CAN A RED CAT CATCH MICE TOO: A STUDY ON CHINESE PRODUCTIVITY FROM DENG TO HU

by

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(Under the Direction of SCOTT ATKINSON)

ABSTRACT

This study on the Chinese economy uses stochastic frontier analysis (SFA) methods to estimate industry level productivity from 1980 to 2010. Results suggest that government policy favoring heavy industry and manufacturing led to positive technical change in the respective sectors, contrary to many previous studies using TFP-based methods for growth accounting. Although SFA offers many advantages over TFP, its effectiveness is limited due to data aggregation issues. Moreover, lack of Chinese data presents additional challenges of applying SFA on productivity analysis.

INDEX WORDS: Productivity, Stochastic Frontier Analysis, China, Technical Change

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SECTION 1

INTRODUCTION AND LITERATURE REVIEW

"It doesn't matter whether a cat is black or white, as long as it catches mice." This quote by Deng Xiaoping has become almost synonymous with his "Socialism with Chinese Characteristics" policies that brought a considerable degree of market freedom to a previously closed economy. In the period of 1980 to 2010, the Chinese real GDP grew from in 338 billion to 6.04 trillion in constant 2000 US dollar, post-secondary education attainment rate tripled, and 600 million citizens escaped poverty. While it is reductionist to attribute this period of growth solely to market reforms, Deng's policies are instrumental in the economic development of the Middle Kingdom.

However, while China continues to enjoy enviable growth rates, productivity remains significantly lower than those of developed OECD countries. The root of this problem, as Zhang (2008) argues, is buried in politics. Because government promotions are often tied to economic performance of administrated regions, lower ranking government officials have strong incentives to out-produce rivals. An inevitable consequence of such "growth tournaments" is an overemphasis on capital accumulation with very marginal, if any, attention given to improving productivity (Du, et al 2014). Zheng (2009) finds that physical capital stock has grown by more than 8-fold since 1978. Liu (2015) also suggests recent growth in the Chinese economy is almost entirely been driven by capital accumulation.

At higher levels of government, Deng's policies significantly reduced state interference on the economy and led to an explosion of private enterprises in China. China's leadership in the 1990s continued Deng's market liberalization policies, but began imposing stricter control on the economy after 2003 in the wake of Hu Jingtao's more conservative views (Tisdell, 2009). If there is indeed a significant relationship between government policies and economic productivity, then there should be a measurable difference in productivity in the era before 2003 and afterwards.

To estimate productivity over time, traditional growth accounting studies often rely on a non-parametric measure known as total factor productivity, or TFP. However, a critical weakness of TFP is its excessively high sensitivity to model formulation and the somewhat ambiguous mapping of TFP growth to productivity change. Using a simple production function with only capital and labor as inputs, Bosworth & Collins (2008) and Perkins & Rawski (2008) both report estimated averages of roughly 15% TFP growth with 40% of economic growth attributed to TFP since Deng's reforms. However, using data from roughly the same time period, Wu (2015) calculated average TFP growth of 1.24% while Cao, et al (2009) reached an estimate of 2.51%. The only difference in the latter two studies is the inclusion of intermediate inputs into the growth accounting equation.

An alternative method is to estimate a production frontier using panel data, as seen in the stochastic frontier analysis (SFA) framework. Since SFA productivity estimates measure inefficiency through deviations from the frontier, the end results are directly interpretable for productivity analysis and avoids the ambiguity of TFP. Thus, this paper will employ the SFA method to complete the study on Chinese data, using the FRONTIER 4.1 software methods described in Coelli (1996).

SECTION 2

THEORETICAL FRAMEWORK

Estimation Model

Following the model used in Atkinson, et ak (2003), let β_k be a vector of k coefficients, Y_{ft} be the output of firm f at time t, and X_{fjt} be the j inputs used in production of Y_{ft}. The shadow input distance function is given by

$$1 = D(y_{ft}, x^{\star}_{ft}, t)g(\epsilon_{ft}) \tag{1}$$

The random error component, ε_{ft}, comprises of an industry specific one-sided u_{ft} and a mean zero random noise component v_{ft} given by

$$g(\epsilon_{ft}) = exp(v_{ft} - \mu_{ft}) \tag{2}$$

As with Cornwell, et al (1990), u_{ft} can be expressed as

$$\mu_{ft} = \eta_0 + \eta_{f0}d_f + \eta_{f1}d_f t + \eta_{f2}d_f t^2 \tag{3}$$

where d_f is a firm dummy and η_{f0}, η_{f1}, and η_{f2} are estimation parameters. From equation (1), the translog functional form is

$$0 = lnD(y_{ft}, x^{\star}_{ft}, t) + lng(\epsilon_{ft}) \tag{4}$$

Since Hu Jintao's entry into office is a focal point in this study, the final estimation equation includes a dummy variable to mark China's regime change in 2003. A time trend is added to account for possible time effects on production. Finally, after including the 3 inputs in the production function—capital (*K*), labor (*L*), and intermediate goods (*Z*)—equation (4) can be written as

$$0 = \beta_0 + \beta_1 REG + \beta_2 K_{ft} + \beta_3 L_{ft} + \beta_4 Z_{ft} + \beta_{t1} t + \frac{1}{2}\beta_{t2} t^2 + lng(\epsilon_{ft}) \quad (5)$$

<u>Productivity Estimate</u>

Productivity change (PC_{ft}) can be represented as the sum of technical change (TC_{ft}) and efficiency change (EC_{ft}).

$$PC_{ft} = TC_{ft} + EC_{ft} \quad (6)$$

TC_{ft} is given by the difference in the distance formulas for two time periods, expressed as

$$TC_{ft} = ln\hat{D}(y_t, x_t^\star, t) - ln\hat{D}(y_t, x_t^\star, t-1) \quad (7)$$

Which expands to

$$TC_{ft} = \sum_n \hat{\beta}_{nt} lnx^\star_{nft}(d_t - d_{t-1}) + \beta_t - \beta_{t-1} + (\hat{\mu}_t - \hat{\mu}_{t-1}) \quad (8)$$

Here, changes to the TC_{ft} component represents shifts of the production frontier, and positive technical change thus implies an outward shift of the frontier. The second component, EC_{ft}, represents an individual firm's distance from the production frontier. However, since this study uses data aggregated at the industry level, each industry only contains a single series of data. Thus, it is not possible to derive meaningful estimates of efficiency change.

