The Quarterly Review of Economics and Finance 67 (2018) 191–218

Contents lists available at ScienceDirect

The Quarterly Review of Economics and Finance

journal homepage: www.elsevier.com/locate/qref

Real effects of working capital shocks: Theory and evidence from micro data☆

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ARTICLE INFO

Article history:
Received 6 November 2016
Received in revised form 29 June 2017
Accepted 2 July 2017
Available online 21 July 2017

JEL classification:
D92
E44
G32
O47

Keywords:
Working capital
Financial friction
Capacity utilization
Misallocation
TFP

ABSTRACT

Our study investigates the real consequences of variations in the first and second moments of working capital requirement (WCR) in the presence of financial frictions. We introduce a theoretical link from imperfect information about WCR to firms' performance. Firms choose non-prepaid factors of production with uncertainty about required prepayments, where their access to credit is constrained by collateral. After realization, firms with higher WCR may face financial constraints. This uncertainty influences their demand for inputs, albeit risk-neutrality. Unable to employ the projected level of prepaid input, constrained firms encounter capacity underutilization, leading to misallocation of factors. Aggregate productivity and output, will thus be deteriorated during credit contraction due to higher inefficiency. Empirical assessment of our findings, using the "Annual Survey of Iranian Manufacturing Enterprises," shows that higher requirement for working capital tightens firms' hired prepaid inputs, production, and capacity utilization. Furthermore, firms with more uncertain working capital will choose a lower level of production. These results are especially scaled up, when firms face financial constraints.

1. Introduction

Firms require working capital to overcome the time mismatch between payments and income, which introduces working capital finance as a complementary channel to connect the real and financial sectors. Having considered the size[1] and the role of working capital loans in the continuity of the firm's activities, we would expect that the rate, size and ease of access of these loans have significant impact on production. This channel is specifically observable during widespread changes in loan conditions, e.g. credit contractions when the production level of the firms with higher working capital requirement (WCR) declines more strongly and persistently.[2]

The main reported mechanism activated by WCR is the change of the inputs' relative price. The interest rate of working capital loan and the shadow price of credit for constrained firms are two main sources that affect both the composition of inputs and the level of production. The common assumption in the current literature is that, firms are certain about their WCR. This is in spite of the fact that determinants of the firms' cash inflows and outflows, e.g. unexpected changes in prices, trade credit conditions, and production process, alter the realized WCR. To the best of our knowledge, none of the theoretical and empirical aspects of the real consequences of uncertainty about working capital has been studied yet. While the main part of the literature emphasizes the first order impacts of working capital

☆ This paper is part of Amineh Mahmoudzadeh Ph.D. thesis at Graduate School of Management and Economics, Sharif University of Technology. The authors would like to thank Arash Alavian, Razieh Zahedi, S. Ali Madanizadeh, Amir Kermani, and Asghar Shahmoradi for their constructive comments, and particularly, the reviewers for their insightful comments on an earlier version of this article. The authors remain solely responsible for the content. Farhad Nili acknowledges that the views expressed here are authors' opinions and do not reflect views of the World Bank Group and its Board of Executive Directors.

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1 According to Bae and Goyal (2009), investment and WCR are the two most important goals of loan demands with equal weights of 44%.

2 Studies by Raddatz (2006), Fernandez-Corugedo, McMahon, Millard, and Rachel (2011), Claessens, Tong, and Wei (2012), and Schwartzman (2014) provide empirical examples.

https://doi.org/10.1016/j.qref.2017.07.004
1062-9769/

requirement activated by changes in the relative price of inputs, this paper concentrates on the real consequences of variations in the first and second moments of WCR when there are financial frictions.

We introduce a complementary mechanism through which uncertainty about WCR affects production in association with financial frictions. We argue that not only the quantity and composition of inputs vary due to the firm's requirement for prepayments, but also the capacity utilization at the firm level, and subsequently the productivity at the aggregate level are affected by WCR. In our model, where firms choose the prepaid factor under uncertainty about WCR, they may confront credit ceiling. This activates the following two mechanisms, which influence firms' decisions about hiring inputs and production: first, the probability of being financially constrained which lowers the ex-ante hired level of firms' non-prepaid inputs and consequently their production through the *uncertainty effect*. This is specifically observable during deterioration of the financial market efficiencies and higher working capital uncertainties (WCU). The mentioned effect introduces a new link from financial sector to total output despite the risk-neutrality of the firms. The second mechanism, named as the *binding effect*, is associated with the firms that are constrained and hence are unable to employ their required level of prepaid inputs to utilize their projected capacity. This mechanism activates after realization of WCR. This novel impact of WCR on ex post utilization rate of non-prepaid input is referred as an efficiency wedge,[3] which is more important in explaining business cycles compared to other wedges, according to Chari, Kehoe, and McGrattan (2007).

