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Madden, Gary G and Savage, Scott J

Curtin University of Technology, School of Economics and Finance, Perth WA 6845, Australia, Curtin University of Technology, School of Economics and Finance, Perth WA 6845, Australia

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Gary Madden[a,*], Scott J. Savage[b]

[a]*Communications Economics Research Program, School of Economics and Finance*
[b]*Curtin University of Technology, GPO Box U1987, Perth 6001, Australia*

Abstract

This study examines telecommunications productivity, technological catch-up and innovation in 74 countries for the period 1991–1995. A summary of partial productivity indicators is presented, and total factor productivity (TFP) growth is calculated using the Malmquist productivity change index. Decomposition of the Malmquist index provides preliminary evidence that developing countries can enhance productivity through catch-up. An econometric model is estimated that relates innovation to market size and two measures of market structure, viz., market concentration and private ownership. Model estimates support the Schumpeterian hypothesis that market size is conducive to innovation. However, the hypothesis that concentration (the dominant carrier's share of international message telephone service (IMTS) traffic) is positively related to innovation is rejected. Finally, the model suggests that increased private ownership of the dominant local-exchange carrier can enhance innovation. © 1999 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Telecommunications enhance national productivity by reducing transaction costs, improving marketing information, and accelerating the diffusion of knowledge (Antonelli, 1991; Greenstein & Spiller, 1995). In an emerging global economy, characterised by greater trade liberalisation and increasing information needs, telecommunications provide a basis for competitive advantage. The

*Corresponding author. Tel.: +61 9 351 7763; fax: +61 9 351 3026; e-mail: maddorg@cbs.curtin.edu.au.

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efficient provision of telecommunications services facilitates the ordering, payment and delivery of traded goods and services, whilst electronic commerce promises to make trade less expensive, easier to transact, and more extensive in geographical scope (ITU, 1997a). Further, as new technology and applications become available when there is potential to open up new information-based service markets. As such, telecommunications sector investments and reforms to market structure are a priority for many governments and international development agencies (European Bank for Reconstruction and Development (EBRD), 1995; Federal Communications Commission (FCC), 1997; Kaji, 1996; Organisation for Economic Cooperation and Development (OECD), 1997a; World Trade Organisation (WTO), 1997). In developed nations, policy makers and telecommunications management are endeavoring to attract investment to fund the rapid growth of Internet infrastructure and related value-added services. Whilst developing countries wish to access the range of opportunities offered by the new infrastructures and related services, universal and affordable access to basic services remains a priority.

Until recently, telecommunications services have been provided almost exclusively by publicly owned monopolies. This mandated supply was typically justified by natural monopoly arguments and was often tied to an obligation to provide universal service (basic telephony) to customers even if not economically viable to do so. In an environment of rapid technological change, recent telecommunications sector reform recognises that competition is better able to deliver innovation, increased productivity and lower prices. The transfer of telecommunications from the public to the private sector has also become an important objective of policy. It is generally believed that private sector ownership supports greater efficiency, innovation and improved customer service as managers formulate strategies in accordance with commercial motives.

The measurement of carrier (sector) performance is an essential part of the development, monitoring and evaluation of government reform. Productivity measurement allows evaluation of telecommunications sector performance against international best practice. It is also possible to decompose productivity into its catch-up and innovation components, and to isolate factors that explain productivity variations across countries. This study examines trends in telecommunications productivity, technological and innovation catch-up in 74 countries for the period 1991–1995. Section 2 describes sample data, whilst Section 3 presents a selection of commonly used telecommunications productivity indicators. Linear programming methods are used in Section 4 to calculate the Malmquist index of TFP growth. Further, the index is decomposed into changes in technical efficiency over time (catch-up) and shifts in the frontier technology (innovation). An econometric model is specified in Section 5 to relate innovation to market size and the measures of market structure: market concentration; and private ownership. Model estimates are then reported herein, and are used to test the Schumpeterian (1934, 1939, 1942) hypotheses that market size and monopoly power are conducive to innovation. Conclusions and policy implications are presented in Section 6.

2. Data and sample characteristics

Annual data is collected from the ITU's (1997b) *World Telecommunication Indicators Database* for 74 countries for the period 1991–1995. According to IMF classification (1997), 19 of the countries contained in the sample are African (AF), 13 are Asian (AS), five are Developing Europe

(DE), 20 are industrialised (I), six are Middle Eastern (ME), and eleven are from the Western Hemisphere (WH). Indicators of economic and telecommunications development for the sample are presented in Table 1.

Countries are ranked from lowest-to-highest GDP per capita. Teledensity, an international standard measure of network development, varies from 0.08 mainlines per 100 persons for Chad to 68.34 for Sweden.[1] As expected, teledensity, international outgoing minutes per capita, and the number of cellular subscribers are greater for higher-income countries. Received evidence suggests a positive relationship between telecommunications infrastructure and usage and national income (Cronin et al., 1991; Taylor, 1994). Outgoing minutes per capita are particularly high for Hong Kong, Luxembourg and Switzerland. This is not surprising as Hong Kong is a significant trading entrepot in the Asia-Pacific, whilst Hong Kong, Luxembourg and Switzerland are important entrepots for the information-intensive finance sector. A positive relationship between population per square km and teledensity is also apparent. Many lower-income countries have low population densities with the majority of the population living in rural and remote regions. In these countries, however, over 80% of telephone main lines are located in urban areas (ITU, 1997a). Telecommunications market structure is described here by the private ownership share of the dominant local-exchange carrier (Priv), and the presence of facilities-based competition in IMTS markets (Comp). Of the 74 sample countries, 18 permitted private ownership of the dominant facilities-based local exchange carrier at 1995, whilst 11 allowed competition in IMTS markets.[2] The most liberal countries, in terms of permitting both private ownership and competition, are Indonesia, Japan, New Zealand, Philippines, South Korea, the UK and the US. Sampled countries are typically characterised by public ownership of local-exchange markets and monopoly service provision in IMTS markets.

