}(x^t,y^t;g_x,g_y) - \vec{D}_{T^{t+1}}(x^{t+1},y^{t+1};g_x,g_y) \tag{9}$$

and a technical change component

$$\begin{aligned} TECH = {} & \tfrac{1}{2}(\vec{D}_{T^{t+1}}(x^{t+1},y^{t+1};g_x,g_y) - \vec{D}_{T^t}(x^{t+1},y^{t+1};g_x,g_y) \\ & + \vec{D}_{T^{t+1}}(x^t,y^t;g_x,g_y) - \vec{D}_{T^t}(x^t,y^t;g_x,g_y)) \end{aligned} \tag{10}$$

The sum of EFFCH and TECH is of course equal to the Luenberger indicator. Next, we illustrate the productivity indicator and its component measures.

---

[4]As in Färe, Grosskopf, Norris and Zhang (1994), we can decompose EFFCH into a scale change component and an efficiency change component, where the latter is computed relative to technologies satisfying variable returns to scale.

Figure 2. The Luenberger Productivity Indicator

The following notation is adopted in connection with Figure 2. The direction of expansion (g_x, g_y) is denoted by g. The t input-output vector (x^t, y^t) is denoted by a, and the (t+1) vector (x^{t+1}, y^{t+1}) is denoted by d. The two technologies are T^t and T^{t+1}. In this notation we get

$$b = a + \vec{D}_{T^t}(a;g)g$$

$$c = a + \vec{D}_{T^{t+1}}(a;g)g$$

$$e = d + \vec{D}_{T^t}(d;g)g$$

$$f = d + \vec{D}_{T^{t+1}}(d;g)g$$

and

$$EFFCH = (b-a) - (f-d) = (\vec{D}_{T^t}(a;g) - \vec{D}_{T^{t+1}}(d;g))g$$

$$TECH = ½((f-e) + (c-b)) = ½(\vec{D}_{T^{t+1}}(d;g) - \vec{D}_{T^t}(d;g) + \vec{D}_{T^{t+1}}(a;g) - \vec{D}_{T^t}(a;g))g$$

Thus efficiency change measures how close the observations a and d are to the technologies T^t and T^{t+1}. Technical change is the average distance between the two technologies.

To formalize the linear programming problem needed for the calculation of Luenberger productivity indicator and its component measures, we assume that at each t there are K observations of inputs and outputs $(x^{k,t},y^{k,t})$, k=1,...,K. Following Färe, Grosskopf and Lovell (1994) the constant returns to scale technology associated with the observations may be written as

$$
\begin{aligned}
T^t = \{(x^t,y^t) :\ & \sum_{k=1}^{K} z_k y^t_{km} \geq y^t_m,\ m=1,\ldots,M, \\
& \sum_{k=1}^{k} z_k x^t_{kn} \leq x^t_n,\ n=1,\ldots,N, \\
& z_k \geq 0,\ k=1,\ldots,k\}.
\end{aligned}
\tag{11}
$$

The inequalities in (11) indicate that both inputs and outputs are freely disposable, thus here we have imposed constant returns to scale and free disposability of inputs and outputs.

The linear programming problems required for computing the Luenberger productivity indicator are as follows,

$$
\vec{D}_{T^t}(x^{k',t},y^{k',t};g_x,g_y) = \max \beta \tag{12}
$$

$$
\begin{aligned}
\text{s.t.}\quad & \sum_{k=1}^{K} z_k y^t_{km} \geq y^t_{k'm} + \beta g_{y_m},\ m=1,\ldots,M, \\
& \sum_{k=1}^{K} z_k x^t_{kn} \leq x^t_{k'n} - \beta g_{x_n},\ n=1,\ldots,N, \\
& z_k \geq 0,\ k=1,\ldots,K.
\end{aligned}
$$

This programming problem evaluates observation k′ at t relative to the reference technology T^t, in the direction of (g_x,g_y). Similar programs can be formed for $\vec{D}_{T^{t+1}}(x^{k',t},y^{k't};g_x,g_y)$ and $\vec{D}_{T^t}(x^{k',t+1},y^{k',t+1};g_x,g_y)$.