These effects shed light on financial origins of misallocation. Our study belongs to the growing literature that explores the role of financial frictions on the allocation of resources across firms. Gilchrist et al. (2013), Meza, Pratap, and Urrutia (2016), and Uras (2014) describe the roots of misallocation when financial frictions alter firms' access to the working capital loan. In these papers, heterogeneity among firms originates from financial market conditions, e.g., lending rate and access to loan. Though in ours, misallocation initiates from heterogeneity of WCR, a new complementary source that researchers have not identified it yet.

Although theoretical links are similar in developed and developing countries, owing to their institutional conditions (lesser availability of trade credit, severity of financial frictions, and shallower financial markets) firms in developing countries, *ceteris paribus*, need more working capital (Chan, 2014). Thus, we expect a stronger real impact of working capital in developing countries like Iran. After constructing a theoretical model, we estimate the reduced form equations of our model to illustrate the real impacts of working capital when its first and second moments change. Testing this idea introduces challenges associated with mapping the theoretical concepts with empirical variables, especially we had to construct prompt indices for WCR, WCU and being financially constrained regarding to the available data and endogeneity problem.

To measure the impacts of WCR on firms' financial positions, hired level of labor and materials, production, and capacity utilization in a developing economy, we resort to firm-level data of Iran. Our rich newly introduced "*Annual Survey of Iranian Manufacturing Enterprises*" database, a panel from 2005 to 2011, covers more than 12,000 enterprises with 70–80% of value-added of the manufacturing sector in Iran. This database, containing the price and quantity of outputs and detailed information about inputs of individual enterprises, enables us to assess empirically our theoretical findings.

Our results, in line with our theoretical prediction, specify that requirement for working capital, shrinks firms' hired prepaid input, e.g. labor and raw material, production, and capacity utilization, especially when they are financially constrained. Additionally, we show that WCU reduces firms' production. These outcomes are robust to changes in the definition of performance indices, explanatory variables, WCR and WCU, and classification of financially constrained firms as well as methods of estimation.

The rest of the paper proceeds as follows. We sketch a theoretical model for production under imperfect financial markets and firm's uncertainty about WCR. We, then, estimate empirical merit of the model in Section 3, followed by robustness test of the results. Section 4 concludes the paper.

2. Theoretical model

The setup that we develop in this section highlights channels through which uncertainty about working capital requirement transmits to the real economy in the presence of incomplete financial markets. To this end, we build a model where heterogeneous firms face incomplete information about WCR. We then investigate the real effects of changes in financial market conditions and information content of WCR.

Consider an economy comprised of a representative bank and a continuum of competitive firms along the unit interval. Firms are risk-neutral and have no access to savings and internal finance resources. They own a Cobb–Douglas technology with decreasing return to scale[4] and two inputs of production, one, for example, labor (h), as a prepaid input with price w, and capital (k) as a non-prepaid input with price r. Firms are price-takers in both input markets.[5]

The requirement for working capital originates from a time mismatch between firms' payments and revenues, which consists of the time period to access inputs, produce, sale, and receive the receivables minus the time period to pay for the payables. To model WCR, we match this time interval with the share of inputs' prepayments. As an example, a 2-month time interval for a firm is equal to a necessity for prepayment of one-sixth of its costs. Consequently, events that unexpectedly change the timing and values of cash inflows and outflows, variation in prices, trade credit contracts, and the production process are sources of change in WCR and WCU.

The variation in WCR is ex-post to hiring some of the inputs like capital, including machinery and buildings, considered as non-prepaid inputs in the model. By naming them as non-prepaid, we mean that payments for these inputs are not influenced by changes in the WCR. However, the unexpected changes in WCR influence a firm's decision about those inputs, which are recruited gradually during the production process, for example, labor and raw materials. Firms with limited access to finance to enable operating at full capacity decrease their capital utilization, hoard their employed human capital, and slacken their hiring of new employment and purchases of raw materials.

[3] The difference between marginal cost and marginal product as defined by Chari et al. (2007).

