APPENDIX

Re-examining Regional Total-factor Water Efficiency and Its Determinants in China: A Parametric Distance Function Approach

Jiao Zheng, Hengquan Zhang and Zhencheng Xing *

11 pages

Content

Table S1. TFWE estimation results from the SFA model.

Province	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Beijing	0.854	0.838	0.951	0.894	0.950	0.808	0.797	0.850	0.877	0.999	0.899	0.925	0.816	0.866	0.915	0.905
Tianjin	0.732	0.961	0.956	0.837	0.786	0.833	0.785	0.732	0.765	0.702	0.796	0.719	0.878	0.865	0.929	0.966
Hebei	0.677	0.638	0.620	0.654	0.685	0.647	0.631	0.628	0.653	0.643	0.649	0.657	0.673	0.685	0.674	0.698
Liaoning	0.582	0.632	0.683	0.734	0.719	0.703	0.688	0.720	0.751	0.732	0.710	0.726	0.724	0.691	0.747	0.727
Shanghai	0.971	0.995	0.923	0.827	0.883	0.938	0.811	0.867	0.922	0.888	0.853	0.871	0.888	0.905	0.872	0.869
Jiangsu	0.481	0.505	0.480	0.509	0.453	0.494	0.448	0.417	0.411	0.407	0.418	0.435	0.420	0.474	0.527	0.480
Zhejiang	0.680	0.687	0.687	0.699	0.693	0.729	0.742	0.736	0.731	0.804	0.830	0.869	0.863	0.834	0.833	0.880
Fujian	0.559	0.549	0.520	0.545	0.586	0.592	0.583	0.575	0.581	0.575	0.549	0.716	0.575	0.559	0.553	0.555
Shandong	0.978	0.911	0.879	0.985	0.997	0.981	0.897	0.916	0.922	0.899	0.912	0.891	0.907	0.916	0.936	0.997
Guangdong	0.663	0.701	0.643	0.676	0.646	0.835	0.828	0.850	0.826	0.787	0.797	0.860	0.931	0.953	0.994	0.974
Hainan	0.524	0.532	0.534	0.521	0.562	0.610	0.582	0.581	0.589	0.643	0.635	0.622	0.624	0.659	0.664	0.673
Shanxi	0.967	0.943	0.944	0.993	0.998	0.989	0.951	0.947	0.953	0.938	0.841	0.799	0.758	0.780	0.856	0.851
Jilin	0.463	0.497	0.473	0.504	0.537	0.563	0.523	0.518	0.507	0.464	0.424	0.412	0.379	0.360	0.362	0.377
Heilongjiang	0.274	0.278	0.307	0.318	0.310	0.282	0.265	0.256	0.249	0.220	0.216	0.233	0.215	0.203	0.198	0.202
Anhui	0.651	0.629	0.585	0.679	0.608	0.596	0.510	0.547	0.516	0.462	0.478	0.484	0.487	0.488	0.533	0.502
Jiangxi	0.328	0.336	0.356	0.421	0.372	0.372	0.386	0.348	0.356	0.346	0.361	0.393	0.394	0.366	0.375	0.416
Henan	0.953	0.818	0.848	0.999	0.970	0.986	0.846	0.917	0.843	0.808	0.848	0.860	0.820	0.813	0.941	0.896
Hubei	0.502	0.482	0.529	0.526	0.545	0.495	0.490	0.504	0.498	0.477	0.472	0.491	0.461	0.467	0.472	0.457
Hunan	0.383	0.377	0.377	0.371	0.388	0.395	0.401	0.421	0.432	0.430	0.435	0.444	0.448	0.439	0.434	0.434
Neimenggu	0.282	0.272	0.267	0.255	0.243	0.226	0.211	0.198	0.198	0.189	0.208	0.212	0.211	0.223	0.240	0.251
Guangxi	0.246	0.253	0.253	0.289	0.295	0.321	0.324	0.402	0.453	0.426	0.451	0.350	0.366	0.328	0.313	0.314
Chongqing	0.996	0.987	0.963	0.964	0.938	0.969	0.970	0.854	0.846	0.825	0.741	0.748	0.780	0.808	0.857	0.894
Sichuan	0.681	0.700	0.689	0.687	0.701	0.690	0.692	0.706	0.735	0.672	0.648	0.655	0.606	0.626	0.658	0.594