SECTION 3

DATA AND GROUPING

Data Sources

Data used in this study are from the Chinese Industrial Productivity (CIP) database and various issues of the Chinese Statistical Yearbook (CSY). The raw data variables for Y_{it}, and $Z_{ij,t}$, are calculated using the input-output tables provided by the CSY under National Accounts. Also from the CSY is the variable L_{it} and found under Employment and Wages. Finally, the CIP provides capital input data, K_{i0}, capital accumulation data for industry, and type of capital, $I_{n,it}$. All values used in this study are given in 1990 Chinese Yuan.

Periodization

To enhance the results, this study divides the data into two sub-periods based on regime changes in China. The first sub-period starts from 1984. As part of Deng Xiaoping's market reforms, China began the process of allowing privatization of state-owned industries (SOEs), cutting the number of SOEs by an estimated 50% (Rawski, 2008). In addition, the reforms reopened the Shanghai Stock Exchange, significantly privatized the banking system, and shifted the heavily agrarian Maoist economy towards heavier industry.

The second sub-period begins with Hu Jingtao's ascension to power in 2003. This regime change led to an influx of more conservative economic policies in China, a phenomenon occasionally referred to in the literature as *Guo jin min tui* (GJMT), a Chinese phrase that translates literally to "State Advances, People Retreat," and characterized by significant expansions of state influence in the economy. Du, et al (2014) argues that GJMT may have caused a widespread increase in resource misallocation and contributed to losses in productivity. The problem may also have been exacerbated by China's adoption of loose money policies in the latter half of the decade which often systematically favorited the inefficient SOEs.

Industry Grouping

For the purposes of discussion, this study follows the work of Wu (2013) and groups the 24 industries of the manufacturing and industrial sector into "Energy," Commodities and Primary Input Materials (C&P)," "Semi-Finished Goods," "Finished Goods," and "Semi-Finished and Finished Goods (SF&F)," which is treated separately as it produces both semi-finished and finished goods and cannot be specifically categorized. The remaining industries consists of "Services I," mainly comprising of "strategic" services such as financial intermediaries and transportation, "Services II" include other market service industries not included in "Services I," while "Service III" include non-market services such as healthcare and education. Finally, Agriculture and Construction are each separately grouped.

Literature often refers to groups further away from the final goods market as upstream industries while groups closer are consequently referred to as downstream. Energy is generally considered to be the most upstream group, followed by C&P, then Semi-Finished Goods, SF&F, and finally with Finished goods considered to be the most downstream and closest to the final goods market. Construction is generally upstream, but also produces final goods in the form of residential structures. Similarly, the agricultural sector provides large amounts of intermediate input to food processing and manufacturing industries, but generally serves as final demand. The three service groups are similarly difficult to categorize, as all three include both upstream and downstream components and are grouped primarily by similar function rather than distance from final goods.

Wu (2015) argues that greater distance from the final goods market is associated with higher degrees of government intervention. Intuitively, since upstream industries generally consist of raw materials and other inputs required for production of goods, they tend to hold high strategic value and thus often receive preferential treatment to credit and capital but are in turn closely regulated. The Energy group, for example, effectively remains dominated by large state-run monopolies despite attempts, albeit largely perfunctory, at privatization (Wang & Chen, 2012). Additionally, state owned enterprises within more downstream industries also tend to experience lesser degrees of government interference due to higher levels of competition (Li, Li S., & Zhang, 2002).

SECTION 4

DESCRIPTIVE STATISTICS

Aggregate Indicators

Accuracy of Chinese growth measures is a perennial topic. Young (2000) estimates a systematic underestimation of Chinese inflation by up to 2.5%, while Holz (2005) suggests artificial inflating production figures to meet quotas. In this study, the overall average real value-added grew at 8.69% per year. While the estimates for 1984-2002 of 9.3% average growth are consistent with the official growth rate estimates of roughly 10%, the estimates for 2003-2010 of 4.7% are substantially lower than the commonly quoted 7%.

Indicator Growth Rate (Aggregate)

Period	%Δ Y	%Δ K	%Δ L*	%Δ L**	%Δ Z	%Δ V
Aggregate						
Average (Full Period)	6.73%	13.63%	1.56%	1.95%	18.30%	8.69%
Period (1984 – 2003)	7.10%	12.45%	1.64%	2.06%	19.14%	9.30%
Period (2004 – 2010)	6.07%	19.15%	0.70%	1.11%	18.99%	4.70%

Table 4.1

*   = Labor measured by employment

** = Labor measured by hours

On average, Chinese laborers are working more hours as employment grew slower than labor hours in both sub-periods, with 1.64% compared to 2.06% in the first sub-period, and 0.7% to 1.11% in the second. Capital growth averaged 12.45% in the first period and accelerated to 19.15% in the second.