[4] Like Midrigan and Xu (2014) and Gilchrist et al. (2013), Gilchrist, Sim, and Zakrajšek (2014), decreasing returns may result from the managerial span of control or, alternatively, monopolistic competition in an environment with Dixit–Stiglitz preferences over heterogeneous goods.

[5] This is a common assumption in the literature of misallocation of inputs, e.g., Hsieh and Klenow (2009), Gilchrist et al. (2013), Uras (2014), and Meza et al. (2016).

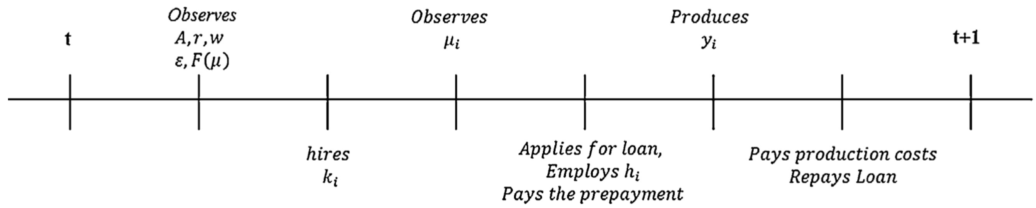

Fig. 1. Timing of the events.

These inputs are considered as being prepaid. For simplicity to follow the model, we label the first category as capital and the second as labor.

Working capital as the only source of ex-ante heterogeneity across firms is demanded because a part of the wage bill must be paid prior to the revenue realization. Thus, firm i finances the prepaid portion of wage bill (μ_i) by external funds. Since μ_i is unknown at the onset of the inputs' market, it acts as an idiosyncratic shock with a commonly known cumulative distribution function, $F(\mu_i)$.

To finance working capital, firms borrow intra-period loans from the bank. To highlight the underutilization effect, we eliminate the direct impact of interest rates on the relative price of inputs[6]; and like Jermann and Quadrini (2012), we assume that loans are interest-free. The bank has unlimited access to external funds and confronts no borrowing constraint. Owning to financial frictions caused by the probability of default, illiquidity of collaterals, or regulations on loan to value ratio, the ability to borrow is restricted by the limited enforceability of debt contracts. Therefore, the firms must provide collateral in the form of current period output.[7]

The fraction of output that a bank accepts as collateral ($0 \le \varepsilon \le 1$) represents credit market efficiencies. Thus, ε is a parameter that governs the strength of the borrowing constraint. Various values of ε embodies degrees of efficiency of the financial markets, e.g., $\varepsilon = 1$ refers to a perfect financial market, and $\varepsilon = 0$ indicates the case where it is completely shut down. Consequently, unexpected changes in ε represent shocks in financial market conditions.

At the beginning of each period, firms have common knowledge about the input prices (w and r), aggregate technology level (A), degree of efficiency in the financial market (ε), and cumulative distribution function of WCR, $F(\mu_i)$.

Fig. 1 depicts the sequence of events for each firm. Using mentioned information, firm i hires capital,[8] which specifies the production capacity. After closing the capital market, it then observes the realized value of WCR, μ_i, and the demands for loan and labor.[9] The hired level of capital is not adjustable because of capital market closeness. The firm borrows working capital (minimum of required and available), pays the prepayment to labor, produces output, receives income, and lastly pays the rest of the labor cost, capital rent, bank loan, and dividend.

Firm i solves problem 1:

$$\max_{k} \quad E\left\{ \begin{array}{ll} \max\limits_{h_i} & Ak_i^{\alpha}h_i^{\beta} - wh_i - rk_i \\ s.t. & \mu_i wh_i \le \varepsilon Ak_i^{\alpha}h_i^{\beta} \end{array} \right. \qquad \alpha + \beta < 1, \quad \mu_i \sim F(\mu) \tag{1}$$

Since the price of the production is normalized to one, wh_i and rk_i represent the real wage bill and capital rent. Furthermore, $\mu_i wh_i$ and $\varepsilon Ak_i^{\alpha}h_i^{\beta}$ represent the demand for the working capital loan and credit ceiling, respectively.