Guizhou	0.743	0.828	0.888	0.867	0.915	0.805	0.807	0.806	0.783	0.748	0.697	0.642	0.643	0.713	0.708	0.702
Yunnan	0.719	0.767	0.724	0.725	0.681	0.774	0.765	0.762	0.814	0.763	0.792	0.662	0.646	0.661	0.662	0.652
Shaanxi	0.888	0.906	0.945	0.976	0.959	0.926	0.855	0.862	0.817	0.816	0.809	0.783	0.730	0.707	0.725	0.794
Gansu	0.578	0.634	0.647	0.548	0.578	0.515	0.505	0.512	0.499	0.519	0.492	0.454	0.439	0.434	0.435	0.462
Qinghai	0.859	0.915	0.984	0.931	0.816	0.796	0.762	0.786	0.690	0.882	0.816	0.771	0.883	0.860	0.958	0.994
Ningxia	0.245	0.255	0.283	0.376	0.334	0.389	0.361	0.441	0.420	0.473	0.454	0.420	0.437	0.418	0.422	0.379
Xinjiang	0.071	0.070	0.072	0.071	0.073	0.074	0.072	0.072	0.074	0.075	0.076	0.075	0.073	0.077	0.079	0.080
Eastern China	0.700	0.723	0.716	0.716	0.724	0.743	0.708	0.716	0.730	0.734	0.732	0.754	0.755	0.764	0.786	0.793
Central China	0.565	0.545	0.552	0.601	0.591	0.585	0.546	0.557	0.544	0.518	0.510	0.515	0.495	0.490	0.521	0.517
Western China	0.573	0.599	0.610	0.608	0.594	0.590	0.575	0.582	0.575	0.581	0.562	0.525	0.529	0.532	0.550	0.556
China	0.618	0.630	0.634	0.646	0.641	0.645	0.616	0.624	0.624	0.620	0.610	0.606	0.603	0.606	0.629	0.633

Table S2. TFWE estimation results from the DEA model.

