Capacity Utilization and Production Function Estimation: Implications for Productivity Analysis

Jianmin Tang
Innovation, Science, and Economic Development Canada
Weimin Wang
Statistics Canada[1]

Abstract

During business cycles and disruptions of global value chains, capacity utilization has important implications for explaining variations in productivity and for evaluating the effectiveness of a certain investments such as R&D and ICTs. Unfortunately, data on capacity utilization is not easily available, especially at the firm level. This article develops and evaluates a methodology for measuring capacity utilization at the micro level. Unlike the literature using ad-hoc proxies (for example, the ratio of energy use to capital stock) or ex-post return to capital which is endogenous to productivity shocks, the new measure is practical and easily implemented. Importantly, it is based on the theory of the firm in terms of profit-maximizing and price-taking and is exogenous to productivity shocks. Using Canadian micro data, this article shows that the developed new measure under the assumption of capital being not adjustable in the short term explain well the variations in firm productivity. It also finds that controlling for capacity utilization may be essential in evaluating the economic impact of certain investments such as in ICT.

1 Jianmin Tang is senior economist in the Strategy, Research and Results Branch at Innovation, Science, and Economic Development Canada. Weimin Wang is a senior research economist in the Analytical Studies and Modelling Branch at Statistics Canada. We are grateful to Andrew Sharpe, Someshwar Rao, Hasina Rasata, Bart van Ark, and three anonymous reviewers for comments and suggestions. The views and opinions expressed in the research report are, however, those of the authors alone and do not represent, in any way, the views of opinions of Innovation, Science, and Economic Development Canada or of Statistics Canada. Email: jianmin.tang@ised-isde.gc.ca; weimin.wang@statcan.gc.ca.

A firm installs machines and hires workers to meet expected demand for its products. The maximum production level under normal economic conditions of the firm's operating practice with respect to the use of installed machines and the deployment of workers is the production capacity of the firm (Klein and Long, 1973). In reality, however, the operation of the firm may often not be at its capacity as the realized demand for its products may be lower/higher than expected or there is a shortage of necessary parts due to a disruption of global value chains. If actual demand is lower than expected or there is a shortage in necessary inputs, a firm may have to reduce its production. This leads to underutilization of production capacity as it is difficult or costly to adjust the installed capacity in a short-term. Similarly, if actual demand is higher than expected, the firm may want to increase production by operating overtime, resulting in capacity utilization higher than normal.

The variation in capacity utilization has important implications for production function estimation or measured productivity. If productivity is simply an indicator for how much output is produced by a unit of all inputs, including all workers and all installed capital, then measured productivity is not affected and capacity utilization is not an issue. However, if productivity is used as an indicator for technological change or production efficiency, which is often the case, then measured productivity under the full capacity utilization assumption may be misleading, particularly during shorter periods of time when the firm has not been able to adjust input levels to match demand. In this case, the appropriate measure should only include the actually-used inputs – the unutilized portion of production capacity should be excluded from the calculation. Thus, it has become important to adjust for capacity utilization in estimating productivity function.

Capacity utilization may also indirectly affect the estimation of the economic performance of policy programs or certain investments such as R&D and ICTs. Without controlling for capacity utilization, econometric analyses may incorrectly estimate the economic impact of policy programs or investments. Thus, controlling for capacity utilization is also important for evaluation and development of industrial policies.

Capacity utilization is commonly measured as a ratio of the actual level of output to a sustainable maximum level of output (Corrado and Mattey, 1997). Unfortunately, despite several decades of research and a well defined definition, how to actually measure capacity utilization is still debated. Importantly, data on capacity utilization is not readily available for economic analysis and research at the firm level or at the industry level for service industries. This opens the door for various proxies for capacity utilization. Measures based on both inputs and output have been put forward. For input-based measures, the proxies includes uses unemployment rates by Solow (1957), an index of electric motor utilization by Jorgenson and Griliches (1967), the ratio of energy costs to capital stock by Burnside *et al.* (1995), the growth of materials by Basu (1996), and hours worked per worker by Basu and Fernald (2001) and Basu *et al.* (2006). For output-based measures, the most popular and traditional one is actual output divided by potential/capacity output (Berndt and Fuss, 1989; Statistics Canada, 2022 for non-manufacturing goods industries). Following Berndt and Fuss (1986) and Hulten (1986), more recently, Baldwin *et al.* (2013) and Gu and Wang (2013) suggest a measure based on ex-post return to capital, and propose capacity utilization as the ratio of the ex-post return to the ex-ante expected return on capital.

However, these measures have limitations. The input-based proxies are unsatisfactory due to lacks a theoretical framework (Berndt and Fuss, 1986). They tend to capture the utilization of labour/energy utilization rather than capital utilization, which is the most difficult to adjust in the short term. Also, these proxies can be different across different groups of firms or industries, and can change over time even in normal economic conditions (for example, from input substitution effect due to relative price changes). These measures are found to be poor indicators for capacity utilization in Canada, and are unable to significantly remove the cyclical fluctuations in productivity growth (Baldwin *et al.* 2013).

Output-based measures are also questionable as the ex-post return to capital is endogenous to productivity. Ex-post income to capital is measured as output net of labour and intermediate inputs costs. Firms are often price takers for labour and intermediate inputs. Most of the gains (or loss) from positive (or negative) productivity improvements accrue to capital, which leads to over estimation (under estimation) of capacity utilization. An over- or under-estimation may be problematic if the measure is used to adjust variation in productivity or for assessing the economic performance of some economic policy instruments. The practice will also lead to the endogeneity problem in estimating production functions when capacity utilization enters regressions as an explanatory variable.

The objective of this article is to use the theory of the firm, which assumes that firms are profit maximizing and price-taking in both output and input markets, to develop a practical methodology under the Cobb-Douglas production function for estimating capacity utilization.[2] Unlike output-based measures in the literature, the theory-based measure is also exogenous to productivity shocks. Using econometric analyses, we validate the new methodology by its effectiveness in explaining variations in productivity performance of firms over business cycles. We also provide evidence on the importance of controlling for capacity utilization in assessing the economic performance of investments in R&D and ICTs during business cycles.

It is important to note that the main objective of this study is not to replace the valuable data development programs on capacity utilization at statistical agencies around world. Instead, it is to provide a practical way for researchers to estimate capacity utilization at the firm level or at

2 The project also contributes to the data development at Statistics Canada by estimating capacity utilization at the micro level.

the industry level for services industries, which currently have no capacity utilization estimates at least in Canada.

Following the introduction section, this article develops a methodology to estimate capacity utilization at the firm level, together with two hypotheses. In the data section, it briefly describes the micro data, which is used to evaluate the developed methodology. This is followed by a discussion of the measured capacity utilization under two different hypotheses. It then tests and evaluates the two hypotheses, by associating the measured capacity utilization with output, labour, investments, and official capacity utilization at the sector or industry level. It also shows whether or not controlling for capacity utilization is important in measuring productivity and in evaluating the economic impact of investments in R&D and ICTs. Finally, it concludes.

Methodology

We assume that a firm uses two inputs for its production: one input is fully adjustable (for example, combined labour and intermediate inputs) and the other is not adjustable in the short term (for example, capital). In formulation, firm i at time t maximizes profit from its production as follows:

$$\begin{cases} \max \pi_{it} = P_{it}^{Y} Y_{it} - P_{it}^{C} C_{it} - P_{it}^{F} V_{it} \\ \text{s.t. } Y_{it} = A C_{it}^{\alpha} V_{it}^{\beta} \end{cases} \tag{1}$$

Where π, Y, C, and V denote profit, output, un-adjustable input, and adjustable input, respectively; P^{Y}, P^{C}, and P^{V} are the prices corresponding to Y, C, and V. Note that A is a production efficiency parameter, and α and β are the output elasticities with respect to inputs C and V.