However, a cut-off value for working capital requirement ($\bar{\mu}$) separates firms as constrained or unconstrained based on their access to credit. The cut-off value depends positively on financial market conditions and negatively on the elasticity of production with respect to the prepaid input.[10]

Proposition 1. *Credit constrained firms employ labor less than unconstrained firms do.*

Proof. The higher WCR raises the shadow price of credit, which makes labor more expensive because of its stronger dependency on credit. Firms with lower WCR, compared to their cut-off value, employ $h_i = \left[\left(\beta/w\right)Ak^{\alpha}\right]^{1/1-\beta}$ level of labor. Constrained firms,[11] however, employ labor based on their credit limitations, $h_i = \left[\left(\beta/w\right)\left(\bar{\mu}/\mu_i\right)Ak^{\alpha}\right]^{1/1-\beta}$, which is less than the former by $\left[\left(\bar{\mu}/\mu_i\right)\right]^{1/1-\beta}$. □

Considering labor demand as a function of capital, firms maximize their expected profit with respect to capital as follow:

$$\max_{k} \int_{-\infty}^{\bar{\mu}} \left[Ak^{\alpha}\left[\frac{\beta}{w}Ak^{\alpha}\right]^{\frac{\beta}{1-\beta}} - w\left[\frac{\beta}{w}Ak^{\alpha}\right]^{\frac{1}{1-\beta}} - rk \right] dF(\mu_i) + \int_{\bar{\mu}}^{\infty} \left[Ak^{\alpha}\left[\frac{\beta}{w}\frac{\bar{\mu}}{\mu_i}Ak^{\alpha}\right]^{\frac{\beta}{1-\beta}} - w\left[\frac{\beta}{w}\frac{\bar{\mu}}{\mu_i}Ak^{\alpha}\right]^{\frac{1}{1-\beta}} - rk \right] dF(\mu_i) \tag{2}$$

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[6] Adding the price effect to the model strengthens our proposed channel.
[7] Similar to Boissay (2001) and Waters (2013), current period output is used as a proxy for firms' turnover.
[8] This study investigates a complementary mechanism through which working capital causes real effects. To this end, we avoid details of other markets frictions.
[9] The two-phase decision-making is similar to the Putty-Clay model where substitution between capital and labor is feasible based on the ex-ante production technology, but after installation of the capital, the technology is Leontief. This creates a link between capacity utilization and changes in employment and output (Gilchrist & Williams, 1998).
[10] The cut-off value is equal for all firms because of assumed similarities, e.g., all firms experience the same financial market conditions and production functions.
[11] Sun and Wang (2015) show firms spending more on working capital have less money on hand, and face credit constraints.

Eq. (2) gives an optimal level of capital for all firms as

$$k = \left[A\left(\frac{\alpha}{r}\right)^{1-\beta} \left(\frac{\beta}{w}\right)^{\beta} UE^{1-\beta} \right]^{\frac{1}{1-(\alpha+\beta)}}$$

where, $\left[A\left(\frac{\alpha}{r}\right)^{1-\beta} \left(\frac{\beta}{w}\right)^{\beta} \right]^{\frac{1}{1-(\alpha+\beta)}}$ is the hired level of capital in a frictionless economy, and uncertainty effect, UE, equal to $F(\bar{\mu}) + \frac{1}{1-\beta}\int_{\bar{\mu}}^{\infty} \left[\left(\frac{\bar{\mu}}{\mu_i}\right)^{\beta/1-\beta} - \beta\left(\frac{\bar{\mu}}{\mu_i}\right)^{1/1-\beta} \right] dF(\mu_i)$ represents the impact of uncertainty on capital demand. WCU reduces the ex-ante investment of firms in non-prepaid input as compared to a frictionless economy (UE < 1). This indicates that firms may experience capital wedges even when loans are interest-free. Uncertainty effect is raised by an improvement in financial market conditions ($\frac{\partial \mathrm{UE}}{\partial \varepsilon} > 0$) and is intensified with WCU[12] [$\frac{\partial \mathrm{UE}}{\partial \sigma} < 0$, for $\mathrm{F}(\mu) \sim \mathrm{N}(\mathrm{m}, \sigma)$].[13]

Departures from the hypothesis of complete financial markets create a channel through which uncertainty affects firms regardless of their access to finance. Once uncertainty rises, the probability of limited credit constraint increases and input demands and production drop (similar to Arellano, Bai, & Kehoe, 2012). Therefore, without referring to the risk-aversion behavior of the firms, uncertainty may affect production in both micro and macro levels. This inference is compatible with recent trends in the literature. Caldara, Fuentes-Albero, Gilchrist, and Zakrajšek (2016) provide evidences of the large impact of uncertainty shocks on GDP when the shock transmits through the financial channel.