3. Productivity indicators

Given the problems associated with measuring the financial performance and program effectiveness for publicly owned monopolies, productivity measures are generally regarded as a more reliable indicator of industry performance than profitability. When multiple inputs and outputs are involved in the production process it is possible to construct a variety of partial productivity measures to compare inputs and outputs. Commonly used telecommunications (partial) productivity measures are mainlines per employee, output per employee and capital per employee. A summary of these indicators for the period 1991–1995 are reported in Table 2.

Mainlines per employee (MPE), the ratio of telephone mainlines to the number of full-time equivalent employees, provides an indication of labour productivity relating to the construction, maintenance and operation of the network.[3] Although not strictly comparable due to differences in

[1]The ITU (1998) consider a teledensity of 50 as a level reflecting high telecommunications development.

[2]Canada permitted facilities-based competition on the US–Canada route only.

[3]The rapid take-up of mobile cellular services suggests that mobile access paths should be factored into calculations of the total number of telecommunications network access paths. Unfortunately, these data are unavailable for many of the sampled countries so we use the traditional measure, telephone mainlines.

Table 1
Sample characteristics

Country		Annual averages (1991–1995)							1995	
		Population (per km^2)	GDP per capita (1987 USD)	Tele-density (%)	Labour	Outgoing calls per capita	Revenue (million 1987 USD)	Cellular subscribers (thousands)	Priv	Comp
Ethiopia	AF	47.05	146	0.26	5502	0.19	60.37	0.00	N	N
Malawi	AF	78.01	147	0.31	3214	0.80	27.52	0.08	N	N
Tanzania	AF	31.63	154	0.30	4781	0.16	68.52	0.77	N	N
Chad	AF	4.78	178	0.08	385	0.27	10.29	0.00	N	N
Sierra Leone	AF	57.28	186	0.33	810	0.40	11.32	0.00	N	N
Nepal	AS	138.74	197	0.35	3547	0.60	35.73	0.00	N	N
Zambia	AF	11.28	279	0.85	3193	1.33	105.91	0.31	N	N
Gambia	AF	97.39	294	1.49	707	3.45	17.18	0.58	N	N
Togo	AF	67.91	328	0.44	849	2.16	26.48	0.00	N	N
Nigeria	AF	113.69	362	0.33	15172	0.54	491.77	6.97	N	N
Kenya	AF	43.51	376	0.86	14196	0.88	254.79	1.31	N	N
Kiribati	AF	93.89	394	2.19	98	3.63	2.66	0.00	N	N
Sri Lanka	AS	273.03	472	0.90	7551	1.17	154.57	20.26	N	N
Philippines	AS	218.94	612	1.44	19026	2.17	774.88	167.06	Y	Y
Zimbabwe	AF	26.93	621	1.26	5162	3.86	118.62	0.00	N	N
Senegal	AF	40.92	638	0.82	1898	2.10	138.77	0.04	N	N
Indonesia	AS	96.15	643	1.12	41395	0.82	1895.38	82.03	Y	Y
Egypt	ME	55.65	729	3.97	53429	1.46	517.60	6.19	N	N
Swaziland	AF	49.33	794	1.91	429	19.51	22.54	0.00	N	N
Guatemala	WH	92.17	885	2.35	5791	3.86	170.78	9.36	N	N
Honduras	WH	49.84	907	2.27	4558	6.25	104.36	0.00	N	N
Morocco	AF	57.20	912	3.19	12497	4.46	524.69	10.95	N	N
PNG	AS	8.88	1017	0.94	1627	5.28	128.23	0.00	N	N
Syria	ME	71.90	1183	4.63	15450	2.67	197.99	0.00	N	N
Ecuador	WH	40.38	1223	5.49	5917	2.89	197.92	13.53	N	N
Romania	DE	96.13	1259	11.79	53866	2.65	277.87	2.53	N	N
Tunisia	AF	53.05	1400	4.90	6538	7.72	205.41	2.28	N	N
Poland	DE	122.48	1553	11.81	70536	6.97	1568.50	26.06	N	N
Thailand	AS	111.41	1601	4.05	30639	2.93	1636.90	507.75	N	N
Botswana	AF	2.38	1810	3.18	1501	20.37	68.82	0.00	N	N
Costa Rica	WH	63.34	1831	12.17	3880	13.68	180.76	6.65	N	N
Mexico	WH	45.00	1845	8.56	49004	8.39	6840.96	414.19	Y	N
Fiji	AS	41.50	2022	7.16	1091	17.06	53.96	0.66	N	N
Suriname	WH	2.48	2145	11.39	1218	17.01	57.11	1.34	N	N
South Africa	AF	32.51	2174	9.01	60503	6.26	2731.83	186.92	N	N
Hungary	DE	110.62	2273	14.70	18965	20.08	608.63	97.10	Y	N
Panama	WH	33.71	2297	10.40	3684	14.37	209.71	0.00	N	N
Mauritius	AF	537.87	2372	9.60	1457	16.07	66.58	5.38	N	N
Uruguay	WH	17.75	2697	17.00	6955	12.35	396.70	10.56	N	N
Venezuela	WH	22.72	2735	9.73	20787	5.88	1079.06	199.35	Y	N
Malaysia	AS	58.28	2751	13.04	29396	14.05	1553.50	449.48	Y	N
Iran	ME	866.24	2905	5.72	56061	2.65	574.46	7.10	N	N

Table 1
(*Continued*)