Assume that the firm is a price taker in both output and in inputs markets. From the first order conditions of the maximization problem of equation (1), we obtain

$$\frac{V_{it}^{*}}{C_{it}^{*}} = \frac{\beta P_{t}^{C}}{\alpha P_{t}^{V}} \tag{2}$$

where V_{it}^{*} and C_{it}^{*} represent the optimal levels of the adjustable and un-adjustable inputs for a given output Y_{it} for firm i at time t.

Equation (2) is the input ratio of the adjustable input to the un-adjustable input. It captures the substitution effect between the two inputs due to a relative change in input prices.

We define capacity utilization as the extent to which a firm uses its installed productive capacity. Thus, for firm i at time t, it equals

$$U_{it} = \frac{C_{it}^{*}}{C_{it}} \tag{3}$$

where C_{it} is the total installed production capacity for firm i at time t.

By this definition, we implicitly assume that a firm will install production capacity to meet expected demand in the medium- or long-term while actual use of the installed capacity is based on the short term (or yearly) demand.

This is an input-based measure of capacity utilization. The optimal level of C_{it}^{*} for a realized demand can be smaller or larger than the installed C_{it}. If actual demand is lower than expected, a firm may have to adjust its operation, leading to under-utilization of installed production capacity.

In contrast, if actual demand is higher than expected, the firm may want to increase production by operating overtime, resulting in capacity utilization higher than normal. Substituting (2) into (3), we derive capacity utilization as:

$$U_{it} = \frac{\alpha}{\beta} \frac{P_{it}^{V} V_{it}^{*}}{P_{it}^{C} C_{it}} \tag{4}$$

The measure has a desirable property. It is exogenous as it is not influenced by the production efficiency parameter (A), which is affected by productivity shocks, in equation (1).[3] During normal business operation under the Cobb-Douglas production function, the capacity utilization measure equals 1. When there is a negative (positive) shock to the demand condition, the capacity utilization measure is below (above) 1 as C_{it} is larger (smaller) than C_{it}^{*}.

It is important to note that in the context of this study, the price of the installed capacity, C_{it}, should not be determined endogenously, that is, the compensation for C_{it} should not be equal to the output value $P_{it}^{V} Y_{it}$ minus the cost of the adjustable input $P_{it}^{V} V_{it}^{*}$. It should be exogenously determined, which will be discussed further when we introduce our hypotheses.

For an empirical analysis, the output elasticity parameters α and β can be obtained by estimating the production function. Alternatively, they can be estimated by income shares as they are equivalent to income shares when inputs are paid the value of their marginal products (Hulten, 2009). Accordingly, we derive the firm-specific ratio of the two elasticity parameters for firm i as the firm sample average, that is,

$$\begin{aligned} \frac{\alpha_i}{\beta_i} &\approx \frac{1}{T_i} \sum_{t=1}^{T_i} \frac{\alpha_{it}}{\beta_{it}} \\ &= \frac{1}{T_i} \sum_{t=1}^{T_i} \frac{\left(P_{it}^{Y} Y_{it} - P_{it}^{V} V_{it}^{*}\right) / P_{it}^{Y} Y_{it}}{P_{it}^{V} V_{it}^{*} / P_{it}^{Y} Y_{it}} \\ &= \frac{1}{T_i} \sum_{t=1}^{T_i} \frac{P_{it}^{Y} Y_{it} - P_{it}^{V} V_{it}^{*}}{P_{it}^{V} V_{it}^{*}} \quad (5) \end{aligned}$$

where T_i is the total number of yearly observations for firm i.

Under this model, the average capacity utilization over time will be one. The model is then used to test two hypotheses.

Hypothesis 1: Labour and intermediate inputs are fully adjustable, and capital cannot be adjusted in the short term.

In this case, like intermediate inputs, employment can be adjusted in the short term and labour hoarding is insignificant.[4] Under this hypothesis, the adjustable input F is both labour and intermediate inputs and the un-adjustable input is capital, that is, in formulation:

$$U_{it}^{K} = \frac{\alpha^{K}}{\beta^{LM}} \frac{P_{it}^{LM} V_{it}^{LM*}}{P_{it}^{K} C_{it}^{K}} \tag{5}$$

The combined labour-intermediate input for firm i at time t is calculated as a weighted sum of labour and real interme-

3 Note also that firms are price-taking in labour and intermediate inputs and the price of capital is determined by the long-term return to capital, which will be discussed later.

4 To reflect the full adjustment in labour input, employment here should ideally be measured in hours worked. In the empirical analysis of this study, we have only data on the number of employees."

diate inputs in the Törnqvist index as follows:

$$\Delta \ln(V_{it}^{LM*}) = \overline{\phi}_{it} \Delta \ln(L_{it}^{*}) + (1 - \overline{\phi}_{it}) \Delta \ln(M_{it}^{*}) \quad (6)$$

where $\overline{\phi}_{it}$ is the average share of labour cost in the total cost of labour and intermediate inputs between t and $t-1$.

Firm-level price data are not easily available. Fortunately, for our estimation of capacity utilization, we do not have to obtain firm-level price data for all inputs. According to equation (6), $P_{it}^{LM} Y_{it}^{LM*}$ is equal to the sum of the labour compensation $P_{it}^{L} L_{it}^{*}$ and the nominal value of intermediate inputs $P_{it}^{M} M_{it}^{*}$, that is,

$$P_{it}^{LM} Y_{it}^{LM*} = P_{it}^{L} L_{it}^{*} + P_{it}^{M} M_{it}^{*}$$

and

$$P_{it}^{K} C_{it}^{K} = P_{it}^{K} K_{it}$$

is the cost of installed capital. To estimate the cost of installed capital, we need to estimate the price of capital, P_{it}^{K}. As capital investment is in the long term and also to avoid the volatility in return to the investments in the short term we approximate P_{it}^{K} by the average return to capital over the whole sample period. [5]

$$P_{it}^{K} \approx P_{i}^{K} = \frac{1}{T_i} \sum_{s=1}^{T_i} \frac{P_{is}^{Y} Y_{is} - P_{is}^{L} L_{is} - P_{is}^{M} M_{is}}{K_{is}}. \quad (7)$$

The ratio of the output elasticity of the adjustable input to the output elasticity of the un-adjustable input can also be estimated by

$$\frac{\alpha_i^K}{\beta_i^{LM}} \approx \frac{1}{T_i} \sum_{t=1}^{T_i} \frac{P_{it}^{Y} Y_{it} - P_{it}^{L} L_{it} - P_{it}^{M} M_{it}}{P_{it}^{L} L_{it} + P_{it}^{M} M_{it}} \quad (8)$$

Hypothesis 1 has been developed under the assumption that both labour and intermediate inputs are fully adjusted in the short term. If the assumption that labour is fully adjustable in the short term is violated and there is labour hoarding when demand is lower than expected is significant, then installed capacity should also include labour. Although it will be rejected later on, we develop our second hypothesis by going to extremes and assuming that like capital, labour is not adjustable.

Hypothesis 2: Intermediate inputs are fully adjustable and both labour and capital are not adjustable in the short-term.

Thus, in this case, installed capital cannot be adjusted in the short term and labour hording is significant. They together form the installed capacity, C^{LK}. In contrast, intermediate inputs are fully adjustable, and $V^* = M^*$.

Under this hypothesis, the capacity utilization firm i at time t is:

$$U_{it}^{LK} = \left(\frac{\alpha^{LK}}{\beta^{M}}\right) \left(\frac{P_{it}^{M} V_{it}^{M^*}}{P_{it}^{LK} C_{it}^{LK}}\right) \quad (9)$$

The combined labour-capital input for firm i at time t can be calculated as a

5 The micro data we have are for 2000-2017. Also, the measure is firm-specific. Alternatively, for a general ex-ante user cost of capital, we can use a standard rate of return to capital for all firms. For example, Diewert (2001) suggests that a constant real interest rate of 4% per year plus the actual rate of consumer price inflation may be used for the user cost of capital.

weighted sum of labour and capital input in the Törnqvist index as follows:

$$\Delta \ln \left(C_{it}^{LK}\right) = \bar{w}_{it} \Delta \ln \left(L_{it}\right) + \left(1 - \bar{w}_{it}\right) \Delta \ln \left(K_{it}\right) \tag{10}$$

where $\bar{w}_{it}$ is the average share of labour cost in the total cost of labour and capital at time $t-1$ and $t.\Delta \ln \left(C_{it}^{LK}\right), \Delta \ln \left(L_{it}\right)$, and $\Delta \ln \left(K_{it}\right)$ are log difference of C^{LK}, L, and K between t and $t-1$, respectively.