Realizing their access to finance, firms set their production levels via Eq. (3). Proposition 2 investigates responses of production to changes in WCR and financial market conditions:

$$y_i = \begin{cases} \left[A\left(\frac{\alpha}{r}\right)^{\alpha} \left(\frac{\beta}{w}\right)^{\beta} \right]^{\dfrac{1}{1-(\alpha+\beta)}} UE^{\dfrac{\alpha}{1-(\alpha+\beta)}} & \mu_i \le \bar{\mu} \\ \left[A\left(\frac{\alpha}{r}\right)^{\alpha} \left(\frac{\beta}{w}\right)^{\beta} \right]^{\dfrac{1}{1-(\alpha+\beta)}} UE^{\dfrac{\alpha}{1-(\alpha+\beta)}} \left(\frac{\bar{\mu}}{\mu_i}\right)^{\dfrac{\beta}{1-\beta}} & \mu_i > \bar{\mu} \end{cases} \tag{3}$$

Proposition 2

i *Production level declines in constrained firms as their need for working capital rises; however, unconstrained firms' production does not vary with WCR* ($\frac{\partial \mathrm{y_i}}{\partial \mu_\mathrm{i}} \le 0$).

ii *WCU affects negatively and universally, the production level of firms regardless of their access to finance*, ($\frac{\partial \mathrm{y_i}}{\partial \sigma} < 0$, *for* $\mathrm{F}(\mu) \sim \mathrm{N}(\mathrm{m}, \sigma)$).

iii *Regardless of a firm's financial situation, an improvement in financial market conditions increase its production level*, ($\frac{\partial \mathrm{y_i}}{\partial \varepsilon} > 0$). *However, in constrained firms, the impact intensifies with WCR* ($\frac{\partial^2 \mathrm{y_i}}{\partial \varepsilon \partial \mu_\mathrm{i}} \le 0$).

Proof and intuitions. Proof is provided in Appendix A. The intuitions are as follow:

i Having full access to financial markets, unconstrained firms are not affected by idiosyncratic shocks to WCR. However, because of higher shadow price of credit, labor employment and thus capacity utilization decline with WCR in constrained firm[14]:

$$\frac{\partial y_i}{\partial \mu_i} = \begin{cases} 0 & \mu_i \le \bar{\mu} \\ -\dfrac{\beta y_i}{(1-\beta)} \cdot \dfrac{1}{\mu_i} & \mu_i > \bar{\mu} \end{cases} \tag{4}$$

ii Higher WCU increases the likelihood of being constrained, and because of that the expected profit, the hired level of inputs and production decreases among all producers:

$$\frac{\partial y_i}{\partial \sigma} = y_i \cdot \frac{\alpha}{1-(\alpha+\beta)} \cdot \frac{1}{\mathrm{UE}} \cdot \frac{\partial UE}{\partial \sigma} \tag{5}$$

[12] As mentioned by David, Hopenhayn, and Venkateswaran (2014), macroeconomic variables generally fluctuate as result of exogenous shocks. To analyze the effect of uncertainty shocks, we consider changes in the variance rather than in the level of those exogenous variables.

[13] All statements hold true regardless of the distribution function, though the functional form of F must be specified for the part ii. Results also hold true for Pareto distribution. Proofs are available on request.

[14] See Proposition 3 for more details.

iii An improvement in financial market conditions mitigates severity of financial constraint from three paths. Since higher ε decreases the probability of being constrained, expected profit rises and firms increase their capacity by hiring more capital. Besides, fewer numbers of firms confront financial constraint. Moreover, capacity utilization of constrained firms increases resulting from higher access to finance:

$$\frac{\partial y_i}{\partial \varepsilon} = \begin{cases} y_i \cdot \dfrac{\alpha}{1-(\alpha+\beta)} \cdot \dfrac{1}{\mathrm{UE}} \cdot \dfrac{\partial UE}{\partial \varepsilon} & \mu_i \le \bar{\mu} \\ y_i \cdot \left[\dfrac{\alpha}{1-(\alpha+\beta)} \cdot \dfrac{1}{\mathrm{UE}} \cdot \dfrac{\partial UE}{\partial \varepsilon} + \dfrac{1}{1-\beta} \cdot \dfrac{1}{\bar{\mu}} \right] & \mu_i > \bar{\mu} \end{cases} \tag{6}$$