Industry Group Indicators

Table 4.2 shows the statistics by industry group. Energy saw the highest overall capital growth rates at 21.31% average annual growth, though Service III and Service II saw the fastest capital growth in the second sub-period with 23.91% and 22.69% respectively. The Semi-Finished had the largest jump in capital growth rates, from 5.52% in the first sub-period to 22.29% in the second sub-period. However, total output growth rate for Semi-Finished only increased from 15.35% to 17.6%, while total output growth rates for Energy, Service III, and Service II decreased in the second sub-period despite increases to capital growth rates. Furthermore, SF&F and Service I also experienced slowing output growth with increases to capital growth rates, while Finished, C&P, and Agriculture only saw minor increases to output growth rates despite significant quickening to capital growth rates. Construction is the only exception where output growth increased by a larger degree than capital growth.

Another notable find is that labor inputs for Agriculture decreased by -0.53% and -0.59% for total employment and labor hours, respectively, while labor inputs for all other groups experienced growth overall. As Zhang & Song (2003) find, the economic reformation ushered massive movements of Chinese rural populations into urban areas, accounting for the largest source of increase in Chinese urban populations since 1978. Consequently, significant levels of labor reallocation out of the agricultural sector occurred (Cao & Birchenall, 2013). According to the estimates in this study, while Agriculture experienced low growth rates of labor input with 0.16% for employment and 0.19% for hours worked in the first sub-period, these figures decreased to -3.38% and -3.46% respectively in the second sub-period.

Indicator Growth Rate (By Industry Group)						
Period	%Δ Y	%Δ K	%Δ L*	%Δ L**	%Δ Z	%Δ V
Energy						
Average (Full Period)	10.42%	16.75%	4.02%	4.54%	18.63%	8.03%
Period (1984 – 2003)	10.37%	16.36%	4.01%	4.76%	20.60%	9.35%
Period (2004 – 2010)	8.24%	22.82%	2.22%	1.81%	16.49%	1.82%
Construction						
Average (Full Period)	15.62%	12.63%	6.11%	6.62%	18.71%	10.39%
Period (1984 – 2003)	15.37%	12.30%	5.51%	6.12%	19.52%	10.61%
Period (2004 – 2010)	18.26%	13.18%	6.49%	6.83%	21.70%	8.24%
C&P						
Average (Full Period)	13.80%	11.48%	0.84%	1.87%	17.31%	7.61%
Period (1984 – 2003)	14.31%	9.50%	-0.48%	0.58%	18.24%	8.78%
Period (2004 – 2010)	14.55%	18.50%	2.94%	3.68%	18.63%	3.71%
Semi-Finished						
Average (Full Period)	16.31%	8.73%	0.79%	1.56%	17.92%	7.39%
Period (1984 – 2003)	15.35%	5.52%	-0.92%	-0.03%	17.71%	7.47%
Period (2004 – 2010)	17.60%	22.29%	5.95%	6.07%	18.46%	3.43%
SF&F						
Average (Full Period)	19.41%	14.32%	2.21%	3.35%	21.45%	10.18%
Period (1984 – 2003)	19.22%	13.36%	0.64%	1.87%	22.29%	11.46%
Period (2004 – 2010)	18.92%	19.44%	7.06%	7.39%	18.98%	3.77%
Finished						
Average (Full Period)	17.10%	12.49%	0.67%	1.83%	19.35%	9.93%
Period (1984 – 2003)	16.24%	10.78%	-0.96%	0.18%	19.25%	11.05%
Period (2004 – 2010)	22.82%	19.27%	4.37%	5.31%	24.72%	7.06%
Agriculture						
Average (Full Period)	9.12%	9.43%	-0.53%	-0.59%	13.78%	4.40%
Period (1984 – 2003)	8.01%	7.50%	0.16%	0.19%	13.95%	4.04%
Period (2004 – 2010)	8.18%	17.14%	-3.38%	-3.46%	11.49%	-0.12%
Service I						
Average (Full Period)	18.46%	15.37%	2.67%	3.13%	19.20%	11.16%
Period (1984 – 2003)	19.51%	16.21%	2.27%	3.06%	23.12%	11.78%
Period (2004 – 2010)	15.64%	15.04%	1.85%	1.12%	13.62%	5.31%
Service II						
Average (Full Period)	17.94%	17.51%	5.45%	6.15%	17.79%	11.64%
Period (1984 – 2003)	18.47%	16.71%	7.13%	7.72%	19.23%	12.66%
Period (2004 – 2010)	18.20%	22.69%	0.61%	1.79%	17.76%	6.71%
Service III						
Average (Full Period)	17.34%	16.50%	4.38%	5.00%	17.81%	10.46%
Period (1984 – 2003)	18.27%	14.08%	3.98%	5.00%	19.46%	12.06%
Period (2004 – 2010)	17.16%	23.91%	4.25%	3.59%	18.05%	4.67%

Table 4.2

*   = Labor measured by employment

** = Labor measured by hours

Output / Factor Ratios

Figure 4.1 shows a general and consistent capital deepening occurred over the entire period of study at the aggregate level, with K/L increasing roughly 7-fold from 1981 to 2010. During the same time period, K/Y and Y/L increased by roughly 3-fold. Output-labor ratios increased steadily but stagnated after 1998 while K/L and Y/L growth accelerated after 1992, continuing for the rest of the study period.