For this hypothesis, $P_{it}^{M} V_{it}^{M^*} = P_{it}^{M} M_{it}^{*}$ and $P_{it}^{LK} C_{it}^{LK} = P_{it}^{L} L_{it} + P_{it}^{K} K_{it}.P_{it}^{LK}$ is the price of installed capacity. As capacity investments are in the long term and also to avoid the volatility in return to the investments in the short term, in this article, we approximate P_{it}^{LK} by the average return to installed capacity over the whole sample period: [6]

$$P_{it}^{LK} \approx P_{i}^{LK} = \frac{1}{T_i} \sum_{s=1}^{T_i} \frac{P_{is}^{Y} Y_{is} - P_{is}^{M} M_{is}}{C_{is}^{LK}} \tag{11}$$

$$\frac{\alpha_i^{LK}}{\beta_i^{M}} \approx \frac{1}{T_i} \sum_{t=1}^{T_i} \frac{P_{it}^{Y} Y_{it} - P_{it}^{M} M_{it}}{P_{it}^{M} M_{it}} \tag{12}$$

Thus the new method in estimating capacity utilization is an input-based measure, which utilizes all information on labour, capital and intermediate inputs. As such, it is exogenous to output and productivity shocks.

Micro Data

The empirical analysis for evaluating the proposed measure of capacity utilization is based on micro data in Canada, covering total business sector from 2000-2017. The micro data file is from National Accounts Longitudinal Microdata File (NALMF), which is an administrative data file created by the Economic Analysis Division at Statistics Canada. The NALMF makes use of administrative tax records (T2 and PD7), T4 data, and information from the Business Register (BR), and the Survey of Employment, Payrolls and Hours (SEPH).[7] The T2 data includes corporations that file a T2 tax return with the Canada Revenue Agency (CRA). The T4 data, PD7 and SEPH include corporations and unincorporated firm that hire employees.

From the NALMF dataset, we extract for each firm, gross output, physical capital stock, intermediate inputs, R&D stock, and ICT capital stock. R&D stock is derived using the perpetual inventory method (PIM).

NALMF also has data on foreign ownership and firm birth year. These data are originally from Business Register (BR). BR is the central repository of information on businesses in Canada. Used as the principal frame for the economic statistics program at Statistics Canada, it maintains a complete, up-to-date and unduplicated list

6 The micro data we have are for 2000-2017. Also, the measure is firm-specific. Alternatively, for a general ex-ante user cost of capital, we can use a standard rate of return to capital for all firms. For example, Diewert (2001) suggests that a constant real interest rate of 4 per cent per year plus the actual rate of consumer price inflation may be used for the user cost of capital.

7 When a firm files its tax return, PD7 is the statement of account for payroll deduction containing the total number of employees and the gross payrolls. For an employee, T4 is the statement of remuneration paid by an employer, containing employment earnings.

on all active businesses in Canada that have a corporate income tax (T2) account, are an employer or have a goods and services tax account. The BR information on foreign ownership is combined with an updated foreign ownership information from Industrial Organization and Finance division (IOFD) at Statistics Canada.

Output and intermediate inputs in the NALMF database are in nominal dollars. To ensure comparison over time, it is necessary to deflate the nominal variables. Deflators at the firm level are not available so detailed industry deflators based on the KLEMS database are used.[8]

We end up with 12.3 million observations for the whole sample period (Table 1). The number of observations gradually increased for most of the non-manufacturing industries from 2000 to 2017, and it decreased for most of the manufacturing industries. This reflects the general change in the industrial structure of the Canadian economy, moving into a more service oriented economy.

Measured Capacity Utilization

Using the micro data, we estimate capacity utilization using our developed methodology under the two hypotheses. To reflect the importance of each firm in an industry group, capacity utilization for the industry is the average of capacity utilization of all firms in the industry, weighted by their output. Table 2 is the measured capacity utilization under hypothesis 1 (or CU1) for selected years, which assumes that only capital input is not adjustable in the short term. The years are the beginning and the ending points of our data, or they are associated with the two significant economic downturns in Canada.[9] In general, the measured capacity utilization is consistent with the movement in real GDP, that is, capacity utilization was high when the Canadian economy was performing well while it was low in economic downturns, especially in the 2008-2009 global financial crisis. Over the data period, the annual correlation between the measured capacity utilization (level) and real GDP growth for the business sector was highly significant at 0.49.

Chart 1 illustrates the movement of capacity utilization for industry groups for the analysis period. In general, capacity utilization decreased over time, mainly driven by non-manufacturing industries. The capacity utilization of the non-manufacturing goods-producing industry group is more volatile than manufacturing and services, with standard deviation being 0.18, 0.09 and 0.10, respectively. The high volatility in capacity utilization in the non-manufacturing goods-producing industry group can be partly explained by the high volatility of commodity price and economic activities in the mining sector.

The measured capacity utilization also captures well the change in economic condi-

8 For a description of the KLEMS database for Canada, see Baldwin *et al.* (2007).

9 Over the sample period 2000-2017, Canada only experienced one recession due to the great financial crisis, with real GDP declining 2.9 percent in 2009. Unlike the United States, Canada did not enter recession in 2001. However, due to our export industries heavily depending on the U.S. economy, Canada's real GDP growth slowed significantly from an average of 2.9 percent per year in 1990-2000 to 1.8 percent in 2001, with many manufacturing and information related services industries being hit hard.

Table 1: Number of Firms (Observations by Industry in Sample, between 2000-2017)

Industry	2000	2009	2017	**Total 2000-2017**
Forestry and logging	5855	4449	3709	86221
Fishing, hunting and trapping	1836	2137	2311	38237
Support activities for agriculture and forestry	2642	2827	3016	51081
Crop and animal production	4944	5124	4675	89940
Oil and gas extraction	1071	1616	1235	26005
Mining and quarrying	725	676	605	12145
Support activities for mining and oil and gas extraction	3820	6523	5473	101892
Utilities	445	588	545	10124
Construction	73654	104003	122712	1807629
Total manufacturing	48985	46042	42890	834814
Food	4657	4285	4568	80049
Beverage and tobacco	433	531	1106	10862
Textile and product mills	1524	1088	858	20641
Clothing, leather and allied product	3178	1818	1303	37665
Wood product	3269	3000	2709	54477
Paper	604	498	362	8990
Printing	4450	3859	3096	69113
Petroleum and coal	188	134	161	2680
Chemical	1616	1548	1528	28271
Plastics and rubber	2036	1896	1781	34499
Non-metallic mineral	1688	1651	1475	29194
Primary metal	543	552	467	9444
Fabricated metal	7386	7335	6800	131063
Machinery	4710	4615	4212	82774
Computer and electronics	2066	1796	1529	32167
Electrical equipment	1018	1017	1004	18275
Transportation equipment	2011	1800	1621	32747
Furniture	3342	3672	3352	64037
Miscellaneous manufacturing	4266	4947	4958	87866
Wholesale trade	44964	47292	42383	823391
Retail trade	77681	84197	85365	1512108
Transportation and warehousing	29958	42657	59588	775239
Information and cultural industries	8674	10434	10894	185604
Finance, insurance, real estate, and company management	58225	68136	62587	1154877
Professional, scientific and technical services	70947	106856	122517	1833234
Administrative, waste management	26892	37186	38999	635512
Arts, entertainment and recreation	10145	13698	13302	234670
Accommodation and food services	44444	53697	62411	973437
Other services except public administration	43452	62825	60446	1072343
Total business sector	559359	700963	745663	12258503

Source: Authors' own compilations based on the micro dataset for this study.