Province	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Beijing	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Tianjin	1.000	1.000	1.000	1.000	1.000	0.751	0.724	0.694	0.779	1.000	0.745	1.000	0.716	0.685	0.686	0.625
Hebei	0.701	0.687	0.689	0.686	0.734	0.693	0.716	0.767	0.753	0.754	0.727	0.722	0.664	0.639	0.596	0.527
Liaoning	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Shanghai	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Jiangsu	0.517	0.470	0.467	0.521	0.450	0.439	0.438	0.430	0.424	0.426	0.425	0.418	0.399	0.376	0.369	0.362
Zhejiang	0.966	0.793	0.813	0.843	0.862	0.826	0.892	0.886	0.844	0.927	0.939	0.949	0.939	0.945	0.971	1.000
Fujian	1.000	1.000	1.000	1.000	1.000	0.587	0.630	0.643	0.635	0.651	0.652	0.637	0.620	0.589	0.595	0.635
Shandong	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.862	0.796	0.755	0.739	0.728	0.671
Guangdong	0.623	0.582	0.592	0.577	0.577	0.736	1.000	1.000	0.787	0.777	0.747	0.730	0.725	0.740	0.755	1.000
Hainan	0.319	0.299	0.305	0.292	0.295	0.327	0.339	0.344	0.355	0.374	0.382	0.389	0.378	0.392	0.381	0.362
Shanxi	0.701	0.645	0.649	0.697	0.700	0.794	0.754	0.755	0.829	0.694	0.601	0.544	0.382	0.284	0.289	0.275
Jilin	0.439	0.468	0.459	0.493	0.524	0.567	0.565	0.567	0.497	0.441	0.372	0.354	0.305	0.284	0.270	0.226
Heilongjiang	0.381	0.374	0.478	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.280	0.240	0.227	1.000	0.214
Anhui	0.987	0.917	0.919	1.000	0.922	0.845	0.726	0.782	0.689	0.662	0.672	0.691	0.697	0.678	0.733	0.692
Jiangxi	0.258	0.256	0.281	0.329	0.296	0.290	0.328	0.298	0.300	0.283	0.295	0.306	0.290	0.267	0.273	0.283
Henan	0.683	0.579	0.626	0.741	0.735	0.761	0.696	0.757	0.676	0.610	0.599	0.539	0.457	0.412	0.452	0.372
Hubei	0.564	0.427	0.483	0.478	0.506	0.435	0.459	0.477	0.460	0.455	0.452	0.454	0.428	0.439	0.450	0.436
Hunan	0.334	0.314	0.320	0.311	0.331	0.338	0.371	0.391	0.424	0.425	0.417	0.421	0.392	0.387	0.389	0.394
Neimenggu	0.224	0.219	0.220	0.215	0.194	0.187	0.181	0.169	0.165	0.133	0.099	0.100	0.098	0.095	0.096	0.088
Guangxi	0.195	0.188	0.189	0.201	0.204	0.197	0.214	0.222	0.221	0.208	0.199	0.188	0.166	0.149	0.142	0.131
Chongqing	0.804	0.753	0.753	0.718	0.684	0.759	0.772	0.728	0.689	0.666	0.640	0.649	0.653	0.633	0.670	0.679
Sichuan	0.522	0.504	0.511	0.495	0.499	0.475	0.513	0.530	0.546	0.497	0.476	0.464	0.417	0.413	0.419	0.343

Guizhou	0.320	0.297	0.293	0.286	0.283	0.309	0.330	0.358	0.375	0.374	0.362	0.363	0.374	0.428	0.432	0.442
Yunnan	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Shaanxi	0.538	0.543	0.583	0.585	0.564	0.667	0.695	0.719	0.690	0.672	0.676	0.664	0.602	0.567	0.543	0.439
Gansu	0.185	0.178	0.169	0.167	0.168	0.145	0.158	0.157	0.141	0.124	0.125	0.116	0.096	0.091	0.093	0.088
Qinghai	0.245	0.243	0.247	0.227	0.212	0.202	0.216	0.241	0.241	0.272	0.256	0.252	0.253	0.224	0.220	0.179
Ningxia	0.080	0.080	0.084	0.108	0.091	0.106	0.118	0.145	0.156	0.159	0.163	0.169	0.165	0.153	0.152	0.139
Xinjiang	0.077	0.075	0.077	0.072	0.074	0.072	0.079	0.078	0.080	0.075	0.086	0.088	0.076	0.076	0.075	0.063
Eastern China	0.830	0.803	0.806	0.811	0.811	0.760	0.795	0.797	0.780	0.810	0.771	0.786	0.745	0.737	0.735	0.744
Central China	0.543	0.498	0.527	0.631	0.627	0.629	0.612	0.629	0.609	0.571	0.551	0.448	0.399	0.372	0.482	0.361
Western China	0.381	0.371	0.375	0.370	0.361	0.374	0.389	0.395	0.391	0.380	0.371	0.368	0.355	0.348	0.349	0.326
China	0.589	0.563	0.574	0.601	0.597	0.584	0.597	0.605	0.592	0.589	0.566	0.543	0.510	0.497	0.526	0.489

Table S3. Estimation results of β parameters.