The linear program evaluating k′ at t relative to T^t in the direction of $g_x = x^{k',t}$ and $g_y = y^{k',t}$ is

$$\vec{D}_{T^t}(x^{k',t},y^{k',t};x^{k',t},y^{k',t}) = \max \beta \tag{13}$$

$$\text{s.t.} \quad \sum_{k=1}^{K} z_k y_{km}^t \geq (1+\beta) y_{k'm}^t, \; m=1,\ldots,M$$

$$\sum_{k=1}^{K} z_k x_{kn}^t \leq (1-\beta) x_{k'n}^t, \; n=1,\ldots,N$$

$$z_k \geq 0, \; k=1,\ldots,K.$$

If we choose $g_x = 0$ and $g_y = y^{k',t}$, we will compute the reciprocal of the Shephard output distance function minus one, i.e.,

$$\vec{D}_{T^t}(x^{k',t},y^{k',t};0,y^{k',t}) = \max \beta$$

$$\text{s.t.} \quad \sum_{k=1}^{K} z_k y_{km}^t \geq (1+\beta) y_{k'm}^t, \; m=1,\ldots,M,$$

$$\sum_{k=1}^{K} z_k x_{kn} \leq x_{k'n}, \; n=1,\ldots,N,$$

$$z_k \geq 0, \; k=1,\ldots,K.$$

The final direction we choose is $g_x = 1$ and $g_y = 1$, i.e., we treat inputs and outputs symmetrically. Under this assumption, the directional distance function is equivalent to

Blackorby and Donaldson's (1980) translation function. This may be computed for k for the technology T^t as[5]

$$\vec{D}_{T^t}(x^{k',t}, y^{k',t}; 1,1) = \max \beta \tag{14}$$

$$\text{s.t.} \quad \sum_{k=1}^{K} z_k y_{km}^t \geq y_{k'm}^t + \beta, \; m=1,\ldots,M,$$

$$\sum_{k=1}^{K} z_k x_{kn}^t \leq x_{k'n}^t - \beta, \; n=1,\ldots,N,$$

$$z_k \geq 0, \; k=1,\ldots,K.$$

We also show how the directional distance for k' relative to T^{t+1} is computed, i.e.,

$$\vec{D}_{T^{t+1}}(x^{k',t}, y^{k',t}; 1,1) = \max \beta \tag{15}$$

$$\text{s.t.} \quad \sum_{k=1}^{K} z_k y_{km}^{t+1} \geq y_{k'm}^t + \beta, \; m=1,\ldots,M,$$

$$\sum_{k=1}^{K} z_k x_{kn}^{t+1} \leq x_{k'n}^t - \beta, \; n=1,\ldots,N,$$

$$z_k \geq 0, \; k=1,\ldots,K.$$

Some more economic insight into the nonparametric method is provided by considering the dual formulation of (14). We have for observation k,

$$\vec{D}_{T^t}(x^{k,t}, y^{k,t}; 1,1) = \min_{(w,p)} \left\{ \sum_{n=1}^{N} w_n x_{kn}^t - \sum_{m=1}^{M} p_m y_{km}^t : \right.$$

[5]In practice, we mean-deflate the data, and therefore also the direction, g. In order to arrive at the specification in (14), we set $g_{x_n} = \sum_{k=1}^{K} x_{kn}/K$, $n=1,\ldots,N$ and $g_{y_m} = \sum_{k=1}^{K} y_{km}/K$, $m=1,\ldots,M$.

$$\sum_{n=1}^{N} w_n x_{kn}^t - \sum_{m=1}^{M} p_m y_{km}^t \geq 0, \quad k=1,\ldots,K$$

$$\sum_{m=1}^{M} p_m + \sum_{n=1}^{N} w_n \geq 1\}.$$

The nonparametric method for calculating the directional technology distance function can also be viewed as choosing vectors of normalized input and output prices which allow no firm to more than break even (this reflects constant returns), but which minimizes the loss for individual firms. If firm k is efficient, then its loss is equal to zero.

Figure 3 illustrates. For graphical clarity, we have only depicted observations from period t. For these observations, the range of feasible input-output price ratios are those having higher input-output price ratios than that given by the ray through $(x^{3,t},y^{3,t})$, which under the assumption of constant returns is the only efficient point. The price ratio which is ultimately picked for each observation will be the one which has the smallest economic loss associated with the observation subject to the normalization that $\sum_{m=1}^{M} p_m + \sum_{n=1}^{N} w_n \geq 1$. A similar depiction exists for the period t+1 technology.

With these points in mind, it is then apparent that our productivity indicators can always be decomposed directly into profit-based measures of efficiency change and technical change using the reference shadow prices derived from the dual linear programs. Intuitively, this is very appealing because Chambers (1996) has shown that under the assumption of technical efficiency superlative indicators of productivity are profit differences calculated using an average of normalized period t and period t+1 prices. Here the reference prices are shadow prices derived from the above linear programs.