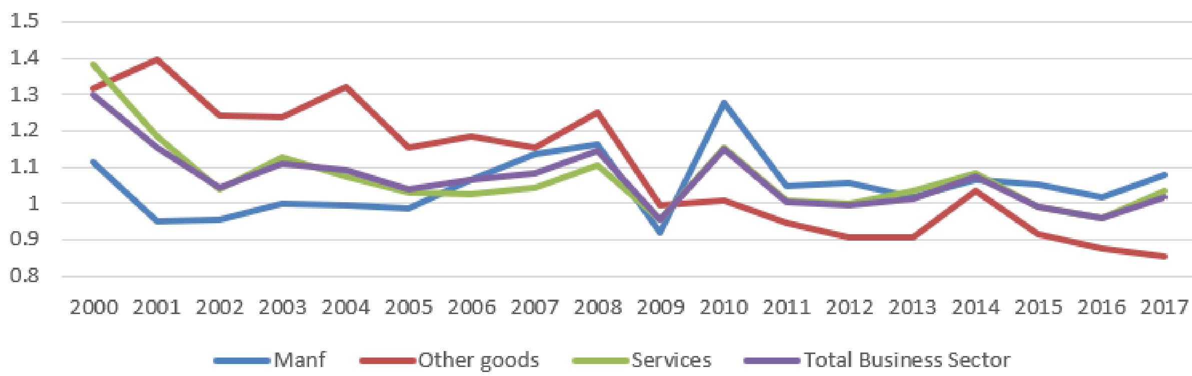
Table 2: Capacity Utilization When Only Capital Cannot Be Adjustable in the Short Term (Hypothesis 1, CU1)

Industry	2000	2001	2009	2017	**Average 2000-2017**
Forestry and logging	1.44	1.23	0.90	0.91	1.06
Fishing, hunting and trapping	1.63	1.40	0.89	1.03	1.09
Support activities for agriculture and forestry	1.48	1.33	1.00	0.97	1.08
Crop and animal production	1.42	1.26	2.36	1.01	1.18
Oil and gas extraction	0.79	1.49	1.08	0.79	1.12
Mining and quarrying	0.96	0.88	1.25	0.68	1.05
Support activities for mining and oil and gas extraction	1.42	1.28	0.91	0.88	1.07
Utilities	1.69	1.64	0.58	0.48	0.91
Construction	1.49	1.28	1.02	0.97	1.11
Total manufacturing	1.11	0.95	0.92	1.08	1.05
Food	1.24	1.14	1.00	0.94	1.01
Beverage and tobacco	1.18	0.92	0.68	0.96	0.97
Textile and product mills	1.19	1.04	1.01	0.91	1.01
Clothing, leather and allied product	1.34	1.25	1.02	0.91	1.05
Wood product	1.15	1.10	0.79	1.01	0.99
Paper	0.90	0.78	0.73	1.09	1.07
Printing	1.07	0.99	1.09	1.02	0.97
Petroleum and coal	1.11	0.92	0.84	0.97	1.12
Chemical	0.97	0.84	0.86	1.46	1.03
Plastics and rubber	1.35	0.96	0.89	0.91	0.96
Non-metallic mineral	1.09	1.14	0.91	0.95	1.02
Primary metal	1.06	0.96	1.00	0.85	1.05
Fabricated metal	1.31	1.08	0.96	0.93	1.03
Machinery	1.19	1.17	1.00	0.92	1.04
Computer and electronics	1.48	0.85	1.57	1.04	1.06
Electrical equipment	1.52	0.88	1.05	1.11	1.08
Transportation equipment	0.90	0.83	0.75	1.14	1.02
Furniture	1.28	1.30	0.84	0.92	0.99
Miscellaneous manufacturing	1.29	1.13	1.04	0.92	1.07
Wholesale trade	1.35	1.16	0.98	1.00	1.06
Retail trade	1.18	1.10	0.94	1.07	1.02
Transportation and warehousing	2.13	1.66	0.90	0.92	1.09
Information and cultural industries	0.96	0.90	0.97	0.74	1.05
Finance, insurance, real estate, and company management	1.48	1.18	0.92	1.09	1.08
Professional, scientific and technical services	1.28	1.20	1.00	1.06	1.16
Administrative, waste management	1.35	1.26	1.03	1.07	1.09
Arts, entertainment and recreation	1.43	1.18	0.79	0.93	1.10
Accommodation and food services	1.21	1.09	1.05	0.97	1.02
Other services except public administration	1.51	1.31	0.96	1.05	1.06
Total business sector	1.30	1.15	0.96	1.02	1.07

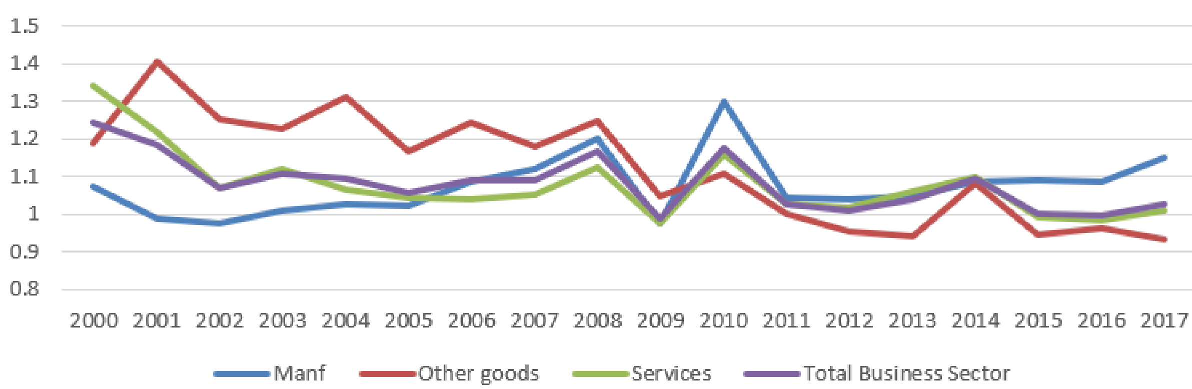
Note: The years selected are the peaks and troughs of real GDP line in Canada. The capacity utilization at the industry level is aggregated from the firm level, weighted by gross output.
Source: Authors' own compilations based on the micro dataset for this study.

Chart 1 : Capacity Utilization

Panel A: When Only Capital Cannot Be Adjustable in the Short Term (Hypothesis 1, CU1) for Aggregated Industry Groups



Panel B: When Both Labour and Capital Input Cannot Be Adjustable in the Short Term (Hypothesis 2, CU2) for Aggregated Industry Groups



tion at the industry level, although the general annual correlation between real GDP growth and the measured capacity utilization was 0.13 at the industry level, as shown later on in Table 5.[10] For the 2001 U.S. recession, which was mainly due to the collapse of the dotcom bubble and the 9/11 attacks, Canada's export-orientated manufacturing sector, especially computer and electronics and electrical equipment, was significantly affected (Table 2). We observe that the capacity utilization for total manufacturing declined 15 percent, from 1.11 in 2000 to 0.95 in 2001. The decline was more

10 The lower correlation at the industry level than at the aggregate business sector may be due to the fact that the variation in real GDP growth across industries was mainly driven by other industry-specific factors other than capacity utilization.

dramatic for the computer and electronics and electrical equipment manufacturing industry, from 1.48 to 0.85. For the great financial crisis, the negative economic impact was deeper and widespread across industries. Consistent with the development, we observe that 33 out of the 38 industries experienced a significant decline in capacity utilization. In 2009, The industries with the largest decline in capacity utilization were oil and gas extraction, petroleum and coal, primary metal, machinery, and finance, insurance and real estate.

Table 3 and Chart 1 is the measured capacity utilization under hypothesis 2 (or CU2), which assumes that both labour and capital input are not adjustable in the short term. The industry variation and movement pattern of CU2 is generally similar to that of CU1, with a correlation of 0.94 at the industry level and 0.98 for the total business sector.