Country		Annual averages (1991–1995)							1995	
		Population (per km^2)	GDP per capita (1987 USD)	Tele-density (%)	Labour	Outgoing calls per capita	Revenue (million 1987 USD)	Cellular subscribers (thousands)	Priv	Comp
T&T	WH	246.79	3768	15.01	2826	35.86	155.65	2.32	N	N
Greece	I	78.57	4954	45.46	26276	34.15	2097.62	97.60	N	N
South Korea	AS	444.96	4981	37.64	59849	8.55	7059.69	702.22	Y	Y
Portugal	I	107.51	5087	32.38	21859	24.22	2205.57	133.09	Y	N
Saudi Arabia	ME	8.17	5416	9.38	20541	27.01	1774.99	15.81	N	N
Oman	ME	9.38	5680	7.19	2340	21.45	186.91	5.76	N	N
Malta	DE	1154.24	6315	43.04	1873	62.22	77.42	5.87	N	N
Cyprus	DE	121.40	7331	48.02	2348	131.82	158.02	19.51	N	N
Macao	AS	23552.89	7762	33.69	968	205.32	114.51	18.38	N	N
Spain	I	77.40	8876	36.34	73211	22.42	10231.56	384.73	Y	N
Israel	ME	253.18	9775	37.96	9883	35.27	1862.18	112.72	Y	N
Taiwan	AS	581.02	10716	38.11	36069	20.99	4787.53	494.97	N	N
Bermuda	WH	5097.56	10987	19.82	947	85.88	63.89	13.39	N	N
Hong Kong	AS	5547.85	11199	50.14	33280	224.12	3713.05	399.41	Y	N
New Zealand	I	12.91	11430	45.89	10566	65.78	1588.64	186.70	Y	Y
Singapore	AS	4519.34	11748	44.11	7090	188.63	1779.41	184.51	Y	N
UK	I	238.37	12879	47.39	172200	56.81	25415.35	2942.16	Y	Y
Australia	I	2.30	13690	48.52	74817	42.58	9364.18	1014.68	N	Y
Italy	I	1879.65	14944	41.88	112060	27.99	18704.16	1732.40	Y	N
Canada	I	2.90	15660	57.39	86550	84.21	10909.53	1519.46	Y	Y
Belgium	I	330.27	16125	43.56	26370	96.55	3369.82	108.35	N	N
Austria	I	94.94	17645	44.97	17963	96.22	3466.57	234.09	N	N
France	I	105.33	17663	53.52	154043	44.16	23505.47	729.14	N	N
Finland	I	14.98	17735	54.58	16027	49.78	2023.94	552.62	N	Y
Sweden	I	19.39	19233	68.34	34600	89.14	5383.49	1080.74	N	Y
US	I	26.30	19940	58.45	664200	46.07	157405.40	18503.89	Y	Y
Iceland	I	2.56	20997	54.36	998	92.44	109.30	19.66	N	N
Denmark	I	120.38	21289	59.12	16784	88.29	3084.48	414.83	Y	N
Luxembourg	I	153.98	21633	53.70	782	494.02	246.01	9.42	N	N
Norway	I	11.14	23771	53.83	16816	86.46	2593.14	488.34	N	N
Japan	I	329.73	23935	47.15	241020	11.25	67982.32	3951.48	Y	Y
Switzerland	I	167.81	26914	60.58	20437	228.30	6715.42	285.33	N	N
Africa		79.27	688	2.08	7122	4.74	249.49	10.78		
Asia		2954.52	4627	19.36	22332	57.59	1970.97	252.23		
Dev. Europe		320.97	3746	25.87	29517	44.75	538.09	30.21		
Industrialised		188.82	16720	50.37	89379	89.04	17820.10	1719.43		
Middle East		210.75	4281	11.48	26284	15.08	852.35	24.60		
W. Hemisphere		519.25	2847	10.38	9597	18.77	859.72	60.97		
Sample		667.53	6479	21.54	35255	41.72	5436.55	521.63		

Source. ITU (1997b), TeleGeography Inc. (1996), World Bank (1997).
Note. Priv denotes private ownership allowed for the dominant local-exchange carrier. Comp denotes facilities-based competition allowed in IMTS markets. Y is yes. N is no.

Table 2
Productivity indicators

Country	Mainlines per employee			Revenue per mainline			Revenue per employee		
	1991	1995	% change p.a. 1991–1995	1991	1995	% change p.a. 1991–1995	1991	1995	% change p.a. 1991–1995
Australia	99	120	4.83	893	1249	8.74	88565	149531	13.99
Austria	183	216	4.24	910	1149	5.99	166327	247825	10.48
Belgium	153	178	3.96	688	935	7.95	105189	166807	12.22
Bermuda	42	74	14.88	1188	898	−6.75	50416	66387	7.12
Botswana	27	38	9.02	2017	1218	−11.84	54154	46195	−3.90
Canada	165	215	6.83	745	589	−5.72	123060	126621	0.72
Switzerland	193	221	3.43	1262	2059	13.01	243363	454271	16.89
Costa Rica	95	123	6.66	476	394	−4.66	45254	48389	1.69
Cyprus	133	148	2.66	469	564	4.71	62436	83372	7.50
Denmark	163	201	5.35	946	1166	5.37	154142	234093	11.01
Ecuador	74	163	21.75	270	361	7.55	20033	58896	30.94
Egypt	32	51	12.85	261	239	−2.13	8220	12230	10.44
Spain	175	217	5.49	733	729	−0.14	128490	158226	5.34
Ethiopia	24	26	1.58	633	514	−5.07	15215	13157	−3.57
Finland	142	186	6.98	795	902	3.18	112759	167376	10.38
Fiji	49	42	−3.52	954	1082	3.19	46545	45716	−0.45
France	186	214	3.50	710	838	4.24	132382	179347	7.89
UK	119	206	14.74	909	940	0.86	107787	193333	15.73
Gambia	15	25	14.22	1252	989	−5.71	18435	24804	7.70
Greece	152	210	8.50	322	542	13.92	48745	113809	23.61
Guatemala	43	37	−3.74	717	683	−1.22	30521	24957	−4.91
Hong Kong	94	86	−2.12	894	1545	14.65	83692	132748	12.22
Honduras	22	36	12.72	888	763	−3.74	19783	27416	8.50
Hungary	54	111	19.76	412	406	−0.34	22301	45266	19.36
Indonesia	32	82	26.98	940	837	−2.86	29657	68651	23.35
Iran	36	101	29.62	290	147	−15.66	10349	14781	9.32
Iceland	138	147	1.70	657	891	7.92	90440	131218	9.75
Israel	173	257	10.32	908	975	1.80	157264	250243	12.31
Italy	188	241	6.33	800	807	0.20	150718	194210	6.54
Japan	211	276	6.87	871	1531	15.13	184283	422402	23.04
Kenya	15	17	2.74	1071	1229	3.50	16480	21070	6.33
Kiribati	13	20	10.72	1862	1564	−4.27	24675	31140	5.99
South Korea	251	300	4.48	420	469	2.81	105595	140594	7.42
Sri Lanka	17	25	9.17	950	1084	3.35	16551	26818	12.82
Luxembourg	253	290	3.43	1057	1298	5.28	267395	375960	8.89
Macao	130	166	6.27	657	937	9.29	85666	155845	16.14
Morocco	47	79	13.49	751	573	−6.54	35619	45082	6.07
Mexico	125	180	9.59	810	740	−2.26	100895	132796	7.11
Malta	72	93	6.79	526	505	−1.01	37813	47223	5.71
Mauritius	48	88	16.61	559	705	5.96	26738	62325	23.56
Malawi	13	9	−9.24	1407	385	−27.66	17845	3316	−34.35
Malaysia	64	116	16.02	595	629	1.41	37939	72714	17.66