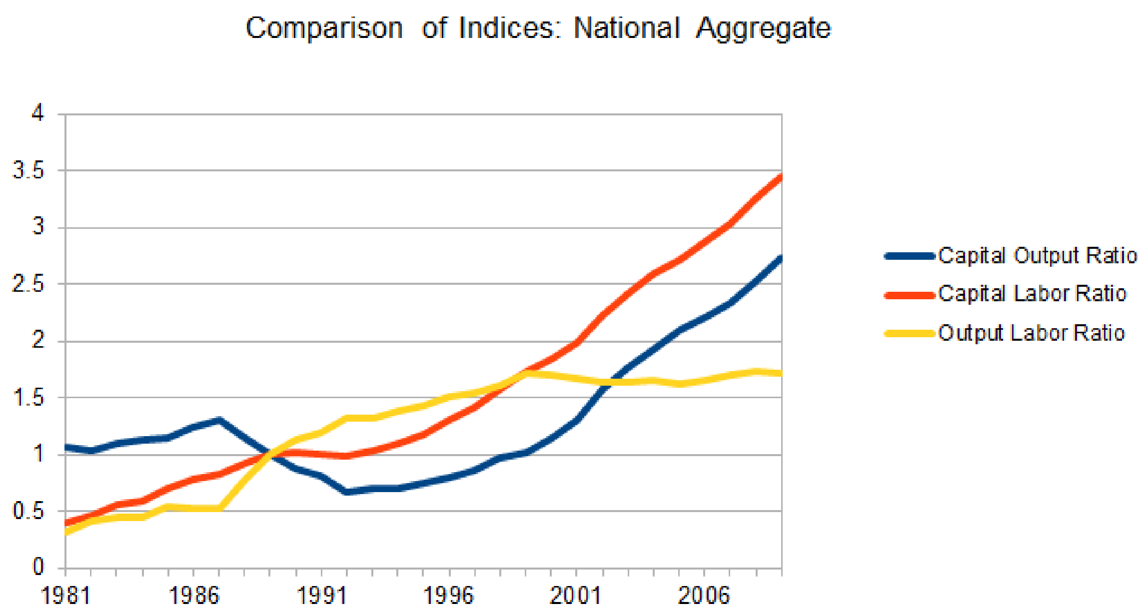

Figure 4.1

Interestingly, this divergence coincided with the year many conservative elders in the Chinese government were forced into retirement and facilitated the implementation of more economic reforms (Naughton, 2008). From here, it appears that widespread capital driven growth occurs prior to the tightening of government control that occurs with Hu's administration and began during the period associated with market liberalization. Thus, although Table 4.1 shows a clear difference in growth rates of capital and output between the two sub-periods, there is limited evidence that the structural break was caused by increased government intervention using the periodization defined in this study.

Figure 4.2 separates the capital-labor, capital-output, and output-labor ratio by industry groups. This comparison reveals that the Energy group saw the largest proportional increase to capital stock, requiring a significantly different scale on the Y-axis to plot K/Y and K/L. However, both principally upstream and downstream groups experience significant levels capital deepening throughout the period of study, with little evidence of a structural break after 2002. Comparing the trends for capital-output ratio and capital deepening reveals that Energy, Construction, Service II, and Service III are nearly identical throughout the entire period of study, while C&P, Semi-Finished, SF&F, and Finished show a slight lag in the growth of capital-output ratio but otherwise saw similar trends between K/L and K/Y. However, the rapid increase to capital-output ratios in these groups appear to be unrelated to the second sub-period.

Finally, it is interesting to highlight the evolution of output-labor indices. The C&P, Semi-Finished, SF&F, Finished, and Service I experienced rapid increases to Y/L until around 1994, after which it stagnates. For the rest of the industry groups, Y/L displays only modest growth throughout the entire period of study, though Agriculture and Service III show a steady upward trend. This is in sharp contrast with the widespread increases to all capital related indices, and provides some evidence to the prevalence of capital driven growth in China's economy.

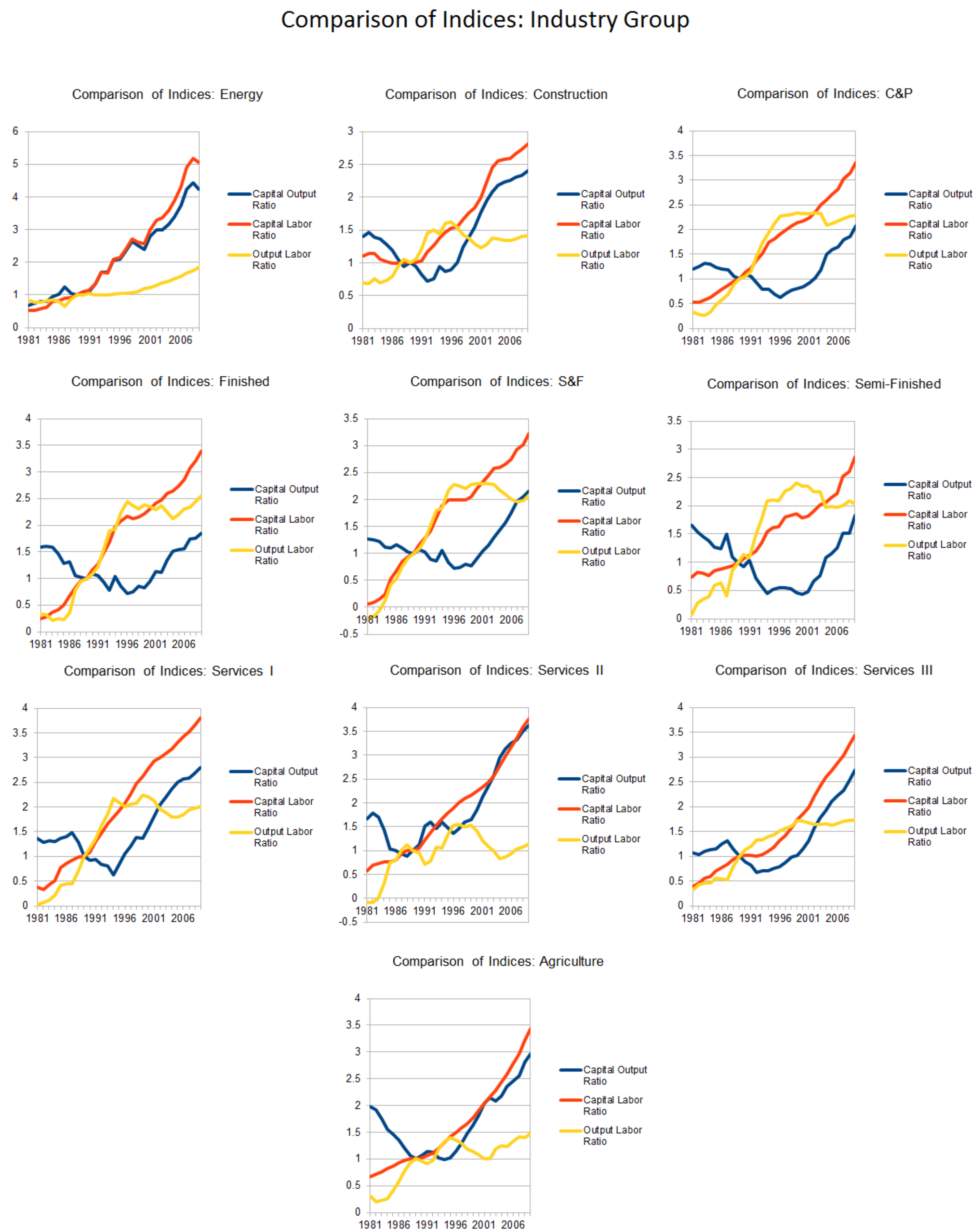
Comparison of Indices: Industry Group
Comparison of Indices: Energy
Comparison of Indices: Construction
Comparison of Indices: C&P
Comparison of Indices: Finished
Comparison of Indices: S&F
Comparison of Indices: Semi-Finished
Comparison of Indices: Services I
Comparison of Indices: Services II
Comparison of Indices: Services III
Comparison of Indices: Agriculture
Capital Output Ratio
Capital Labor Ratio
Output Labor Ratio
1981 1986 1991 1996 2001 2006