The Evaluation of the Measured Capacity Utilization

How well does our estimated capacity utilization capture the actual capacity utilization? In this section, we assess them by correlating our measures with the official measure of capacity utilization and with economic growth.

Against Official Capacity Utilization for the Goods Producing Industries

Statistics Canada regularly releases capacity utilization statistics for the non-agriculture goods producing industries. In its recent practices, two approaches are followed for estimating capacity utilization rates at Statistics Canada (Statistics Canada, 2022). For manufacturing industries, the rates are directly calculated using survey data from the Monthly Survey of Manufacturing (MSM). In the survey, a plant is asked at what percentage of its capacity it has been operating, with capacity being defined as maximum production attainable under normal conditions. For other non-agriculture goods producing industries, the rates are calculated as the actual output-to-capital ratio divided by the potential output-to-capital ratio. The latter is the de-trended output-to-capital ratio, derived from actual output-to-capital ratio using the Hodrick-Prescott filter (HP filter). As discussed before, the capacity utilization estimates using output-to-capital ratio are endogenous to productivity shocks as they reflect the change in productivity.

The official rates are reported in Table 4. For a comparison between our measured capacity utilization and the official one, the official capacity utilization is normalized to the average of CU1 and CU2 for manufacturing over 2000-2017.

The movement pattern of the official capacity utilization is in general similar to that of our measures, although the correlation between our measures and the official measure at the industry level for 2000-2017 is only modest at 0.18 for CU1 and 0.17 for CU2. In consistent with CU1 and CU2, the largest decline in 2001 were computer and electronics and electrical equipment. For the Great Financial Crisis, in 2009, the decline was widespread across all industries.

Chart 2 illustrates the movement of the official measure and our measured capacity utilization for the total manufacturing

Table 3: Capacity Utilization When Both Labour and Capital Input Cannot Be Adjustable in the Short Term (Hypothesis 2, CU2)

Industry	2000	2001	2009	2017	**Average 2000-2017**
Forestry and logging	1.15	1.09	1.02	0.97	1.06
Fishing, hunting and trapping	1.31	1.17	0.99	0.98	1.07
Support activities for agriculture and forestry	1.18	1.20	1.05	1.01	1.11
Crop and animal production	1.44	1.29	2.38	1.07	1.21
Oil and gas extraction	0.77	1.60	1.05	0.98	1.17
Mining and quarrying	0.86	0.98	1.07	0.76	1.08
Support activities for mining and oil and gas extraction	1.27	1.18	1.27	1.02	1.11
Utilities	1.66	1.65	0.82	0.68	1.04
Construction	1.26	1.22	1.05	0.98	1.09
Total manufacturing	1.07	0.99	0.97	1.15	1.07
Food	1.10	1.10	1.01	1.02	1.02
Beverage and tobacco	1.01	1.04	0.86	1.15	1.02
Textile and product mills	1.07	1.02	1.05	1.05	1.02
Clothing, leather and allied product	1.17	1.13	1.03	0.93	1.03
Wood product	1.06	1.09	0.90	1.10	1.02
Paper	0.93	0.79	0.75	1.12	1.12
Printing	1.28	1.36	0.94	1.02	1.04
Petroleum and coal	1.40	1.10	0.95	0.96	1.18
Chemical	0.91	0.88	0.93	1.58	1.09
Plastics and rubber	1.10	1.11	0.96	1.02	1.02
Non-metallic mineral	1.00	1.08	0.96	0.98	1.03
Primary metal	0.91	0.96	1.04	0.93	1.07
Fabricated metal	1.15	1.01	1.00	0.98	1.02
Machinery	1.06	1.08	1.07	1.02	1.05
Computer and electronics	1.61	0.88	1.62	1.18	1.12
Electrical equipment	1.17	0.92	1.07	1.06	1.07
Transportation equipment	0.90	0.91	0.80	1.20	1.02
Furniture	1.09	1.24	0.92	0.98	1.00
Miscellaneous manufacturing	1.17	1.06	1.10	0.98	1.06
Wholesale trade	1.27	1.16	1.01	1.04	1.07
Retail trade	1.14	1.15	0.97	1.05	1.03
Transportation and warehousing	2.18	1.75	0.94	0.97	1.11
Information and cultural industries	1.00	1.03	1.01	0.74	1.07
Finance, insurance, real estate, and company management	1.45	1.24	0.95	1.00	1.08
Professional, scientific and technical services	1.23	1.15	0.99	1.01	1.16
Administrative, waste management	1.21	1.19	1.04	1.10	1.07
Arts, entertainment and recreation	1.34	1.14	0.83	0.97	1.11
Accommodation and food services	1.16	1.13	0.99	0.96	1.02
Other services except public administration	1.29	1.21	0.98	1.04	1.05
Total business sector	1.24	1.18	0.99	1.02	1.08

Note: The years selected are the peaks and troughs of real GDP line in Canada. The capacity utilization at the industry level is aggregated from the firm level, weighted by gross output.
Source: Authors' own compilations based on the micro dataset for this study.

Table 4: Official Capacity Utilization for the Non-Agriculture Goods Producing Industries

Industry	2000	2001	2009	2017	**Average 2000-2017**
Forestry and logging	1.11	1.11	0.88	1.11	1.13
Oil and gas extraction	1.13	1.08	0.98	1.04	1.06
Mining and quarrying	1.13	1.13	0.83	1.01	1.06
Construction	1.15	1.17	1.07	1.16	1.17
Food	1.08	1.08	1.09	1.05	1.06
Beverage and tobacco	1.05	1.05	0.96	1.00	0.99
Textile and product mills	1.10	1.04	0.86	1.02	0.99
Clothing, leather and allied product	1.09	1.04	0.87	1.10	0.99
Wood product	1.13	1.09	0.81	1.10	1.09
Paper	1.22	1.18	1.09	1.16	1.18
Printing	1.06	1.02	0.97	0.99	0.97
Petroleum and coal	1.23	1.26	1.04	1.19	1.14
Chemical	1.06	1.07	0.94	1.05	1.05
Plastics and rubber	1.12	1.11	0.90	1.01	1.07
Non-metallic mineral	1.06	1.07	0.90	0.87	1.03
Primary metal	1.21	1.15	1.01	1.06	1.13
Fabricated metal	1.12	1.06	0.86	0.94	1.04
Machinery	1.11	1.04	0.93	1.01	1.06
Computer and electronics	1.29	0.96	1.11	1.05	1.10
Electrical equipment	1.23	1.01	0.99	1.01	1.03
Transportation equipment	1.18	1.14	0.89	1.12	1.12
Furniture	1.13	1.07	0.92	1.01	1.06
Miscellaneous manufacturing	1.11	1.07	1.01	0.99	1.07
Total Manufacturing	1.14	1.09	0.96	1.04	1.07

Source: Statistics Canada Table 16-10-0109-01.
Note: Official capacity utilization is normalized to the average of CU1 and CU2 for manufacturing over 2000-2017.

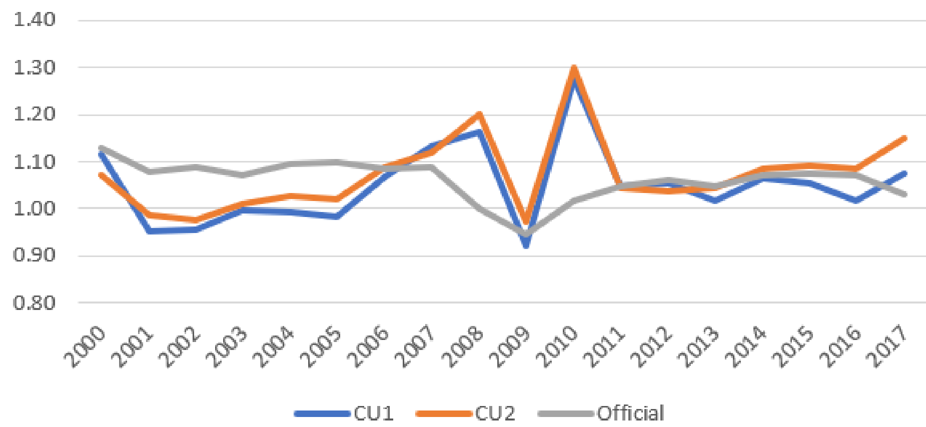
sector. The three measures are broadly similar. For example, during the economic downs in 2001 and 2008-2009, all measures fell substantially. However, our measures are more volatile than the official measure.