Parameter	Coefficient	Std. dev.	t-ratio
β_0	3.7074***	1.2514	2.96
β_k	0.1493*	0.1750	1.85
β_l	0.4905*	0.2943	1.67
β_y	0.2782	0.4152	0.67
β_b	–2.0994***	0.4418	–4.75
β_{kk}	0.0725***	0.0132	5.49
β_{ll}	0.2500***	0.0297	8.42
β_{yy}	–0.0486**	0.0432	–2.12
β_{bb}	0.1314	0.0865	1.42
β_{kl}	–0.0137**	0.0342	–2.40
β_{ky}	0.1798***	0.0604	2.98
β_{kb}	–0.2163***	0.0399	–5.42
β_{ly}	–0.6748***	0.0684	–9.86
β_{lb}	0.0753**	0.0601	2.25
β_{yb}	0.2558***	0.0984	2.60
β_t	0.0493*	0.0288	1.71
β_{tt}	0.0009***	0.0003	3.00
β_{kt}	–0.0124***	0.0038	–3.24
β_{lt}	–0.0012**	0.0044	–2.28
β_{yt}	0.0099***	0.0061	2.61
β_{bt}	–0.0084	0.0085	–0.99

Note: ***, **, and * denote the 1%, 5% and 10% significance levels, respectively.

Table S4. The estimation results of inefficiency equation excluding $\ln(IS)$.

Variable	Coefficient	Std. dev.	t-ratio
C	–4.3735***	0.0439	9.69
$\ln(EL)$	0.7127	0.0290	–1.57
$(\ln(EL))^2$	–0.4263***	0.0278	5.31
$\ln(IET)$	–0.0211**	0.0073	2.39
$\ln(ER)$	–0.0167*	0.0063	1.66
$\ln(RE)$	0.1197	0.0082	1.35
$\ln(UL)$	–0.1059***	0.0249	–3.25
σ^2	0.0031***	0.0003	11.21
γ	0.9383***	0.0008	12.80
log likelihood function	690.22	-	-
LR test of the one-sided error	1988.83***	-	-

Note: ***, **, and * denote the 1%, 5% and 10% significance levels, respectively.

From the comparisons between regression results in Table S4 and those in Table 4, we can observe that the inclusion of this variable would indeed result in an improvement in overall model performance. More specifically, although the significance level of $\ln(UL)$ gets a promotion after excluding $\ln(IS)$, the significance levels of $\ln(IET)$, $\ln(ER)$ and $\ln(RE)$ have a different level of decline. Moreover, γ score increases from 0.7498 to 0.9383. It implies that the random effects are a little weak and the deterministic frontier approach may be a better choice in this context. Taken together, variable $\ln(IS)$ is still worthy of discussion in this model.

Proof.

According to Färe and Primont [1], the property that the Shephard water distance function is homogeneity of degree one in the water use can be derived by the following equation.

$$
\begin{aligned}
& D_w\left(K, L, \mu W, Y, B\right) \\
& = \sup\left\{\beta : \left(K, L, \mu W / \beta, Y, B\right) \in T\right\} \\
& = \sup_{\beta}\left\{\frac{\mu\beta}{\mu} : \left(K, L, \frac{W}{\beta / \mu}, Y, B\right) \in T\right\} \\
& = \mu \sup_{\beta/\mu}\left\{\frac{\beta}{\mu} : \left(K, L, \frac{W}{\beta / \mu}, Y, B\right) \in T\right\} \\
& = \mu D_w\left(K, L, W, Y, B\right)
\end{aligned}
\tag{S1}
$$

[1] Färe, R.; Primont, D. *Multi-Output Production and Duality: Theory and Applications*; Kluwer Academic Publishers: Boston, MA, USA, 1995.