Figure 4.2

SECTION 5

ESTIMATION RESULTS

Productivity Estimates

Table 5.1 provides the estimated productivity change by industry, divided by sub-period, and the difference between the first and second sub-periods.

Productivity Change Estimates by Industry					
Industry	Group	Full Period (1980 - 2010)	First Subperiod (1984 -2002)	Second Subperiod (2003 -2010)	Difference
CLM	Energy	0.27%	0.16%	0.68%	0.52%
PTM	Energy	0.25%	0.05%	1.04%	0.99%
PET	Energy	0.90%	0.79%	1.20%	0.41%
UTL	Energy	0.33%	0.13%	1.81%	1.68%
MEM	C&P	0.30%	-0.18%	-0.62%	-0.44%
NMM	C&P	-0.33%	-0.51%	0.15%	0.65%
TEX	C&P	0.08%	0.03%	0.82%	0.79%
P&P	C&P	0.54%	0.22%	1.14%	0.92%
CHE	C&P	-0.23%	-0.58%	0.70%	1.28%
BUI	C&P	0.38%	0.22%	1.59%	1.38%
MET	C&P	0.17%	-0.55%	2.03%	2.58%
F&B	Finished	0.91%	0.54%	2.44%	1.89%
TBC	Finished	0.31%	0.01%	1.09%	1.09%
WEA	Finished	-0.31%	-1.00%	1.51%	2.51%
LEA	Finished	0.60%	-0.93%	0.27%	1.19%
TRS	Finished	0.38%	-0.05%	1.50%	1.56%
OTH	Finished	0.08%	0.06%	0.27%	0.21%
W&F	SF&F	0.51%	0.37%	-0.13%	-0.51%
R&P	SF&F	-0.08%	-0.16%	0.15%	0.31%
MEP	SF&F	0.27%	0.08%	-0.79%	-0.87%
ELE	SF&F	0.23%	0.06%	1.42%	1.36%
ICT	SF&F	0.85%	0.55%	2.00%	1.45%
INS	SF&F	0.56%	-0.21%	2.58%	2.80%
MCH	Semi-Finished	0.29%	0.08%	0.85%	0.77%
CON	Construction	5.08%	4.36%	6.96%	2.60%
AGR	Agriculture	2.08%	0.26%	6.88%	6.63%
T&S	Service I	0.22%	0.32%	0.05%	-0.27%
P&T	Service I	-1.23%	-1.08%	-1.60%	-0.52%
FIN	Service I	0.43%	0.52%	0.21%	-0.31%
SAL	Service II	0.31%	0.44%	0.24%	-0.21%
HOT	Service II	0.39%	0.50%	0.13%	-0.38%
REA	Service II	-0.49%	-0.37%	-0.63%	-0.27%
BUS	Service II	-0.09%	-0.05%	-0.19%	-0.13%
SER	Service II	-0.10%	-0.06%	-0.20%	-0.14%
ADM	Service III	0.04%	0.14%	0.21%	0.07%
EDU	Service III	-0.11%	0.14%	-0.79%	-0.93%
HEA	Service III	-0.18%	-0.18%	-0.20%	-0.02%

Table 5.1

Interpretation of Results

Positive technical change represents and outward shift of the production frontier and implies an increase to the maximum possible output given fixed inputs. Technological advancement, improved capital quality, and higher education attainment in the labor force can all contribute to this shift. To better understand these results, it is important to discuss the political climate of Hu Jintao's reign. China's economic growth also led to large increases of income disparity (Wang & Gang, 2005), a phenomenon deemed incompatible with the ruling party's ideology. As many of the newly wealthy were high ranking government officials, this increasing wealth gap fueled concerns of corruption within the government (Cole, 2009). The Hu administration, in response to these concerns, called for a series of political reforms. However, drawing form the lessons of Mao's failed cultural revolution, Hu's administration placed emphasis on driving continued economic growth (Holbig 2009) rather than enact policies to encourage wealth distribution. The objective of these reforms, at least in theory, was to improve the income levels of the poorer segments of the population.