Correlation with Output, Employment, and Investment Growth

Measured capacity utilization should generally reflect the change in business conditions. To provide some evidence, we also associate the measured capacity utilization indicators with growth in output (value added), employment (number of employees and hours worked), and investment (total investment and investment in machinery & equipment), which is done at the industry level.

In Table 5, we report the correlations for 38 goods and services industries. All correlations are positive. In general, the associations of CU1 with output, employment and investment growth are better than with CU2 at the manufacturing or the business sector level. This suggests that CU1 may be a better measure for capacity utilization than CU2. It should be noted, however, that a higher correlation of a CU measure with output may not necessarily indicate that the CU measure is a better measure of true capacity utilization as output is determined by many factors besides the use of installed capacity. On the other hand, a higher correlation of a CU measure with inputs directly related to installed capacity may indicate that the CU measure a better measure. This is case for CU1 for

Chart 2: Comparison to the Official Capacity Utilization Manufacturing



Note: Official capacity utilization is normalized to the average of CU1 and CU2 for manufacturing over 2000-2017.

the manufacturing sector as its correlations with growth in total investment and investment in M&E are significantly higher than for CU2. However, at the detailed industry level, we do not observe large differences between CU1 and CU2 as the correlations with output growth, employment growth, and investment growth are generally similar for CU1 and CU2.

In Table 5, we also include the correlations for official CU, which are only available for 22 goods producing industries. The correlation results are mixed for the CU measures. Despite a similar broad trend as shown in Chart 2, the correlations between our CU measures and the official CU is negative, especially for CU2. The correlation of capacity utilization with growth in output and employment/hours worked is higher for official CU than for CU1 or CU2. But, for the manufacturing sector, the correlations with growth in total investment and investment in M&E are significantly higher for CU1 than official CU or CU2.

Correlation is a simple indicator for possible relationship between two variables, without controlling for the effects from other factors. To validate our CU measures related to productivity estimation and the role in evaluation of policy instruments, we need to isolate the effects of other factors. To this end, in the remaining two sections, we conduct an econometric analysis.

Capacity Utilization and Measured Multifactor Productivity

In this section, we assess the role of controlling for capacity utilization in explaining variations of measured productivity. To this end, we compare the smoothness of measured productivity with and without controlling for capacity utilization. We use the mean square error to measure smoothness. The basic production regression model with capacity utilization is:

$$\ln(Y_{i,t}) = \alpha_0 + \alpha_L \ln L_{i,t} + \alpha_K \ln K_{i,t}$$
$$+\alpha_M \ln M_{i,t} + \beta_1 \ln U_{i,t} + \sum_{j=2}^{s} \beta_j Z_{i,j,t} + \varepsilon_{i,t} \tag{14}$$

where $Y_{i,t}$ is gross output; $L_{i,t}$, $K_{i,t}$, and

Table 5: Industry-Year Correlation between Measured Capacity Utilization and Economic Performance Indicators, 2000-2017

Aggregate Manufacturing Sector

	CU1	CU2	OCU	VA	L	H	I	ME
CU Under Hypothesis 1 (CU1)	1.00							
CU Under Hypothesis 2 (CU2)	0.94	1.00						
Official CU (OCU)	-0.08	-0.24	1.00					
Value Added Growth (VA)	0.38	0.25	0.65	1.00				
Employment Growth (L)	0.17	0.09	0.63	0.89	1.00			
Hours Worked Growth (H)	0.30	0.21	0.62	0.91	0.98	1.00		
Total Investment Growth (I)	0.52	0.38	0.31	0.69	0.59	0.63	1.00	
M&E Investment Growth (ME)	0.44	0.36	0.37	0.60	0.55	0.59	0.93	1.00

Aggregate Business Sector

	CU1	CU2	VA	L	H	I	ME
CU Under Hypothesis 1 (CU1)	1.00						
CU Under Hypothesis 2 (CU2)	0.98	1.00					
Value Added Growth (VA)	0.49	0.44	1.00				
Employment Growth (L)	0.40	0.36	0.84	1.00			
Hours Worked Growth (H)	0.37	0.32	0.82	0.95	1.00		
Total Investment Growth (I)	0.52	0.53	0.70	0.65	0.68	1.00	
M&E Investment Growth (ME)	0.44	0.40	0.72	0.71	0.71	0.94	1.00

Goods and Service Industries (38 industries)

	CU1	CU2	VA	L	H	I	ME
CU Under Hypothesis 1 (CU1)	1.00						
CU Under Hypothesis 2 (CU2)	0.94	1.00					
Value Added Growth (VA)	0.13	0.10	1.00				
Employment Growth (L)	0.11	0.12	0.63	1.00			
Hours Worked Growth (H)	0.11	0.12	0.66	0.97	1.00		
Total Investment Growth (I)	0.08	0.10	0.22	0.22	0.22	1.00	
M&E Investment Growth (ME)	0.04	0.06	0.22	0.23	0.23	0.80	1.00

Non-Agriculture Goods Industries (22 industries)

	CU1	CU2	OCU	VA	L	H	I	ME
CU Under Hypothesis 1 (CU1)	1.00							
CU Under Hypothesis 2 (CU2)	0.94	1.00						
Official CU (OCU)	0.18	0.17	1.00					
Value Added Growth (VA)	0.15	0.12	0.40	1.00				
Employment Growth (L)	0.12	0.14	0.32	0.63	1.00			
Hours Worked Growth (H)	0.12	0.14	0.33	0.64	0.98	1.00		
Total Investment Growth (I)	0.10	0.14	0.20	0.06	0.10	0.11	1.00	
M&E Investment Growth (ME)	0.03	0.07	0.21	0.03	0.09	0.09	0.79	1.00

Note: There is no official capacity utilization estimates for service industries.
Source: Authors' own compilations based on Statistics Canada Table 16-10-0109-01 and the micro dataset for this study.

$M_{i,t}$ are the inputs representing labour, capital and intermediate inputs, respectively ; U_{it} is capacity utilization; Z_i is a set of control variables such as foreign ownership, firm age, and industry-year specifics; and $\varepsilon_{i,t}$ is an error term.

In the regression, we control for firm age as it takes time for new entrants young firms to learn their markets, establish supplier and distribution networks and develop scale. Thus, they are generally less efficient than established firms. To reflect this, we introduce a dummy for young firms, which takes 1 for firms being not more than 5 years and 0 otherwise. This is based on Liu and Tang (2017). They show that entrants take about 5 years to become as productive as incumbents.

We also control for foreign ownership as it is well established that foreign controlled firms in Canada are on average more productive than Canadian controlled firms in Canada. Finally, we introduce industry-year dummies to capture any effect at the industry level, including technological progress and changes in competition.

Estimation and Discussion

To ensure robust results, each regression model is estimated by two different methodologies. First, we assume robust standard error when ordinary least square estimation (OLS) is used. Robust standard error is a common and effective way to deal with heteroscedasticity, minor problems associated with the lack of normality, or some observations that exhibit large influence. Second, we estimate the model with firm fixed effects, which concerns only within-firm variation and ignores between-firm changes. The design aims to control for individual firm fixed effects. It also corrects potential miss-specifications of the regression model due to missing time-invariant variables, and addresses the endogeneity problem when a component of the productivity shock is fixed over time at the firm level. To ensure robust results, each regression model is estimated by two different methodologies.