Table 2
(*Continued*)

Country	Mainlines per employee			Revenue per mainline			Revenue per employee		
	1991	1995	% change p.a. 1991 –1995	1991	1995	% change p.a. 1991 –1995	1991	1995	% change p.a. 1991 –1995
Nigeria	18	28	12.09	1073	2142	18.87	19318	60892	33.24
Norway	145	129	−2.86	1002	1335	7.44	145206	172305	4.37
Nepal	18	22	5.10	483	450	−1.77	8682	9863	3.24
New Zealand	110	189	14.51	996	1214	5.06	109674	229695	20.30
Oman	54	70	6.67	1440	1239	−3.70	78351	87249	2.73
Panama	62	83	7.31	770	775	0.15	48053	64097	7.47
Philippines	37	74	18.46	933	686	−7.39	34966	50642	9.70
PNG	23	22	−1.63	3519	2507	−8.13	80954	54011	−9.62
Poland	54	78	9.86	326	377	3.76	17477	29502	13.99
Portugal	117	178	11.02	588	773	7.09	69056	137978	18.89
Romania	45	55	5.05	98	143	9.79	4457	7887	15.33
Saudi Arabia	71	89	5.65	1210	994	−4.79	86408	88466	0.59
Senegal	26	45	15.08	2452	1292	−14.80	63022	58244	−1.95
Singapore	147	224	11.19	1076	1777	13.37	157671	398160	26.06
Sierra Leone	21	16	−7.13	267	1154	44.14	5737	18424	33.87
Suriname	32	44	8.20	1482	583	−20.81	47548	25636	−14.31
Sweden	153	183	4.65	955	957	0.05	145911	175340	4.70
Swaziland	37	62	13.72	1511	1612	1.63	55591	99153	15.57
Syria	36	52	9.64	216	401	16.69	7792	20877	27.94
Chad	10	15	11.22	2504	1311	−14.93	24440	19585	−5.39
Togo	15	24	12.84	2730	1110	−20.15	40652	26795	−9.90
Thailand	62	98	11.84	820	604	−7.36	51247	59050	3.61
T&T	58	75	6.58	897	787	−3.21	52491	59434	3.15
Tunisia	50	90	15.63	458	503	2.35	23140	45377	18.34
Taiwan	187	257	8.18	553	615	2.72	103522	157825	11.12
Tanzania	16	19	3.98	719	932	6.70	11633	17628	10.95
Uruguay	60	98	13.26	642	866	7.78	38408	85286	22.07
US	198	263	7.42	986	1082	2.37	194962	285056	9.96
Venezuela	79	125	12.01	377	663	15.18	29840	82654	29.01
South Africa	51	71	8.76	691	938	7.93	34973	66392	17.38
Zambia	20	21	1.69	1630	1423	−3.34	32361	30206	−1.71
Zimbabwe	25	30	4.66	890	945	1.53	22283	28415	6.26
Africa	25	37	7.84	1248	1050	−1.17	27550	36403	6.39
Asia	91	124	8.78	1026	1064	2.09	69500	113564	10.84
Dev. Europe	72	97	8.83	366	399	3.38	28897	42650	12.38
Industrialised	165	207	6.38	913	1111	5.21	142340	220133	11.87
Middle East	68	105	12.57	609	588	−0.66	53014	75116	11.35
W. Hemisphere	57	87	9.26	704	613	−1.10	39562	55623	8.22
Sample	85	114	8.26	929	922	1.44	69318	104990	9.67

Source. ITU (1997a). *Note*. Revenue is constant USD (1987 = 100); PNG is Papua New Guinea; T&T is Trinidad and Tobago.

sub-contracting arrangements between PTOs, MPE does identify large differences across countries. South Korea, Luxembourg and Japan have the highest MPE, more than twice the sample average in 1995. In terms of growth rates, Iran (30% per annum), Indonesia (27% per annum) and Equador (22% per annum) are the best performing countries for the sample period. Market liberalisation in many countries has resulted in a decrease in employment which would be expected to improve MPE. It is interesting then that despite extensive liberalisation and PTO job shedding in recent years, Australia and New Zealand perform well below average for industrialised countries. This suggests that their labour productivity is still relatively low despite company labour shedding.

Another indicator of labour productivity is revenue per employee (RPE), the ratio of total telecommunications service revenue to the number of full-time equivalent employees. This productivity indicator is particularly sensitive to price and labour shedding effects and should be interpreted with caution. Nevertheless, Switzerland and Japan, have RPE levels more than four times that of the sample average. Japan's performance of USD 422,402 per employee is partly explained by the high value of the yen over the sample period, and by the substantial reforms and labour reductions undertaken by Nippon Telegraph and Telephone Corporation in recent years (Bureau of Industry Economics (BIE), 1995; ITU, 1995). Industrialised countries generate substantially more RPE than other countries contained in the sample. Average RPE for the 20 industrialised countries in 1995 was twice the sample average and six times that of the 19 African nations. However, countries with the greatest proportional increase in RPE between 1991 and 1995 were Nigeria (33% per annum), Equador (31% per annum) and Venezuela (29% per annum).