However, not all firms benefit in the same way from improvements in the financial market conditions. A higher ε affects all unconstrained firms equally through the uncertainty effect regardless of their WCR. Since higher WCR increases constrained firms' limitation to use their capacity, the impact of ε on production magnifies in these firms:

$$\frac{\partial^2 y_i}{\partial \varepsilon \partial \mu_i} = \begin{cases} 0 & \mu_i \le \bar{\mu} \\ -\dfrac{\beta}{(1-\beta)} \cdot \dfrac{1}{\mu_i} \cdot \left[\dfrac{\alpha}{1-(\alpha+\beta)} \cdot \dfrac{1}{\mathrm{UE}} \cdot \dfrac{\partial UE}{\partial \varepsilon} + \dfrac{1}{1-\beta} \cdot \dfrac{1}{\bar{\mu}} \right] & \mu_i > \bar{\mu} \end{cases} \tag{7}$$

□

Firms reduce their ex-ante investment in the non-prepaid input when WCU rises. Whereas in response to WCR shocks, they decrease their use of prepaid inputs. However, the main mechanism that introduces heterogeneous production in our study arises because the firms' capacity utilization varies with their access to finance, as mentioned in Proposition 3.

Proposition 3. *Firms' capacity utilization falls with their need for working capital in constrained firms, though it is not affected by WCR in unconstrained ones. As a result, the marginal product of capital and profitability of constrained firms is lower compared to those of unconstrained firms.*

Proof and intuitions. $\bar{y} = Ak^{\alpha}\left[\frac{\beta}{w}Ak^{\alpha}\right]^{\frac{\beta}{1-\beta}}$ shows the projected level of production determined by the level of capital. Although unconstrained firms produce at full capacity, constrained ones cannot, because they are unable to employ enough labor. Therefore, capacity utilization, represented in Eq. (8), varies inversely with WCR:

$$CU_i = \frac{y_i}{\bar{y}} = \begin{cases} 1 & \mu_i \le \bar{\mu} \\ \left(\dfrac{\bar{\mu}}{\mu_i}\right)^{\dfrac{\beta}{1-\beta}} & \mu_i > \bar{\mu} \end{cases} \tag{8}$$

□

The variation of capital (capacity) utilization with financial market conditions, Proposition 3, is documented in the literature. Ottonello (2014) explains that after a financial contraction, capital utilization decreases based on the key assumption that physical capital is traded in a decentralized market with search frictions. Introducing a different source of capacity utilization. We provide a complementary channel through which financial shocks influence capacity utilization because of unexpected changes in the first and second moments of working capital, respectably.

However, the effects are broader than variations in the firm-level performance. The aggregate consequences of binding borrowing constraint influence total production, Y:

$$Y = \left[A\left(\frac{\alpha}{r}\right)^{\alpha}\left(\frac{\beta}{w}\right)^{\beta}\right]^{\dfrac{1}{1-(\alpha+\beta)}} .UE^{\dfrac{\alpha}{1-(\alpha+\beta)}} .BE_Y, \quad BE_Y = F(\bar{\mu}) + \int_{\bar{\mu}}^{\infty} \left(\frac{\bar{\mu}}{\mu_i}\right)^{\dfrac{\beta}{1-\beta}} dF(\mu) \tag{9}$$

Affected by uncertainty and aggregate binding effects, the aggregate production level is lower compared with a frictionless economy, where the difference is decreasing by an improvement in financial market status, and less uncertainty about working capital.

The above expression asserts that interaction of WCR and financial friction affects aggregate production not only because of the lower levels of prepaid inputs, but because of the capacity utilization and input allocations among firms. Accordingly, the aggregate TFP (ATFP) is affected resulting from the lower efficiency of utilizing inputs among firms:

$$ATFP = \frac{Y}{K^{\alpha}H^{\beta}} = A \times \frac{F(\bar{\mu}) + \displaystyle\int_{\bar{\mu}}^{\infty} \left(\frac{\bar{\mu}}{\mu_i}\right)^{\dfrac{\beta}{1-\beta}} dF(\mu_i)}{\left[F(\bar{\mu}) + \displaystyle\int_{\bar{\mu}}^{\infty} \left(\frac{\bar{\mu}}{\mu_i}\right)^{\dfrac{1}{1-\beta}} dF(\mu_i)\right]^{\beta}} = A \times \frac{BE_Y}{[BE_H]^{\beta}}, \quad BE_H = F(\bar{\mu}) + \int_{\bar{\mu}}^{\infty} \left(\frac{\bar{\mu}}{\mu_i}\right)^{\dfrac{1}{1-\beta}} dF(\mu_i) \tag{10}$$

ATFP is measured by aggregate output relative to a geometrically weighted average of aggregate labor and capital inputs (Gilchrist, Sim, & Zakrajšek, 2013). We show that the misallocation of inputs makes ATFP lower compare to the aggregate productivity level. It rises with an improvement in financial market conditions and decreases with WCU. Appendix A provides technical.