Figure 3. The Dual Problem

To further illustrate the Luenberger productivity indicator, let

$$(w^{t,k},p^{t,k}) = \text{argmin}\{wx^{t,k} - py^{t,k} : wx^{t,k} - py^{tk} \geq 0,\ k=1,\ldots,K,$$
$$w \cdot 1 + p \cdot 1 \geq 1\}.$$

Then we have that the calculated value of the Luenberger productivity indicator is

$$\tfrac{1}{2}(w^{t+1}x^{t} - p^{t+1}y^{t} - w^{t+1}x^{t+1} + p^{t+1}y^{t+1} + w^{t}x^{t} - p^{t}y^{t} - w^{t}x^{t+1} + p^{t}y^{t+1})$$

which can be written as

$$\tfrac{1}{2}(p^{t+1} + p^{t})(y^{t+1} - y^{t}) + \tfrac{1}{2}(w^{t+1} + w^{t})(x^{t} - x^{t+1}).$$

Data and Results

The models derived in the previous section are applied here to analyze the performance of the countries in APEC (Asian-Pacific Economic Community). These include Australia, Canada, Chile, China, Hong Kong, Indonesia, Japan, Korea, Malaysia, Mexico, New Zealand, the Philippines, Papua (New Guinea), Singapore, Taiwan, Thailand and the United States. Data were gleaned from the Penn World Tables, version 5.6. We follow Färe, Grosskopf, Norris and Zhang (1994) and use real GDP, employment and nonresidential capital stock as output and inputs. These are in international prices, base 1984.

The data were compiled for the period 1975-1990.[6] We computed three variations of the productivity index by specifying three different "directions" for the component distance functions:

1) $g_x = x$, $g_y = y$, i.e., the direction is determined by each country's observed inputs and output in that period.

2) $g_x = 0$, $g_y = y$, i.e., the direction is determined by the country's output vector. This is the distance function which is a direct transformation of the Shephard output distance function used in the Malmquist productivity index.

3) $g_x = \bar{x}$, $g_y = \bar{y}$, i.e., the mean of the data in each period. This implies that all observations will be evaluated in the same direction.

For each case, we compute productivity change, efficiency change and technical change for each country for each adjacent pair of years between 1975-1990; i.e., 765 indexes

---

[6]Capital stock data was not available for China, Indonesia, Malaysia, Singapore and Papua (new Guinea). We used the perpetual inventory method (benchmark year 1960, depriciation set at .10) to construct capital stock series for these countries based on investment data from PWT 5.6.

for each of our three cases. By way of summary of these results, we include two tables: Table 1 with average, annual productivity change (and its components) and Table 2 which cumulates the productivity changes over the entire 1975-1990 period.

[Insert Table 1 Here]

Table 1 suggests that average annual productivity has declined over the 1975-1990 period for APEC countries no matter in which direction we measure productivity, based on the mean for the sample. The countries that improve on average in the three models include Australia, Canada, Hong Kong and the U.S. Generally speaking average annual productivity declined due to falling efficiency; technical change was generally positive.

[Insert Table 2 Here]

The cumulated results in Table 2 tell a similar story, with Australia, Canada, Hong Kong and the U.S. showing positive cumulated growth over the period in all these models. Japan, Korea and Singapore exhibit positive cumulated productivity growth in at least one model.