Revenue per line (RPM), the ratio of total telecommunications service revenue to main telephone lines, is a measure of capital productivity. RPM provides a guide to the intensity of telecommunications network usage and is important to investment planners as it provides an indication of the payback period. In 1995, RPM was more than USD 2000 in Papua New Guinea (PNG), Nigeria and Switzerland. Countries with a relatively high ratio of IMTS revenue to total revenue generally perform well on this indicator. Switzerland's telecommunications revenue is dominated by IMTS traffic volumes, whilst telecommunications revenue in PNG and Nigeria is relatively high per telephone mainline because of high IMTS calling prices. Many low-income countries perform well with respect to RPM because their IMTS calling prices are set well above the cost of service provision (ITU, 1995). Their revenues are often used to subsidise domestic telecommunications activities, develop infrastructure, and contribute to government's consolidated revenue (Cave & Donnelly, 1996). Since RPM can reflect high prices rather than improved productivity, this indicator should, ideally, be deflated by a national telecommunications service price index.

Table 2 suggests that the MPE and RPE performance of (higher income) industrialised countries is substantially better than that of all the other countries contained in the sample. Industrial countries also perform relatively well in terms of RPM, but the difference between industrialised and other countries is smaller. These relationships are reflected in Figs. 1–3 which show a strong positive relationship between MPE and GDP per capita, and RPE and GDP per capita. RPM and GDP per capita are effectively unrelated. When examining productivity growth rates across country groups, all non-industrialised country groups outperform the industrial countries with respect to MPE. Industrial country RPE growth rates are behind those of developing Europe, and about equal with the Middle East and Asia. These data provide preliminary support for the

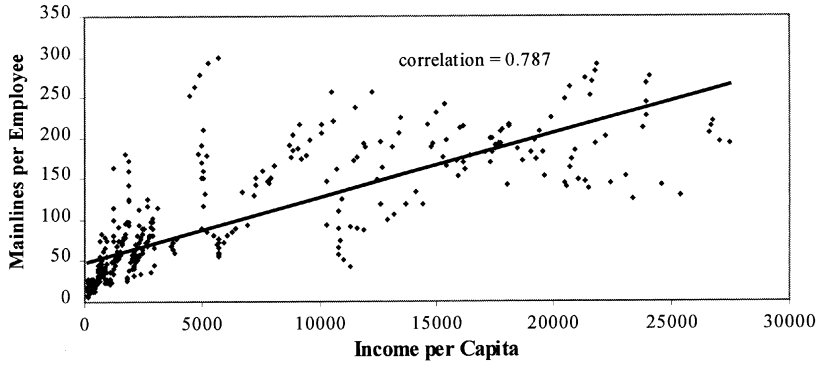

Fig. 1. Mainlines per employee 1991–1995.

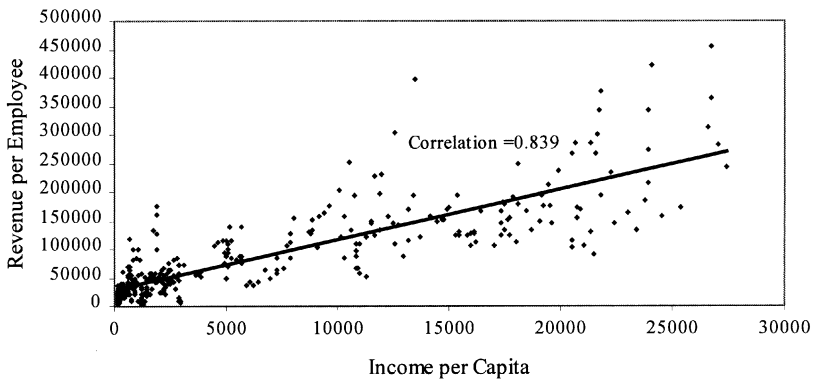

Fig. 2. Revenue per employee 1991–1995.

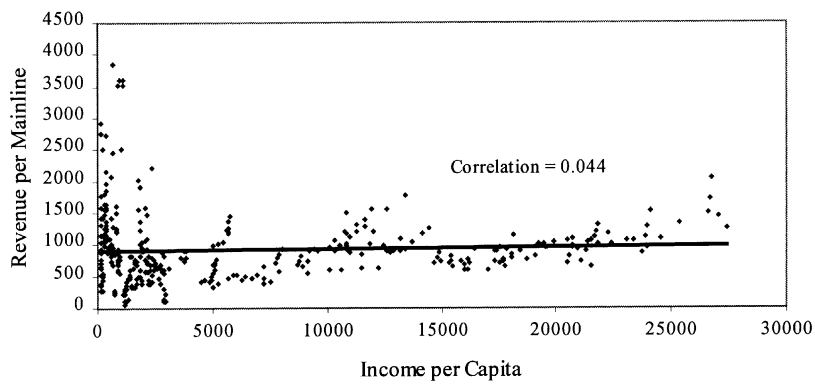

Fig. 3. Revenue per mainline 1991–1995.

existence of a technology catch-up effect in telecommunications, with (lower income) less industrialised countries displaying a propensity for higher productivity growth.