DEA solving model

For comparison purpose, we computed the Shephard water distance function and TFWE in the nonparametric DEA framework. The specific solving model is described as follows:

$$TFWE = \left[D_w \left(K_j, L_j, W_j, Y_j, B_j \right) \right]^{-1} = \min \theta$$

$$\begin{aligned} s.t. \quad & \sum_{j=1}^{n} \lambda_j K_j \le K_0 \\ & \sum_{j=1}^{n} \lambda_j L_j \le L_0 \\ & \sum_{j=1}^{n} \lambda_j W_j \le \theta W_0 \\ & \sum_{j=1}^{n} \lambda_j Y_j \ge Y_0 \\ & \sum_{j=1}^{n} \lambda_j B_j \le B_0 \\ & \lambda_j \ge 0, \; j = 1, 2, ..., n \end{aligned} \tag{S2}$$

where $\left(K_0, L_0, W_0, Y_0, B_0 \right)$ is the observation to be evaluated, λ_j is the intensity variable. Notably, for the case of variable returns to scale, an additional constraint $\sum_j \lambda_j = 1$ is required to be added.

Calculation Formulas of Std. dev. and VC

Std. dev. is a common method to measure absolute differences in regional economy. The formula is as follows:

$$S = \sqrt{\sum_{j=1}^{n}\left(TFWE_j - \overline{TFWE}\right)^2 \Big/ n};\ \overline{TFWE} = \sum_{j=1}^{n} TFWE_j \Big/ n \tag{S3}$$

where S denotes the Std. dev. of TFWE, $TFWE_j$ denotes the water efficiency score of province j, $\overline{TFWE}$ denotes the average water efficiency, n denotes the number of provinces included in this study.

Variation coefficient is independent of the unit in which the measurement has been taken, so it is a dimensionless number. In this paper, VC is used to describe the dispersive or concentrative extent of TFWE in China. It is defined by:

$$V = S \big/ \overline{TFWE} \tag{S4}$$

where V denotes the VC of TFWE.

Definition and derivation of TFWPI

Following the spirit of the total-factor energy productivity index constructed by Du and Lin [2], we combine the Shephard water distance function and the Malmquist index to define the Total-factor Water Productivity Index (TFWPI) as follows:

$$\begin{aligned}TFWPI(t,t+1) &= \left[\frac{D_w^t\left(K^t,L^t,W^t,Y^t,B^t\right)}{D_w^t\left(K^{t+1},L^{t+1},W^{t+1},Y^{t+1},B^{t+1}\right)}\times\frac{D_w^{t+1}\left(K^t,L^t,W^t,Y^t,B^t\right)}{D_w^{t+1}\left(K^{t+1},L^{t+1},W^{t+1},Y^{t+1},B^{t+1}\right)}\right]^{1/2}\\ &= \frac{D_w^t\left(K^t,L^t,W^t,Y^t,B^t\right)}{D_w^{t+1}\left(K^{t+1},L^{t+1},W^{t+1},Y^{t+1},B^{t+1}\right)}\times\left[\frac{D_w^{t+1}\left(K^t,L^t,W^t,Y^t,B^t\right)}{D_w^t\left(K^t,L^t,W^t,Y^t,B^t\right)}\times\frac{D_w^{t+1}\left(K^{t+1},L^{t+1},W^{t+1},Y^{t+1},B^{t+1}\right)}{D_w^t\left(K^{t+1},L^{t+1},W^{t+1},Y^{t+1},B^{t+1}\right)}\right]^{1/2}\end{aligned} \tag{S5}$$

Further, the TFWPI can be decomposed into two components which can be described as:

$$TFWPI(t,t+1)=EFF\text{ch}\times TECH\text{ch} \tag{S6}$$

Based on the results of this paper, we can obtain the TFWE scores by solving the following equation:

$$\begin{aligned}\ln\left(1/W_i^t\right) &= \beta_0+\beta_k\ln K_i^t+\beta_l\ln L_i^t+\beta_y\ln Y_i^t+\beta_b\ln B_i^t\\ &+\beta_{kk}\left(\ln K_i^t\right)^2+\beta_{ll}\left(\ln L_i^t\right)^2+\beta_{yy}\left(\ln Y_i^t\right)^2+\beta_{bb}\left(\ln B_i^t\right)^2\\ &+\beta_{kl}\ln K_i^t\ln L_i^t+\beta_{ky}\ln K_i^t\ln Y_i^t+\beta_{kb}\ln K_i^t\ln B_i^t\\ &+\beta_{ly}\ln L_i^t\ln Y_i^t+\beta_{lb}\ln L_i^t\ln B_i^t+\beta_{yb}\ln Y_i^t\ln B_i^t\\ &+\beta_t t+\beta_{tt}t^2+\beta_{kt}t\ln K_i^t+\beta_{lt}t\ln L_i^t+\beta_{yt}t\ln Y_i^t+\beta_{bt}t\ln B_i^t+v_i^t-u_i^t\end{aligned} \tag{S7}$$

where each β is the parameter to be estimated. v_i^t is a random variable accounting for statistical noises and it is assumed to obey the standard normal distribution. $u_i^t\equiv\ln D_w^t\left(K_i^t,L_i^t,W_i^t,Y_i^t,B_i^t\right)$ is a non-negative variable accounting for water inefficiency.

So, the EFFch in Equation (2) can be calculated by:

$$EFF\text{ch}=\frac{D_w^t\left(K^t,L^t,W^t,Y^t,B^t\right)}{D_w^{t+1}\left(K^{t+1},L^{t+1},W^{t+1},Y^{t+1},B^{t+1}\right)}=\frac{TFWE^{t+1}}{TFWE^t} \tag{S8}$$

With regards to TECHch, we can compute it by calculating $\left(TECH\text{ch}\right)^t$ and $\left(TECH\text{ch}\right)^{t+1}$. Here we still adopt the translog function to specify the Shephard water distance function, which can be described as:

$$\begin{aligned}\ln D_w^t\left(K_i^t,L_i^t,W_i^t,Y_i^t,B_i^t\right) &= \beta_0+\beta_k\ln K_i^t+\beta_l\ln L_i^t+\beta_w\ln W_i^t+\beta_y\ln Y_i^t+\beta_b\ln B_i^t\\ &+\beta_{kk}\left(\ln K_i^t\right)^2+\beta_{ll}\left(\ln L_i^t\right)^2+\beta_{ww}\left(\ln W_i^t\right)^2+\beta_{yy}\left(\ln Y_i^t\right)^2+\beta_{bb}\left(\ln B_i^t\right)^2\\ &+\beta_{kl}\ln K_i^t\ln L_i^t+\beta_{kw}\ln K_i^t\ln W_i^t+\beta_{ky}\ln K_i^t\ln Y_i^t+\beta_{kb}\ln K_i^t\ln B_i^t\\ &+\beta_{lw}\ln L_i^t\ln W_i^t+\beta_{ly}\ln L_i^t\ln Y_i^t+\beta_{lb}\ln L_i^t\ln B_i^t\\ &+\beta_{wy}\ln W_i^t\ln Y_i^t+\beta_{wb}\ln W_i^t\ln B_i^t+\beta_{yb}\ln Y_i^t\ln B_i^t\\ &+\beta_t t+\beta_{tt}t^2+\beta_{kt}t\ln K_i^t+\beta_{lt}t\ln L_i^t+\beta_{wt}t\ln W_i^t+\beta_{yt}t\ln Y_i^t+\beta_{bt}t\ln B_i^t+v_i^t\end{aligned} \tag{S9}$$