Our sample contains many small firms. The data for small firms tend to be noisy. So we limit our estimation to firms with average number of employees being 10 or more.[11]

The regression results based on the whole sample for firms with average number of employees being 10 or more are reported in Table 6. In general, the results based on OLS assuming robust standard error and those with firm fixed effects are fairly similar. As expected, labour, capital, intermediate inputs, and foreign ownership are found to be positive and statistically significant while young firms are found to be less productive.

Important for this article are the estimates related to capacity utilization. For CU1, the coefficients are positive and sta-

11 The possibility that the effect of capacity utilization in economic downturns differs from that in normal times as production capacity is mostly underutilized. To capture this, we divide our sample into two groups: normal times and downturn times. The down times contains two economic downturns: the dotcom bust 2001-2002 and the Great Financial Crisis 2008-2009. The normal times is the rest years in our sample 2000, 2003-2007, and 2010-2017. However, the estimation results with the two sub-samples are fairly similar to those with the whole sample.

Table 6: The Estimation of the Production Function With and Without CU

	Robust standard error			Firm Fixed effects		
	Without CU	With CU1	With CU2	Without CU	With CU1	With CU2
Labour (in log)	0.249***	0.247***	0.241***	0.265***	0.250***	0.241***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Tangible Capital (in log)	0.049***	0.055***	0.042***	0.040***	0.112***	0.016***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Intermediate inputs (in log)	0.706***	0.701***	0.717***	0.605***	0.564***	0.644***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Foreign ownership dummy	0.100***	0.098***	0.095***	0.217***	0.213***	0.200***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Young firm dummy	-0.033***	-0.033***	-0.031***	-0.034***	-0.036***	-0.032***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Capacity utilization		0.034***	-0.071***		0.088***	-0.062***
		(0.000)	(0.000)		(0.000)	(0.000)
Industry-year dummies	Yes	Yes	Yes			
Year dummies				Yes	Yes	Yes
Firm-fixed effects				Yes	Yes	Yes
Number of observations	2978996	2978996	2978996	2978996	2978996	2978996
R-square	0.95	0.95	0.95			
R-square, within				0.85	0.86	0.85
R-square, between				0.94	0.94	0.94

Note: P-values are in parenthesis. "***" denotes significance at the 1% level.

tistically highly significant, indicating that firm production and capacity utilization are positively correlated, that is, higher capacity utilization means higher production. We also observe that with CU1, the relationship between output and capital stock becomes stronger. This suggests that after controlling for capacity utilization, output is more sensitive to capital stock. So, CU1 serves the purpose.

In contrast, the results on CU2 are surprising. First, the coefficient is negative. Second, after controlling for CU2, the relationship between output and capital (or labour) becomes weaker. Thus, after controlling for the effects of other factors, CU2 has a negative relationship with output, which cannot be explained in an economic sense. For those reasons, we reject hypothesis 2.

In the remaining of this paper, we continue to validate the importance of controlling for capacity utilization for CU1.

Productivity Dispersion Before and After Controlling for Capacity Utilization

Firms with lower capacity utilization are likely to be less productive when the measured productivity is estimated with all installed capacity. Controlling for capacity utilization reduce productivity dispersion and the productivity gap between frontier firms and laggards. In Table 6, we report the mean square error (MSE) of multifactor productivity (MFP) by industry, with or without controlling for capacity utilization (CU1).

According to Table 7, without controlling for capacity utilization, productivity dispersion varies significantly across indus-

Table 7: Mean Squared Error of Measured MFP With and Without Capacity Utilization

Industry	2000-2017			2001-2002, 2008-2009		
	Capacity U			Capacity U		
	No	Yes	A/B	No	Yes	C/D
	A	B		C	D	
Forestry and logging	1.08	1.00	1.07	1.12	1.06	1.05
Fishing, hunting and trapping	1.94	1.87	1.04	1.21	1.15	1.05
Support activities for agriculture and forestry	1.14	1.10	1.04	0.91	0.86	1.06
Crop and animal production	4.24	4.15	1.02	3.41	3.41	1.00
Oil and gas extraction	5.06	4.95	1.02	5.16	5.11	1.01
Mining and quarrying	2.52	2.52	1.00	2.10	1.91	1.10
Support activities for mining and oil and gas extraction	2.14	2.12	1.01	2.53	2.52	1.01
Utilities	4.03	3.94	1.02	4.71	4.89	0.96
Construction	1.22	1.16	1.05	1.24	1.19	1.04
Food	0.75	0.74	1.01	0.59	0.57	1.03
Beverage and tobacco	1.06	1.00	1.07	0.45	0.44	1.03
Textile and product mills	0.70	0.67	1.04	1.62	1.52	1.06
Clothing, leather and allied product	0.76	0.74	1.04	1.14	1.08	1.05
Wood product	0.49	0.48	1.02	0.54	0.54	1.00
Paper	0.35	0.33	1.04	0.09	0.09	1.00
Printing	0.63	0.62	1.01	0.54	0.56	0.96
Petroleum and coal	1.09	1.13	0.96	1.53	1.64	0.93
Chemical	1.04	1.02	1.02	0.53	0.52	1.01
Plastics and rubber	0.64	0.61	1.05	0.42	0.42	1.01
Non-metallic mineral	0.47	0.44	1.06	0.31	0.31	1.02
Primary metal	0.48	0.46	1.05	0.20	0.20	0.99
Fabricated metal	0.78	0.75	1.04	0.98	0.93	1.05
Machinery	1.01	0.97	1.03	1.04	1.02	1.01
Computer and electronics	1.28	1.21	1.06	1.45	1.39	1.04
Electrical equipment	0.82	0.77	1.06	0.44	0.45	0.98
Transportation equipment	1.43	1.34	1.07	0.35	0.34	1.01
Furniture	0.48	0.46	1.05	0.24	0.24	1.01
Miscellaneous manufacturing	0.66	0.65	1.02	0.74	0.73	1.02
Wholesale trade	1.00	0.96	1.04	0.93	0.92	1.02
Retail trade	0.51	0.48	1.05	0.43	0.41	1.04
Transportation and warehousing	0.92	0.90	1.02	0.91	0.90	1.00
Information and cultural industries	2.70	2.59	1.04	2.78	2.64	1.05
Finance, insurance, real estate, and company management	8.82	8.47	1.04	7.82	7.58	1.03
Professional, scientific and technical services	3.77	3.59	1.05	3.70	3.52	1.05
Administrative, waste management	3.06	2.94	1.04	2.96	2.85	1.04
Arts, entertainment and recreation	1.68	1.62	1.03	1.44	1.40	1.03
Accommodation and food services	0.58	0.55	1.06	0.62	0.60	1.03
Other services except public administration	1.18	1.14	1.04	1.19	1.14	1.04
Total	2.28	2.18	1.04	2.16	2.09	1.04

Source: Authors' own compilation based on results from columns (1) and (2) in Table 5 with robust standard error and under CU1 tries from 0.35 in the paper manufacturing industry to 8.82 in finance, insurance, real estate and company management. After, controlling for capacity utilization, the dispersion was significantly reduced, about 4 per cent on average. The reduction is mostly significant in forestry and logging, beverage and tobacco, and transportation equipment.

In Table 7, we also single out productivity dispersion in economic downturns 2001-2002 and 2008-2009. Interestingly, the productivity dispersion during downturns is very similar to average for the whole sample period. We also observe that the reduction in dispersion after controlling for capacity utilization in downturns is very similar to that for the whole sample period. Notably, the largest reduction during downturns is in mining and quarrying.

Capacity Utilization and the Economic Performance of Investments in R&D and ICTs

In this section, we use the micro database to demonstrate whether or not controlling capacity utilization is important in evaluating the economic impact of investments in R&D and ICTs. Our basic regression model is following:

$$\ln(Y_{i,t}) = \alpha_0 + \alpha_L \ln L_{i,t} + \alpha_K \ln K_{i,t} + \alpha_M \ln M_{i,t} + \beta_1 \ln U_{i,t} + \sum_{j=2}^{s} \beta_j Z_{i,j,t} + \varepsilon_{i,t}, \tag{15}$$

The regression model above extends regression model (14) by adding two variables: R&D intensity and ICT intensity, which are defined as the ratios of R&D stock to capital and ICT stock to capital, respectively. Basically, here we would like to see if firms with high R&D and ICT investments are doing better in productivity than firms with lower R&D and ICT investments.