4. Total factor productivity growth, catch-up and innovation

The partial productivity measures described above should be interpreted with caution as changes in an indicator may reflect changes in input mix, rather than fundamental productivity change. An apparent rapid increase in labour productivity may simply result from capital for labour substitution. By examining TFP a more accurate indication of productivity performance is gained. TFP is defined as the ratio of aggregate output to aggregate input, with outputs and inputs generally aggregated according to revenue and cost share weights, respectively. TFP growth is often calculated using the Törnqvist index

$$\varepsilon^{\mathrm{T}}_{\mathrm{Yt}} = (\Delta\mathrm{TFP}/\mathrm{TFP}) = \sum_i r_i(\Delta y_i/y_i) - \sum_j s_j(\Delta x_j/x_j)$$

$$= \ln\left(\frac{\mathrm{TFP}_{t+1}}{\mathrm{TFP}_t}\right) = \sum_i \frac{1}{2}(r_{it+1} + r_{it}) \ln\left(\frac{y_{it+1}}{y_{it}}\right) - \sum_j \frac{1}{2}(s_{jt+1} + s_{jt}) \ln\left(\frac{x_{jt+1}}{x_{jt}}\right), \quad (1)$$

where $\varepsilon^{\mathrm{T}}_{\mathrm{Yt}}$ is Törnqvist index calculated TFP growth, Δ represents time differences (proxied by log differences), r_i are output revenue shares, y_i are outputs, s_j are input cost shares, x_j are inputs and ln is the natural logarithmic operator. Eq. (1) states that TFP growth is the weighted sum of output growth rates less input growth rates, where the weights are the average output revenue shares and average input cost shares.

When detailed cost or revenue share data are not available, linear programming methods can be used to calculate productivity growth (Charnes et al., 1978; Färe et al., 1994; Farrell, 1957). The Malmquist index of productivity change is obtained by constructing quantity indices as ratios of distance functions (Caves et al., 1978; Malmquist, 1953).[4] Färe et al. (1994) calculate the component distance functions of the Malmquist index using non-parametric programming methods, and construct a world best-practice frontier from the sampled countries, and compare country performance to the frontier. How much closer a country is to the (best-practice) world frontier the greater is termed 'catch-up'. Further, how much the world frontier shifts at each country's observed input mix is termed 'technical change' or innovation (Färe et al., 1994). This definition of innovation refers specifically to technological process innovation (as opposed to technological product innovation), or that associated with the adoption of new or significantly improved production methods, including methods of product delivery (OECD, 1997b). The product of catch-up and innovation is the frontier measure of productivity change.

Consider a single-output–single-input industry, Färe et al. (1994) specify an output-based Malmquist productivity change index (m_0) as

$$m_0 = (y_{t+1}, x_{t+1}, y_t, x_t) = \left[\frac{d^t_0(x_{t+1}, y_{t+1})}{d^t_0(x_t, y_t)} \times \frac{d^{t+1}_0(x_{t+1}, y_{t+1}}{d^{t+1}_0(x_t, y_t)}\right]^{1/2}, \quad (2)$$

[4]Distance functions are functional representations of multiple-output–multiple-input technology which require only input and output quantity data.

where $d_0^t(x_t, y_t)$ is the output distance function at time t, and x_k^t and y_k^t represent the input and output quantities of firm k at time t. Eq. (2) is the productivity of the production point (x_{t+1}) relative to the production point (x_t). TFP growth is the geometric mean of both output-based Malmquist TFP indices, where one index uses period t technology and the other period $t+1$ technology (Coelli, 1996). The Malmquist productivity change index is rewritten as

$$m_0(y_{t+1}, x_{t+1}, y_t, x_t) = \text{TECHCH} \times \text{PEFFCH} \times \text{SEFFCH}, \tag{3}$$

where TECHCH is technical change, PEFFCH is pure efficiency change, and SEFFCH is scale efficiency change. The scale-change and pure-efficiency change components are decompositions of efficiency change (EFFCH) calculated relative to constant returns to scale (CRS). That is, EFFCH = PEFFCH × SEFFCH. PEFFCH refers to efficiency change calculated under variable returns to scale (VRS). Thus, an interesting feature of the Malmquist index (as opposed to the Törnqvist index) is that it allows productivity growth to be decomposed into technological change or innovation (shifts in the frontier technology) (TECHCH) and changes in technical efficiency (catch-up) (EFFCH).[5]

The Malmquist index and subsequent decompositions are calculated here for the sample of 74 countries for the period 1991–1995. Telecommunications output is measured by international output, domestic output, and quality of output. International output is minutes of international outgoing IMTS traffic. To estimate international revenue, minutes of outgoing IMTS traffic are multiplied by the average per-minute cost of an international telephone call.[6] A proxy for domestic output, domestic revenue, is obtained by subtracting international revenue from total telecommunications service revenue. Domestic revenue is then deflated by the CPI (1987 = 100) to generate real domestic telecommunications service revenue as the measure of domestic output. Quality of output is included to account for differences in service quality across countries. This measure is defined as one less the ratio of waiting list for main lines to total main lines. As quality of output approaches one, a country is deemed to have a higher level of service quality. Input measures are labour, the number of equivalent full-time telecommunications staff, and capital, the number of main telephone lines.

Table 3 reports annual averages for the Malmquist productivity change index and associated CRS and VRS decompositions.[7] A value greater than one for TFP and its components represents an improvement in performance, whilst a value less than one represents declining performance. The average TFP growth rate across the sample from 1991 to 1995 is 0.9%. On average, this growth was due to innovation (TECHCH) rather than improved efficiency (EFFCH). TFP growth is highest for the subsample of industrialised countries (10.2% per annum), whilst average TFP

[5]The Malmquist index is more general than the Törnqvist index as it allows inefficient performance and does not require an underlying functional form for technology to be specified.

[6]The per-minute cost of an average world international telephone call is obtained from TeleGeography Inc. (1996). Whilst the average per-minute cost of an international telephone call for each country is desirable, these data are generally not available for non-OECD countries. As changes in production are being calculated, the TeleGeography Inc. measure provides a reasonable proxy from which to calculate changes in international and domestic revenue for each country.

[7]Malmquist index estimated by *DEAP Version 2.1* (Coelli, 1996).