Then, based on Equation (5), the computation of $\left(TECH\text{ch}\right)^t$ and $\left(TECH\text{ch}\right)^{t+1}$ can be described as:

$$
\begin{aligned}
\left(TECH\mathrm{ch}\right)^{t} &= \frac{D_w^{t+1}\left(K^t, L^t, W^t, Y^t, B^t\right)}{D_w^{t}\left(K^t, L^t, W^t, Y^t, B^t\right)} \\
&= \exp\left[\ln\left(D_w^{t+1}\left(K^t, L^t, W^t, Y^t, B^t\right)\right) - \ln\left(D_w^{t}\left(K^t, L^t, W^t, Y^t, B^t\right)\right)\right] \\
&= \exp\left[\beta_t + \beta_{tt}\left(2t+1\right) + \beta_{kt}\ln K_i^t + \beta_{lt}\ln L_i^t + \beta_{et}\ln E_i^t + \beta_{yt}\ln Y_i^t + \beta_{bt}\ln B_i^t\right]
\end{aligned}
\tag{S10}
$$

$$
\begin{aligned}
\left(TECH\mathrm{ch}\right)^{t+1} &= \frac{D_w^{t+1}\left(K^{t+1}, L^{t+1}, W^{t+1}, Y^{t+1}, B^{t+1}\right)}{D_w^{t}\left(K^{t+1}, L^{t+1}, W^{t+1}, Y^{t+1}, B^{t+1}\right)} \\
&= \exp\left[\ln\left(D_w^{t+1}\left(K^{t+1}, L^{t+1}, W^{t+1}, Y^{t+1}, B^{t+1}\right)\right) - \ln\left(D_w^{t}\left(K^{t+1}, L^{t+1}, W^{t+1}, Y^{t+1}, B^{t+1}\right)\right)\right] \\
&= \exp\left[\beta_t + \beta_{tt}\left(2t+1\right) + \beta_{kt}\ln K_i^{t+1} + \beta_{lt}\ln L_i^{t+1} + \beta_{et}\ln E_i^{t+1} + \beta_{yt}\ln Y_i^{t+1} + \beta_{bt}\ln B_i^{t+1}\right]
\end{aligned}
\tag{S11}
$$

And the TECHch can be computed by:

$$
\begin{aligned}
TECH\mathrm{ch} &= \left[\left(TECH\mathrm{ch}\right)^{t} \times \left(TECH\mathrm{ch}\right)^{t+1}\right]^{1/2} \\
&= \exp\left[\begin{array}{l} \beta_t + \beta_{tt}\left(2t+1\right) + \frac{1}{2}\beta_{kt}\ln K_i^t \ln K_i^{t+1} + \frac{1}{2}\beta_{lt}\ln L_i^t \ln L_i^{t+1} \\ + \frac{1}{2}\beta_{et}\ln E_i^t \ln E_i^{t+1} + \frac{1}{2}\beta_{yt}\ln Y_i^t \ln Y_i^{t+1} + \frac{1}{2}\beta_{bt}\ln B_i^t \ln B_i^{t+1} \end{array}\right]
\end{aligned}
\tag{S12}
$$

As a result, we derive the calculation formula of TFWPI:

$$
\begin{aligned}
TFWPI\left(t, t+1\right) &= EFF\mathrm{ch} \times TECH\mathrm{ch} \\
&= \frac{TFWE^{t+1}}{TFWE^{t}} \times \exp\left[\begin{array}{l} \beta_t + \beta_{tt}\left(2t+1\right) + \frac{1}{2}\beta_{kt}\ln K_i^t \ln K_i^{t+1} + \frac{1}{2}\beta_{lt}\ln L_i^t \ln L_i^{t+1} \\ + \frac{1}{2}\beta_{et}\ln E_i^t \ln E_i^{t+1} + \frac{1}{2}\beta_{yt}\ln Y_i^t \ln Y_i^{t+1} + \frac{1}{2}\beta_{bt}\ln B_i^t \ln B_i^{t+1} \end{array}\right]
\end{aligned}
\tag{S13}
$$

[2] Du, K.R.; Lin, B.Q. International Comparison of Total-factor Energy Productivity Growth: A Parametric Malmquist Index Approach. *Energy*, **2017**, *118*, 481–488.