As Naughton (2005) notes, the early years of Hu's administration coincided with the start of China's 11th 5-year plan, which outlined goals involving expansion of the energy and urban sectors, investment in human capital, and development of China's rural areas. In response to the guidelines set by this plan, China devoted large amounts of resources towards its industrial base, creating large amounts of demand for new urban sprawl, energy grid capacity upgrades, and infrastructure construction.

The results from 5.1 correspond very well to the actions stemming from Hu's policies. As increasingly large amounts of national resources were allocated towards the heart of China's manufacturing complex, industries within the Semi-finished, SF&F, and Finished all experienced positive trends to technical change in the second sub-period, with 3 exceptions. As the manufacturing industries receive new capital to meet national production quotas, the production frontier shifts outwards as output also increased. To meet the increased demand for material and energy inputs, industries within the Energy and Commodities (C&P) group also received bolstered state support, leading to outward shifts of the respective production frontiers as well.

While China's industrial sector enjoys large scale technological advances and new production capital, the urban centers also see an accelerated period of growth following Hu's entry into office (Schneider and Mertes, 2014) as millions of citizens migrate from the rural areas into the cities. While this leads to a steadily declining labor force for the agricultural industry, as shown in table 4.2, Chinese farms experienced a period of rapid mechanization that led to large increases to agricultural production, which yielded positive productivity estimates robust to both SFA and TFP-based productivity calculations.

Finally, the turn of the millennium also saw significant increases to nationwide construction projects, such as the Chinese interstate system, a system of hydroelectric dams along the Yangtze river, high speed rail networks, and mass expansion of metro areas. The central government began a series of education incentives for domestic citizens and sought the expertise from established foreign sources in preparation of these large scale national projects. Thus, construction also experienced positive trends to technical change in the second sub-period.

In stark contrast to the main benefactors of the 5-year plan, China's service sectors received extremely sporadic attention and the corresponding industries often relied on local governments as the chief source of support (Shen, 2007). However, this was often against the interest of local officials, who wished to secure promotions through the earlier mentioned "growth tournaments." As the service industries were left in relative neglect, the respective productivities deteriorated as ten out of the eleven service industries saw negative trends to technical efficiency in the second sub-period.

Comparison with Growth Accounting Literature

The positive technical change in the selected industries fits well to the narrative of Hu's economic plans. Through government directed initiatives, many of the target industries saw improvements to productivity using the SFA method. Yet these results are somewhat contradictory to much of the existing literature in growth accounting, which tend to suggest an inverse relationship of productivity and the degree of state intervention. As Du, et al (2014) suggest, industries owned by the state are not only less efficient at using capital, but also less likely to innovate and improve productivity. Mi and Wang (2001) finds that although SOEs accounted for 70% of China's capital stock, they only produced 50% of the country's total manufacturing output. Here, the positive trends for productivity growth for energy and the manufacturing sectors are surprising both due to the predicted effects of China's regime change and the generally upstream nature of these industries. A simple explanation may be the weaknesses of TFP itself.

Traditional growth accounting studies acquire TFP by subtracting the growth rate of observable inputs from the observed growth in total production; such studies do not estimate a production frontier, in contrast to SFA. Thus, TFP is a measure of residuals as a result of deviations from expected output growth, rather than a measure of inefficiencies as a result from deviations of the maximum possible production given technology and inputs. Because of this difference, TFP is generally an imperfect measure of productivity and lower TFP values do not necessarily imply productivity losses.

Additionally, as Hulten (2001) argues, making conclusions using TFP generally requires invoking the assumptions used in Solow (1956). These include constant returns to scale (CRS), efficient system of prices, perfect input substitution, and exogenous technology growth. Since this study uses industry level data, CRS and efficient prices assumptions are generally taken to be true as significant diminishing returns and heavy price distortions are unlikely at the macroeconomic level. However, the assumptions for perfect substitution of input is likely inappropriate for a rapidly industrializing economy as machinery replaces human labor, and the exogenous technology assumption leads to systematic underestimation technology's role in productivity (Romer 1990). Thus, conclusions based in TFP measured are flawed due to a combination of underestimating the role of technology and imperfect mapping of TFP to productivity.

SECTION 6

CONCERNS AND LIMITATIONS

General Issues

Though there are several weaknesses of TFP, SFA studies using aggregated data also presents its own set of challenges. Here, each industry contains only a single series of data and effectively serves as its own representative firm. Since each representative firm is unique, it will always serve as the industry production frontier as it is a priori the most efficient firm within its respective industry. Thus, the EC_{ft} for every unique representative firm must always be zero since any deviation from the production frontier will cause a shift in the frontier. Since every industry serves as a unique representative firm, every industry used in this study is thus assumed to be perfectly efficient. In this case, SFA productivity change estimates cannot capture true efficiency losses and creates incomplete measures of productivity change. This could potentially cause misleading results and overestimation of productivity in industries that in reality are experiencing negative efficiency change.

Oh (2012) highlights a more serious potential problem while using aggregated data with the SFA framework. In a study using Korean firm and regional level industry data, Oh finds that the estimators from regional data are significantly different than the estimators using firm level data despite using identical production function formulation. If the estimated coefficients for Chinese data are subject to the same potential aggregate bias, not only could this could lead to incorrect conclusions of the production frontier but also incorrect estimates of technical change. Unfortunately, since firm level data is unavailable, it is difficult to test for such bias in this study.

Finally, this study cannot make direct use of Wu's (2015) categorization system of industry groups. Since the SFA framework assumes a single type of output, individual industry used in this study requires a unique production frontier estimate. As economies become more diversified, comprehensive and in-depth macroeconomic studies using SFA become exponentially more complex. Thus, SFA features a few key improvements over TFP but is not a perfect method for aggregate productivity analysis and cross-industry comparison.