Table 3
Malmquist productivity index

Country	Annual averages (1991–1995)				
	EFFCH (CRS)	TECHCH	PEFFCH (VRS)	SEFFCH	TFP
Australia	0.998	1.102	1.000	0.998	1.099
Austria	0.918	1.133	1.001	0.917	1.040
Belgium	0.976	1.095	1.001	0.975	1.069
Bermuda	0.962	0.998	1.087	0.885	0.960
Botswana	0.859	1.038	0.953	0.902	0.892
Canada	0.842	1.127	1.000	0.842	0.949
Switzerland	1.000	1.131	1.000	1.000	1.131
Costa Rica	0.876	1.049	1.024	0.855	0.919
Cyprus	1.001	1.062	1.006	0.995	1.064
Denmark	0.927	1.139	1.000	0.927	1.055
Ecuador	0.991	1.057	1.045	0.948	1.048
Egypt	1.016	0.979	1.116	0.910	0.994
Spain	0.850	1.143	1.003	0.847	0.971
Ethiopia	1.030	0.969	0.888	1.160	0.998
Finland	0.914	1.142	1.000	0.914	1.044
Fiji	1.017	0.988	1.039	0.979	1.005
France	0.907	1.142	1.000	0.907	1.036
UK	0.899	1.145	1.000	0.899	1.030
Gambia	0.996	0.922	0.872	1.142	0.919
Greece	0.992	1.114	1.057	0.939	1.105
Guatemala	0.995	1.022	1.066	0.934	1.017
Hong Kong	1.060	1.034	1.000	1.060	1.096
Honduras	0.893	1.028	0.898	0.994	0.918
Hungary	0.965	1.035	1.167	0.827	0.998
Indonesia	1.007	1.001	1.051	0.957	1.008
Iran	0.858	1.076	0.978	0.877	0.923
Iceland	0.982	1.086	1.000	0.982	1.066
Israel	0.881	1.147	1.000	0.881	1.010
Italy	0.848	1.155	1.000	0.848	0.980
Japan	1.000	1.192	1.000	1.000	1.192
Kenya	1.065	0.878	1.058	1.007	0.936
Kiribati	1.000	0.943	1.000	1.000	0.943
South Korea	0.855	1.209	1.000	0.855	1.033
Sri Lanka	1.134	0.889	0.937	1.209	1.008
Luxembourg	1.000	1.062	1.000	1.000	1.062
Macao	1.001	1.061	1.000	1.001	1.061
Morocco	0.924	1.026	1.091	0.846	0.948
Mexico	0.893	1.115	1.043	0.856	0.996
Malta	0.945	1.063	1.030	0.917	1.004
Mauritius	0.984	1.011	1.234	0.798	0.995
Malawi	0.816	1.021	0.909	0.897	0.833
Malaysia	0.959	1.077	1.009	0.950	1.032
Nigeria	1.168	0.946	1.166	1.001	1.104
Norway	0.953	1.097	0.999	0.954	1.045

Table 3
(*Continued*)

Country	Annual averages (1991–1995)				
	EFFCH (CRS)	TECHCH	PEFFCH (VRS)	SEFFCH	TFP
Nepal	1.009	1.009	1.026	0.984	1.018
New Zealand	0.947	1.148	1.000	0.947	1.087
Oman	0.959	1.028	1.019	0.941	0.985
Panama	0.981	1.042	0.993	0.988	1.022
Philippines	0.941	0.988	0.908	1.037	0.930
PNG	1.000	0.874	1.000	1.000	0.874
Poland	1.103	1.082	1.143	0.965	1.193
Portugal	0.947	1.130	1.020	0.929	1.070
Romania	1.045	1.135	0.993	1.052	1.186
Saudi Arabia	0.924	1.049	0.875	1.055	0.969
Senegal	0.877	0.936	0.955	0.918	0.820
Singapore	1.041	1.100	1.000	1.041	1.146
Sierra Leone	1.049	0.987	0.911	1.152	1.035
Suriname	0.690	1.062	0.967	0.714	0.733
Sweden	0.867	1.137	1.000	0.867	0.986
Swaziland	1.008	1.119	1.000	1.008	1.128
Syria	1.181	0.979	1.037	1.139	1.156
Chad	0.906	0.913	0.916	0.989	0.828
Togo	0.851	0.967	0.936	0.909	0.823
Thailand	0.882	1.052	0.981	0.899	0.928
T&T	0.960	1.033	0.995	0.965	0.992
Tunisia	1.007	1.001	1.067	0.944	1.008
Taiwan	0.879	1.163	1.000	0.879	1.022
Tanzania	1.113	0.886	1.028	1.083	0.987
Uruguay	1.018	1.044	1.019	0.999	1.062
US	0.885	1.168	1.000	0.885	1.034
Venezuela	0.984	1.066	1.115	0.883	1.049
South Africa	1.037	1.023	1.001	1.036	1.061
Zambia	0.949	1.029	1.224	0.776	0.977
Zimbabwe	0.987	1.029	0.972	1.015	1.015
Africa	0.982	0.983	1.010	0.978	0.963
Asia	0.981	1.036	0.994	0.989	1.012
Dev. Europe	1.012	1.075	1.068	0.951	1.089
Industrialised	0.981	1.181	1.055	0.976	1.102
Middle East	0.974	1.045	1.000	0.975	1.012
W. Hemisphere	0.842	0.952	0.933	0.821	0.881
Sample	0.962	1.052	1.011	0.954	1.009

growth is negative for African (3.7% per annum) and Western Hemisphere (10.2% per annum) countries.