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Table 1

Average Annual Productivity Change 1975-1990

	Based on directional distance function: $g_x = x$, $g_x = y$			Based on model analogous to Shephard distance function: $g_x = 0$, $g_y = y$			Based on directional distance function: $g_x = \bar{x}$, $g_y = \bar{y}$		
Country	PROD	EFFCHG	TECHCH	PROD	EFFCHG	TECHCH	PROD	EFFCHG	TECHCH
Canada	0.0067	0.0000	0.0067	0.0133	0.0016	0.0150	0.0021	0.0004	0.0017
Mexico	-0.0027	-0.0106	0.0078	-0.0055	-0.0272	0.0217	-0.0028	-0.0054	0.0027
U.S.A.	0.0032	0.0000	0.0032	0.0067	0.0000	0.0067	0.0108	0.0000	0.0108
Chile	-0.0019	-0.0110	0.0090	-0.0084	-0.0302	0.0219	-0.0003	-0.0007	0.0004
China	-0.0128	-0.0155	0.0027	-0.927	-0.1123	0.0195	-0.0774	-0.0440	-0.0334
Hong Kong	0.0198	0.0093	0.0105	0.0393	0.0177	0.0216	0.0015	0.0008	0.0007
Indonesia	-0.0311	-0.0343	0.0032	-0.1252	-0.1500	0.0248	-0.0227	-0.0194	-0.0033
Japan	-0.0050	-0.0054	0.0004	-0.0318	-0.0337	0.0019	0.0103	0.0138	-0.0035
Korea	0.0007	-0.0104	0.0111	-0.0240	-0.0636	0.0396	-0.0024	-0.0027	0.0003
Malaysia	-0.0101	-0.0155	0.0054	-0.0694	-0.0988	0.0294	-0.0031	-0.0018	-0.0013
Philippines	-0.0024	-0.0087	0.0062	-0.0058	-0.0255	0.0198	-0.0008	-0.0009	0.0001
Singapore	0.0034	-0.0007	0.0041	-0.0233	-0.0390	0.0156	0.0001	0.0002	-0.0001
Taiwan	-0.0064	-0.0104	0.0040	-0.0532	-0.0698	0.0166	-0.0033	-0.0014	-0.0019
Thailand	-0.0035	-0.0092	0.0057	-0.0163	-0.0315	0.0152	-0.0015	-0.0017	0.0002
Australia	0.0041	-0.0025	0.0067	0.0073	-0.0087	0.0160	0.0006	-0.0002	0.0008
New Zealand	-0.0026	-0.0072	0.0047	-0.0083	-0.0202	0.0120	-0.0001	-0.0002	0.0001
Papua	-0.0037	-0.0101	0.0064	-0.0201	-0.0509	0.0309	-0.0001	0.0000	-0.0001
mean	-0.0026	-0.0084	0.0058	-0.0246	-0.0439	0.0193	-0.0052	-0.0037	-0.0015

Table 2

Cumulated Productivity Growth 1975-1990

	Based on directional distance function: $g_x = x$, $g_x = y$			Based on model analogous to Shephard distance function: $g_x = 0$, $g_y = y$			Based on directional distance function: $g_x = \bar{x}$, $g_y = \bar{y}$		
Country	CUM PROD	CUM EFFCHG	CUM TECHCH	CUM PROD	CUM EFFCHG	CUM TECHCH	CUM PROD	CUM EFFCHG	CUM TECHCH
Canada	0.10059	-0.00012	0.10071	0.19965	-0.02466	0.22431	0.03161	0.00541	0.02621
Mexico	-0.04097	-0.15684	0.11737	-0.08257	-0.40124	0.32517	-0.04136	-0.08145	0.04011
U.S.A.	0.04825	0.00000	0.04825	0.10008	0.00000	0.10008	0.16187	0.00000	0.16187
Chile	-0.02882	-0.19442	0.13564	-0.12568	-0.51544	0.32798	-0.00483	-0.01319	0.00602
China	-0.19170	-0.23209	0.04038	-1.39125	-1.68442	0.29321	-1.16169	-0.66043	-0.50126
Hong Kong	0.29768	0.13975	0.15793	0.58914	0.26497	0.32417	0.10879	0.09787	0.01092
Indonesia	-0.46650	-0.51383	0.04733	-1.87781	-2.25049	0.37270	-0.34101	-0.29119	-0.04980
Japan	-0.07481	-0.08063	0.00582	-0.47644	-0.50540	0.02895	0.15390	0.20680	-0.05291
Korea	0.00985	-0.15607	0.16592	-0.36034	-0.95412	0.59376	-0.03642	-0.04089	0.00445
Malaysia	-0.15082	-0.23244	0.08162	-1.04106	-1.48192	0.44085	-0.04626	-0.02707	-0.01919
Philippines	-0.03666	-0.13004	0.09338	-0.08669	-0.38305	0.29636	-0.01144	-0.01346	0.00201
Singapore	0.05154	-0.01008	0.06161	-0.34970	-0.58442	0.23474	0.00172	0.00251	-0.00081
Taiwan	-0.09622	-0.15667	0.06044	-0.79839	-1.04761	0.24922	-0.04932	-0.02158	-0.02775
Thailand	-0.05318	-0.13804	0.08487	-0.24512	-0.47325	0.22815	-0.02215	-0.02517	0.00301
Australia	0.06195	-0.03813	0.10008	0.11025	-0.13003	0.24027	0.00900	-0.00312	0.01212
New Zealand	-0.03838	-0.10838	0.06999	-0.12381	-0.30355	0.17973	-0.00119	-0.00282	0.00163
Papua	-0.05618	-0.15193	0.09574	-0.05328	-0.76404	0.46318	-0.00011	0.00068	-0.00193

List of captions:

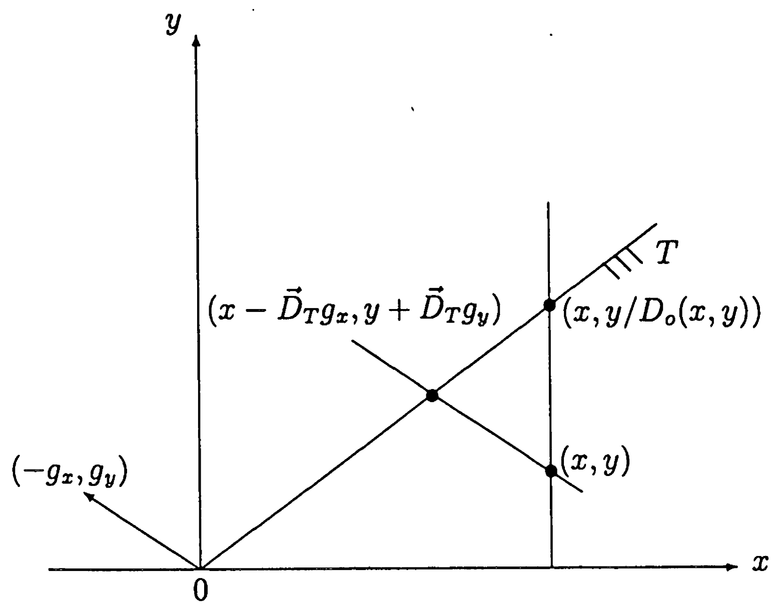

Figure 1:

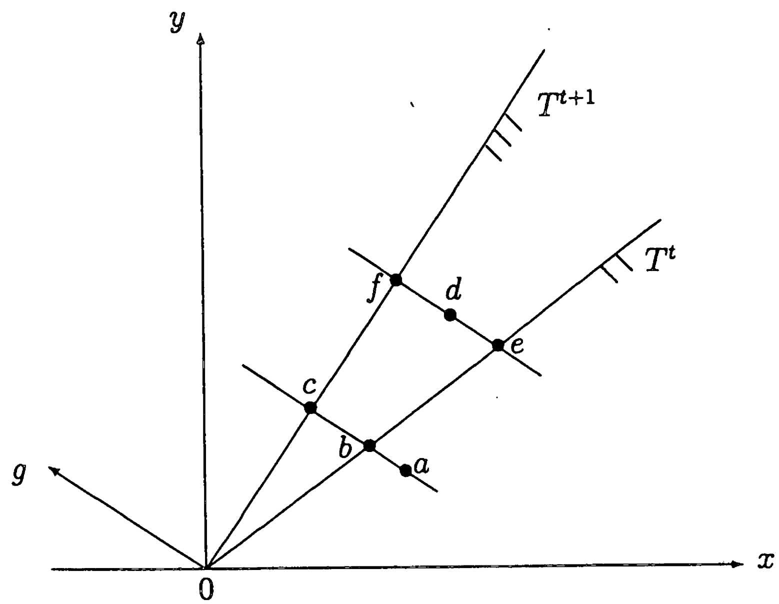

Figure 2: The Luenberger Productivity Indicator

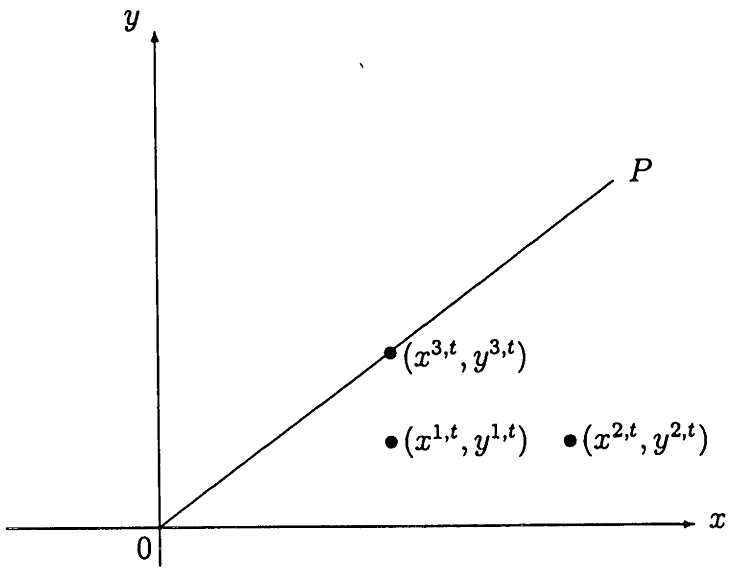

Figure 3:

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