Briefly, based on mentioned arguments, our study is closely related and complementary to the growing literature that explores the link between allocation of resources across firms and measured ATFP, according to the role of financial frictions by, e.g., Gilchrist et al. (2013) and Midrigan and Xu (2014). The worsening of financial market conditions reduces aggregate production level in two ways. The first impact influences all firms by increasing the probability of being constrained, and the second solely affects constrained firms by decreasing capacity utilization. As a result, misallocation of inputs among constrained and unconstrained firms acts as a source of change in the ATFP. Furthermore, our analysis provides a complementary narrative about the observed decline in ATFP after a contraction in financial markets based on capacity underutilization.

3. Empirical study

In this section, we test the firm-level predictions of the model developed in the previous section using a panel database of Iranian manufacturing firms. We estimate the reduced form equations of our theoretical model to illustrate the real impacts of changes in the first and second moments of working capital requirements. Because of the lack of representation of the entire industry, we confine our empirical assessment to our theoretical findings that holds only at the micro level.

3.1. Hypothesis building

The hypotheses to be tested are as follows:

- Hypothesis 1: Higher WCR is associated with lower employment of prepaid inputs in constrained firms, though unconstrained firms do not vary their demand by WCR.
- Hypothesis 2: Production declines in constrained firms as their needs for working capital rise. However, unconstrained firms' production do not vary with WCR.
- Hypothesis 3: While in unconstrained firms, capacity utilization does not change with WCR, the opposite is true for constrained firms.
- Hypothesis 4: Production declines as firms confront with higher WCU.

We explain the mapping from model to the data by describing the main variables[15]:

Working capital requirement: we construct a firm-level measure of WCR by the concept of days inventory outstanding (DIO), which is adopted by Raddatz (2006), Tong and Wei (2011) and Claessens et al. (2012). The DIO is the ratio of the end period raw materials inventory to the sale, which indicates on average how long it takes a firm turns its inventory into sales. We assume that the intrinsic liquidity need for the working capital is indebted to operational reasons, such as the length of time in the production process, the mode of operation, and trade credit conditions. A longer DIO is also interpretable as a higher prepayment for inputs because firms must pay for inputs during the operation cycle when their revenues are not realized. We quantify WCR by calculating the median of the previous values of DIO for each observation. We use an alternative index, median lag of previous values of raw inventories to cost of goods sold, for the robustness checks in Section 3.4.3.

Working capital uncertainty: there are three roots of uncertainty about working capital: the share of prepayments, volatility in prices and changes in the time schedule of cash flows, which has so far been summarized in uncertainty about the share of prepayment. However, the only available data are price volatility and the dispersion of WCR among firms. To construct the WCU, firms are classified based on their size and industry in every year. We consider the standard deviation of DIO in each group as the main WCU index for all group members. Another proxy, constructed based on the volatility of relative wage and price, is used for the robustness tests in Section 3.4.3.

Employment of prepaid inputs: based on contract conditions in Iran, labor is paid monthly, while the average time of DIO from Table 1 is about 0.16 of year, less than 2 months. However, payments to shareholders usually occur yearly because of observations from the listed companies on the Tehran Stock Exchange. These observations encourage us to select labor and materials as prepaid inputs, which is also similar to studies by Chari et al. (2007), Mendoza (2010), and Dong (2014). The cost of material[16] per unit of capital stock is our main proxy for prepaid inputs. We use the alternative index, real wage to capital, in the robustness estimations in Section 3.4.3.

Capacity utilization: In a situation where it is costly to adjust capital, firms try to change the scale of production. For example, a firm might use its capital less to decrease depreciation. A common method of considering this change in capacity utilization, as mentioned by Burnside, Eichenbaum, and Rebelo (1995) and Oberfield (2013), is using energy consumption as a proxy for capital services.

We assume that for a given set of prices, the benchmark ratio of energy to capital[17] is defined by the firm's technology. With some simple assumptions discussed in Oberfield (2013), any deviation from the benchmark ratio can be a sign of changes in capacity utilization. Based on this concept, we construct a capacity utilization index using the amount of fuel usage by firms.[18] The index is the ratio of the firms' British thermal units[19] (Btu) to capital stock divided by the benchmark value. For each firm, the median of Btu to capital is considered the benchmark. The results are robust to alternative index, constructed based on electricity usage in Section 3.4.