Examination of individual countries shows that the highest productivity growth rates occurred in the non-industrialised countries, Poland (19.3% per annum), Romania (18.6% per annum), and

Syria (15.6% per annum). Both Poland and Romania are undergoing transition from centrally planned to market economies, and have been recipients of substantial EBRD and European Investment Bank infrastructure funding in recent years. For instance, Poland received USD 182.1 million from the EBRD in 1992 for the modernisation and expansion of telecommunications infrastructure. Comparison of EFFCH (CRS) with TECHCH, and PEFFCH (VRS) with TECHCH, shows that the TFP growth performance for the above-mentioned non-industrialised countries is due to catch-up. Under CRS, innovation is the main contributing factor to productivity growth in 54 countries, and catch-up is the main contributing factor in the remaining 20 countries. Under VRS, catch-up dominated productivity growth in 22 countries. Under both CRS and VRS, only one of the designated catch-up countries is industrialised, Greece (VRS). In summary, the Malmquist index decomposition broadly supports the conclusions from Section 3. That is, countries with relatively low levels of telecommunications (and economic) development have the ability to enhance telecommunications productivity growth through technological catch-up. These results also suggest that the traditional single-factor productivity measures generally provide a qualitatively similar picture to that of (multi-factor) TFP.

5. Innovation, market size and market structure

Further information on telecommunications performance and competitiveness can be obtained by examining innovation within the structure-conduct-performance framework. An econometric model is specified which relates telecommunications innovation (Inov) to market size (Size), market concentration (Con) and privatisation (Priv):

$$\text{Inov}_{it} = \beta_{0i} + \beta_1 \,\text{Size}_{it} + \beta_2 \,\text{Con}_{it} + \beta_3 \,\text{Priv}_{it} + u_{it}, \tag{4}$$

where $i = 1, \ldots, n$, $t = 1, \ldots, T$, β_{0i} is the intercept for the ith country, β_1 through β_3 are slope parameters, and u_{it} is a white noise error term.

Size is the log of country i telecommunications revenue (1987 USD) less the log of mean sample revenue. Schumpeter (1934, 1939, 1942) suggests that firms in large markets have the scale of production plus the finance and marketing expertise to exploit new technologies quickly. Since capitalism involves innovations continually superceding each other, the incentive to innovate is positively related to a firm's ability to exploit that innovation rapidly. Large firms are also likely to devote more resources (in absolute terms) to research and development (R&D) and will be more successful (assuming R&D displays increasing returns to scale) in generating innovation. Con is proxied here by the log of the dominant country i carrier's share of IMTS traffic.[8] In highly concentrated industries, firms with market power are better able to internalise the profits from innovation. Positive values for β_1 and β_2 support the Schumpeterian hypotheses that market size and fewness (of competitors) are conducive to technological progress, when measured by innovation. Finally, Priv is the log of one plus the private ownership share of the dominant local-exchange

[8]Competition in IMTS markets is a leading indicator of government intention to liberalise other telecommunications services markets. As such, this measure is a proxy for market concentration in the telecommunication industry as a whole.

Table 4
Econometric results

Dependent variable			
Innovation	Inov	Coefficient estimate	*t*-ratio
Market size	Size	0.030	2.265[a]
Market concentration	Con	−0.041	−0.531
Private ownership	Priv	0.104	2.337[a]
NT		296	
Buse R^2		0.83	

[a]Denotes significance at the one percent level.

carrier. Generally, privately owned enterprises have more incentive to innovate and operate efficiently than public enterprises so a positive sign for β_3 is expected.

Eq. (4) is estimated for the sample of 74 countries for the period 1991–1995. Generalised least squares is used to correct for within group autocorrelation and groupwise heteroskedasticity.[9] Model estimates are reported in Table 4.

Model estimates show that the estimated coefficient for Size is both positive and significant. Countries with large telecommunications markets, when measured by revenue, have greater rates of innovation. A percent increase in size leads to a 0.03% increase in innovation. The estimated coefficient for Con is not significant. This estimate does not support Schumpeterian expectations that concentration is conducive to rapid technical change, measured by innovation. The coefficient for privatisation (Priv) is positive and significant. Private ownership, in the short-run, imposes a stricter operational discipline on telecommunications carrier management than the introduction of competition and the consummate decline in market concentration. It is also likely that private ownership is proxying for potential competition, given that telecommunications reforms usually include privatisation as a precursor to the introduction of competition. Any increase in the level of private ownership may provide a signal to telecommunications carriers that increased competition for market share may be forthcoming.

6. Conclusions

In the emerging global economy the efficient delivery of telecommunications services provides a basis for competitive advantage. As such, telecommunications sector investments and reforms to market structure are a priority for many governments and development agencies. Accordingly, the measurement of sector performance is an essential part of the development, monitoring and evaluation of reform programs. By measuring telecommunications productivity across a sample of

[9]Diagnostic testing of OLS residuals suggests the presence of autocorrelation and heteroskedasticity. Estimates of individual intercept terms for all models are available on request from the authors.

countries it is possible to evaluate the performance of this key sector by comparing it to standards of international best practice.

This study examines telecommunications productivity, innovation and technological catch-up in 74 countries for the period 1991–1995. A summary of typical (partial) productivity indicators for telecommunications is presented. The partial productivity measures presented here are comparable with estimates from previous telecommunications studies (BIE, 1995; ITU, 1995, 1998; OECD, 1997c). These indicators provide support for the existence of a technology catch-up effect in telecommunications, with (lower income) non-industrialised countries displaying propensity for higher productivity growth. TFP growth is also calculated by using the Malmquist productivity change index. The index is decomposed into shifts in the frontier technology and changes in technical efficiency. This decomposition allows the identification of countries that are innovating in telecommunications and countries that are catching-up. Evidence from this decomposition is generally consistent with observations from partial productivity indicators. That is, developing countries can enhance telecommunications productivity through technological catch-up. This in turn suggests that the traditional single-factor productivity measures, MPE, RPE and RPM, provide a useful indication of telecommunications productivity performance.

Between 1984 and 1996, 44 publicly owned carriers had been privatised, raising USD 159 billion. Econometric estimates provide some support for the Schumpeterian hypothesis that market size is positively related to innovation; but contrary to Schumpetarian hypothesis expectation, increased market concentration (or fewness of competitors) does not positively influence innovation. The reported positive impact of private ownership on innovation is probably attributable not only to privatisation, but also to the anticipation of competition. This tends to support the ongoing programs of privatisation in the telecommunications sector.

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