The estimation results with or without controlling for capacity utilization (CU1) is reported in Table 8. The estimation shows that controlling for capacity utilization substantially improves the significance of ICT on firm performance. Under the OLS estimation, ICT being insignificant in the absence of capacity utilization becomes highly significant with the presence of the capacity utilization. Under the estimation with fixed effects, the estimated coefficient on ICT doubles after introducing the capacity utilization variable. The effect of R&D on firm performance is highly significant. However, the size of the effect is not influenced by the presence of capacity utilization. This may be because ICT investments are more related to installed capacity than R&D investments.

Conclusions

Firms invest production capacity to meet expected long-term demand. This is often a long process as design, equipment purchase, and installation take time. In other words, capacity cannot be changed in a short time. However, in reality, production in a particular year often deviates from expected, and thus the use of production capacity may not be at the capacity level. When actual demand is more than expected, firms may choose to use overtime

Table 8: The Estimation of the Production Function With and Without CU

	Robust standard error		Firm Fixed effects	
	Without CU	With CU1	Without CU	With CU1
Labour (in log)	0.248***	0.246***	0.266***	0.251***
	(0.000)	(0.000)	(0.000)	(0.000)
Tangible Capital (in log)	0.047***	0.054***	0.039***	0.112***
	(0.000)	(0.000)	(0.000)	(0.000)
Intermediate inputs (in log)	0.705***	0.700***	0.604***	0.562***
	(0.000)	(0.000)	(0.000)	(0.000)
Foreign ownership dummy	0.103***	0.101***	0.217***	0.213***
	(0.000)	(0.000)	(0.000)	(0.000)
Young firm dummy	-0.033***	-0.033***	-0.034***	-0.035***
	(0.000)	(0.000)	(0.000)	(0.000)
Capacity utilization		0.034***		0.090***
		(0.000)		(0.000)
R&D Intensity (in log)	0.009***	0.009***	0.003***	0.003***
	(0.000)	(0.000)	(0.000)	(0.000)
ICT intensity (in log)	-5.8e-5	1.9e-4***	0.002***	0.004***
	(0.316)	(0.001)	(0.000)	(0.000)
Industry-year dummies	Yes	Yes		
Year dummies			Yes	Yes
Firm-fixed effects			Yes	Yes
Number of observations	2978996	2978996	2978996	2978996
R-square	0.95	0.95		
R-square, within			0.85	0.86
R-square, between			0.94	0.94

Note: P-values are in parenthesis. "***" denotes significance at the 1% level.

and the use of capacity will be above the normal. Similarly, when demand is lower than expected or when necessary parts are in shortage due to disruptions of global value chains, say, caused by such as the current COVID-19 pandemic, production will be reduced, leading to under utilization of production capacity.

The issue is that productivity is often estimated under the assumption of full production capacity, that is, installed capacity is always used for whatever level of production. Given inputs are not actual used fractions, this leads to under- or overestimation of productivity. To produce a reliable productivity measures, we need to control for capacity utilization in estimating productivity. Unfortunately, capacity utilization is not available at the firm level. To bridge the data gap, this study developed a methodology in estimation capacity utilization at the firm level. The methodology is based on the theory of the firm in terms of profit-maximizing and price-taking. Unlike some proxies used in the literature, it is exogenous to productivity shocks. Importantly, it is fairly practical to estimate.

We tested two hypotheses, and showed that the hypothesis that labour and intermediate inputs are fully adjustable in the short term and capital cannot be adjusted in the short term is more appropriate. Controlling for capacity utilization based on the hypothesis increased the relationship between capital and output. It also reduced variation in measured productivity across firms, lessened the divergence in productivity between frontiers and laggards. Finally, we found that ICT investments that are insignificant in firm performance before controlling for capacity utilization became highly significant after controlling for capacity utilization.

With micro data being increasingly available, research using micro data to measure productivity or to evaluate policy programs has become increasingly common. The approach to analysis often relies on the estimation of a production function. This study showed that to produce a more reliable estimate, it is important to controlling for capacity utilization in estimation. It leads to more reliable productivity estimates or correct conclusion about the effect of some investments on firm performance, which has important implications for policy developments.

References

Baldwin, J. R., W. Gu and B. Yan (2007) "User Guide for Statistics Canada's Annual Multifactor Productivity Program," Statistics Canada Research Paper, Catalogue no. 15-206-XIE, No. 14.

Baldwin, J. R., W. Gu and B. Yan (2013) "Export Growth, Capacity Utilization, and Productivity Growth: Evidence from the Canadian Manufacturing Plants," *Review of Income and Wealth*, Vol. 59, No. 4, pp. 665-688.

Basu, S. (1996) "Pro-cyclical Productivity: Increasing Returns or Cyclical Utilization?" *Quarterly Journal of Economics* Vol. 111, No. 3, pp. 719–751.

Basu, S. and J. G. Fernald (2001) "Why is Productivity Procyclical? Why do We Care?" in *New Development in Productivity Analysis*, edited by C. R. Hulten, E. R. Dean, and M. J. Harper, pp. 225-302 , University of Chicago Press, Chicago.

Basu, S., J. Fernald and M. Kimball (2006) "Are Technology Improvements Contractionary?" *American Economic Review*, Vol. 96, No. 5, pp. 1418-1448.

Berndt, E. R. and M. A. Fuss (1986) "Productivity Measurement with Adjustments for Variations in Capacity Utilization and Other Forms of Temporary Equilibrium," *Journal of Econometrics*, Vol. 33, pp. 7–29.

Berndt, E. R. and M. A. Fuss (1989) "Economic Capacity Utilization and Productivity Measurement for Multi-product Firms with Multiple Quasi-fixed Inputs," NBER Working Paper, No. 2932.

Burnside, C., M. Eichenbaum, and S. Rebelo (1995) "Capital Utilization and Returns to Scale," in *NBER Macroeconomics Annual 1995*, edited by B. S. Bernanke and J. J. Rotemberg, pp. 67-110, MIT Press, Cambridge.

Corrado, C. and J. Mattey (1997) "Capacity Utilization," *Journal of Economic Perspectives*, Vol. 11, No. 1, pp. 151-167.

Diewert, W. E. (2001) "Measuring the Price and Quantity of Capital Services Under Alternative Assumptions," Department of Economics Discussion Paper, No. 01-24, University of British Columbia.

Jorgenson, D. W. and Z. Griliches (1967) "The Explanation of Productivity Change," *Review of Economic Studies*, Vol. 34, pp. 249–283.

Gu, W. and W. Wang (2013) "Correction for Variations in Capacity Utilization in the Measurement of Productivity Growth: A Nonparametric Approach," *Journal of Economic and Social Measurement*, Vol. 38, No. 4, pp. 347-369.

Hulten, C. R. (1986) "Productivity Change, Capacity Utilization, and the Sources of Productivity Growth," *Journal of Econometrics*, Vol. 33, pp. 31–50.

Hulten, C. R. (2009) "Growth Accounting," NBER Working Paper, No. 15341.

Klein, L. R. and V. Long (1973) "Capacity Utilization: Concept, Measurement, and Recent Estimates," Brookings Papers on Economic Activity, No. 3, pp. 743-763.

Liu, H. and J. Tang (2017) "Age-productivity Profiles of Entrants and Exits: Evidence from Canadian Manufacturing," *Structural Change and Economic Dynamics*, Vol. 40.

Solow, R.M. (1957) "Technical Change and the Aggregate Production Function,"*Review of Economics and Statistics* Vol 39, No. 3, pp. 312–320.

Statistics Canada (2022) "Industrial Capacity Utilization Rates (ICUR) Methodology," Manuscript, Statistics Canada.