Issues with Chinese Data

A perennial issue with Chinese macroeconomic studies is the relatively small size of datasets. This is perhaps a contributing reason to the popularity of non-parametric TFP analysis methods, as it creates a few extra limitations with the SFA. Most notably, fewer data points discourage the use of interaction terms among the input factors. Since these factors are rarely used in isolation during the production process, the interaction terms are likely to be highly significant. As a result, any possible nonlinear relationships among the inputs and the associated effects are lost.

Curiously, the results show that the coefficients for capital and labor are negative for several of Chinese industries, implying that increasing a production input leads to production losses. This is an irrational conclusion, yet studies by Zhang and Song (2003) and De Brau (2008) also report similar findings. A possible culprit is the assumption of homogenous labor and capital inputs. Since skilled workers are generally more productive, it is possible for production to increase despite a decrease to labor input. China's unusually heavy investment to education was likewise met with an unusually quick growth in the number of skilled workers. As industries replace large numbers of unskilled workers with smaller numbers of skilled workers, the effect was significant enough in certain industries to create a negative correlation of labor input and production. A similar argument can be made for capital and other inputs. Thus, until quality of inputs can be properly accounted for, this paradoxical negative correlation is likely to remain.

The aggregation issues and limitations from small data sets can be solved by conducting studies using firm level data, where SFA is commonly used. However, another issue with studying Chinese data is below the level of national aggregates, there are few standardized methods data collecting. Thus, data quality is not only often poor, but it is difficult to make meaningful comparisons across studies, especially if different data sources are used. However, the Chinese government has been taking steps to improve data quality at all levels, and it is likely in the future more of these studies will be possible.

SECTION 7

CONCLUSION

Cross-industry studies using aggregated data provide insight on policy and structural changes that affect economic systems at the highest level. While this paper acknowledges the large body of existing growth accounting literature using TFP-based measures of productivity change, total factor productivity may be an unsatisfactory method due to its high sensitivity to formulation and general opaqueness. Thus, this paper proposes using stochastic frontier analysis to estimate industry level productivity in the Chinese economy.

The results of SFA contrasts with many previous studies as it showed positive trends for productivity not only for upstream firms, but also in a period with the expectation of increased government control over the economy. These results would imply that government intervention is beneficial, or at least non-detrimental. Though the weaknesses of TFP as a measure of productivity likely plays a role in this disparity from previous studies, there are also certain issues that impair the effectiveness of SFA on macroeconomic level studies.

Firstly, highly aggregated data often prevents meaningful estimation of efficiency change at the industry level, leading to incomplete and potentially misleading results from productivity analysis. Moreover, industry level data may be subject to aggregation bias and ultimately lead to inaccurate estimation coefficients, which in turn can lead to an incorrect production frontier. Finally, since SFA requires a single output, cross industry comparisons can lead to overly complex analysis. Thus, while SFA corrects for many of TFP's deficiencies, it also has its weaknesses.

Studies on the Chinese economy have additional difficulties. At the aggregate level, since the earliest available data from the CIP and CSY only dates to 1980, the small sample sizes impose limits to the SFA framework. Moreover, common macro level assumptions of homogenous inputs are likely inappropriate for China due to its unusually high investment in technology and human capital in recent years. For Chinese firm level studies, the sporadically available data is also associated with equally sporadically available quality control. Thus, meaningful comparisons of studies using different sources are difficult as data collection methods are rarely standardized below the national aggregate level. More importantly, firm level data even within the same study may be incomparable due to similar reasons. However, as China is gradually adopting stricter standards of quality control, it would be a worthwhile endeavor to revisit such topics at a later date.

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APPENDIX A

INDUSTRY GROUP CLASSIFICATION

Industry Group Classification				
CIP Code	EU-KLEMS Code	Industry	Industry Code	Group
1	A-B	Agriculture, forestry, animal husbandry & fishery	AGR	Agriculture
2	10	Coal mining	CLM	Energy
3	11	Oil & gas excavation	PTM	Energy
4	13	Metal mining	MEM	C&P
5	14	Non-metallic minerals mining	NMM	C&P
6	15	Food and kindred products	F&B	Finished
7	16	Tobacco products	TBC	Finished
8	17	Textile mill products	TEX	C&P
9	18	Apparel and other textile products	WEA	Finished
10	19	Leather and leather products	LEA	Finished
11	20	Saw mill products, furniture, fixtures	W&F	SF&F
12	21-22	Paper products, printing & publishing	P&P	C&P
13	23	Petroleum and coal products	PET	Energy
14	24	Chemicals and allied products	CHE	C&P
15	25	Rubber and plastics products	R&P	SF&F
16	26	Stone, clay, and glass products	BUI	C&P
17	27-28	Primary & fabricated metal industries	MET	C&P
18	27-28	Metal products (excluding rolling products)	MEP	SF&F
19	29	Industrial machinery and equipment	MCH	Semi-Finished
20	31	Electric equipment	ELE	SF&F
21	32	Electronic and telecommunication equipment	ICT	SF&F
22	30-33	Instruments and office equipment	INS	SF&F
23	34-35	Motor vehicles & other transportation equipment	TRS	Finished
24	36-37	Miscellaneous manufacturing industries	OTH	Finished
25	E	Power, steam, gas and tap water supply	UTL	Energy
26	F	Construction	CON	Construction
27	G	Wholesale and retail trades	SAL	Services II
28	H	Hotels and restaurants	HOT	Services II
29	I	Transport, storage & post services	T&S	Services I
30	71-74	Information & computer services	P&T	Services I
31	J	Financial Intermediary Services	FIN	Services I
32	K	Real estate services	REA	Services II
33	71-74	Leasing, technical, science & business services	BUS	Services II
34	L	Government and social organizations, etc.	ADM	Services III
35	M	Education	EDU	Services III
36	N	Healthcare and social security services	HEA	Services III
37	O-P	Cultural, sports, entertainment, and other services	SER	Services II

APPENDIX B

CAPITAL STOCK ESTIMATION

To estimate capital stock (K_{f1}, Ki_2, ... K_{fT}), literature often uses the perpetual inventory method (PIM) given as

$$K_{ft} = I_{ft} - (1 + \delta_t) K_{ft-1}$$

where K_{ft} is capital stock, I_{ft} is investment, and δ_{ft} is depreciation rate. However, Holz (2006) highlights the issues with conventional PIM methods, particularly the assumption of linear effects of depreciation. Instead, he suggests a modification to δ_{ft} that accounts for voluntary retirement of capital as well as depreciation, given by

$$ROFA_{ft} = ROFA_{f0} + \sum_{f=1}^{t} \frac{I_{ft}}{P_{ft}} - \frac{scrap_{ft} \times \delta_{ft}}{P_{ft-1}}$$

In this formula, $ROFA_{ft}$ is the real original value of fixed assets, $scrap_{ft}$ is the scrap rate of capital, and P_{ift} is the price deflator for year t.

APPENDIX C

ESTIMATION COEFFICIENTS BY INDUSTRY

Coefficients by Industry

Industry	Group	β0 (Constant)	β1 (Regime Dummy)	β2 (Capital)	β3 (Labor)	β4 (Intermediates)	βt1 (Time)	βt2 ($Time^2$)
CLM	Energy	6.1207	0.3055	-0.0098	0.0462	0.0839	-0.0012	0.0268
PTM	Energy	-2.7904	0.2267	1.4188	-0.1595	-0.0675	-0.1059	-0.0005
PET	Energy	9.4018	0.0773	-0.4035	0.5827	0.0905	0.0983	0.0006
UTL	Energy	23.7157	0.2138	-1.2406	-0.4025	0.3646	0.2426	-0.0008
MEM	C&P	5.3015	0.3753	-0.4863	0.3494	0.0751	-0.0004	0.0492
NMM	C&P	-5.4208	0.2248	0.2609	0.7299	0.6937	-0.0047	-0.0004
TEX	C&P	-1.2796	-0.4304	0.8454	0.8430	0.0543	-0.0009	0.0854
P&P	C&P	-1.0941	0.1610	0.3375	0.6939	0.1602	0.1342	-0.0024
CHE	C&P	4.8841	-0.0302	-0.3758	0.8824	0.2703	0.1125	0.0001
BUI	C&P	-3.1778	-0.0820	0.1473	0.8316	0.4454	0.0283	0.0008
MET	C&P	14.3493	0.0218	-1.3560	1.1788	0.2025	0.1204	0.0036
F&B	Finished	-5.7366	-0.1718	1.2792	0.5980	0.0832	-0.0013	0.0736
TBC	Finished	8.7939	0.0569	-0.9610	0.7057	0.4542	0.2805	-0.0033
WEA	Finished	-3.7274	0.0388	0.8609	0.2856	0.3825	-0.0175	-0.0007
LEA	Finished	1.2378	0.8522	-0.1361	0.1911	0.0505	-0.0010	0.1491
TRS	Finished	4.3591	-0.0465	-1.2890	1.5033	0.7336	0.0714	0.0023
OTH	Finished	-0.3249	0.1331	-0.1550	0.3744	0.8462	0.0361	0.0001
W&F	SF&F	4.7252	0.0743	0.0677	-0.2350	0.6719	0.0189	0.0005
R&P	SF&F	6.0005	0.0258	-0.0007	0.3957	0.0327	0.1676	-0.0014
MEP	SF&F	1.9713	-0.0786	0.1620	0.5261	0.1551	0.1478	-0.0020
ELE	SF&F	1.1884	-0.0016	0.0035	0.5736	0.4192	0.0978	-0.0011
ICT	SF&F	-2.1671	0.2958	0.1495	0.7279	0.5358	0.0378	-0.0008
INS	SF&F	4.9547	-0.0119	-0.0943	-0.4491	0.9515	-0.0261	0.0012
MCH	Semi-Finished	2.0151	0.0126	-0.3738	0.8318	0.5323	0.0615	0.0008
CON	Construction	16.1908	0.0941	-0.4819	0.3012	-0.4293	0.1879	0.0006
AGR	Agriculture	38.3000	-0.0885	0.2412	-2.2177	-0.0895	0.1950	-0.0045
T&S	Service I	14.6361	0.1059	-0.4698	-0.1979	0.2884	0.2051	-0.0009
P&T	Service I	1.2485	0.1802	-0.0886	0.6599	0.3183	0.1758	-0.0014
FIN	Service I	18.8900	-0.3980	-1.1750	-0.0097	0.2150	0.2590	-0.0010
SAL	Service II	-0.6038	-0.1022	-0.7971	1.2664	0.7592	-0.0168	0.0028
HOT	Service II	4.2439	0.2741	0.1920	-0.4389	0.7878	0.0672	-0.0015
REA	Service II	12.1314	-0.1218	-0.1854	-0.0336	-0.0325	0.2200	-0.0002
BUS	Service II	0.2497	0.0408	0.2442	0.0632	0.7334	0.0136	-0.0003
SER	Service II	-10.0621	0.3844	0.9776	0.3794	0.9155	-0.2017	0.0005
ADM	Service III	10.0211	0.0173	-0.3764	0.0236	0.4011	0.1038	0.0017
EDU	Service III	4.4094	0.0249	0.1279	0.0843	0.3677	0.0757	0.0001
HEA	Service III	6.7700	0.0528	0.0550	-0.1810	0.3954	0.1168	-0.0005

All estimates are significant at the .05 significance level