Production index: we assume that firms are similar, except in their WCR. Consequently, to test the hypothesis about investigating the real impacts of WCR, we must control for other sources of variation in the firm's production level. Therefore, the residuals of the estimated production function are used as the production index. We apply the method of Blundell and Bond (2000) to estimate the production function and then use the residuals to compute adjusted production. Real sales to capital is our alternative index.

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[15] The details of alternative and industry level variables are provided in Appendix B.

[16] We deflate the numerator with the industry's input price index. Materials expenditure includes fuels cost.

[17] As an input with low frequency changes.

[18] Our energy portfolio consists of kerosene, gasoline, liquefied natural gas, natural gas, gas oil, crude oil, fuel oil, coal, wood coal, and electricity.

[19] To compare different fuels that firms use in their operations on an equal basis, we compute Btu as a unit of energy content. Fuels can be converted from physical measurement units (such as weight or volume) to a common measurement unit of the energy or heat content of each fuel. Btu is the quantity of heat required to raise the temperature of 1 pound of liquid water by 1 °F.

Table 1
Summary statistics.

	Observations	Mean	Median	SD	Min	Max
DIO	80,556	0.163	0.050	0.346	0.000	3.024
WCR	90,448	0.133	0.049	0.255	0.000	2.333
WCU_Dispersion	80,269	0.286	0.264	0.171	0.000	1.930
WCU_Price	80,133	0.363	0.370	0.130	0.036	0.698
Production_BB	61,591	1.357	0.999	1.321	0.051	11.911
Sales/K	86,539	0.024	0.012	0.039	0.000	0.308
CU_Btu	86,818	1.243	1.000	1.252	0.043	15.549
CU_Electricity	86,435	1.226	1.000	1.177	0.025	11.889
Materials/K	87,164	0.014	0.006	0.024	0.000	0.196
Wage/K	87,025	0.007	0.003	0.013	0.000	0.121
Z_Raw	48,386	0.000	−0.210	1.000	−0.550	9.147
Z_Corr	75,817	0.000	0.010	0.927	−1.532	1.539
Growth_Ind	101,490	0.034	0.045	0.143	−1.120	1.120
Inflation_Ind	101,490	0.131	0.112	0.112	−0.133	0.992
WCR_Ind	80,556	0.173	0.162	0.066	0.021	0.585

Notes: "Annual Survey of Iranian Manufacturing Enterprises" from 2005 to 2011. DIO is the ratio of inventory of raw materials to sales. WCR is the median of lags of DIO. WCU_Dispersion is the standard deviation of DIO among firms who are in the same industry and size group. WCU_Price is a weighted average of price and wage volatility. Production_BB is the residual of an estimated production function using Blundell and Bond method. Sales/K is real sales per unit of capital. CU_Btu (electricity) is the index for capacity utilization based on Btu (electricity) usage. Materials/K is the average expenditure of materials per unit of capital. Wage/K is the real wage per unit of capital. Z_Raw presents the z-score of scaled growth rate of raw materials for each observation. Z_Corr is the z-score of correlation between Prod_BB and financial market conditions for each firm. Growth_Ind is the real growth rate of value-added in each industry. Inflation_Ind is the inflation rate of production price index (PPI) for each industry. WCR_Ind is ratio of sum of raw materials inventories to sum of sales for all firms in each industry. See the definition details in Section 3.2 and Appendix B.

Financial constraint index: although our database is rich in real variables, it contains a few financial variables. While we are unable to compute the common continuous indices, we use the ex-ante classification, which is customary since Fazzari and Petersen (1993). Financial constrained firms have fewer opportunities to invest in raw materials, because they must spend available financial resources to fulfill other current expenditures or expired payables.[20] Therefore, we expect that after controlling for the industry fixed effects, a firm with a larger inventory of raw materials should be less constrained compared to one with a lower inventory. This method provides a time-variant firm-specific dummy variable for financial constraint, which fits the purpose.

Thus, we compute the scaled[21] growth rate of the inventory of raw materials and sort firms based on it. For each year, we mark three quarters[22] of firms with the lower-scaled growth rate as potentially constrained and the rest as potentially unconstrained.[23] This method gives us a time-variant firm-specific dummy variable for financial constraint. The results are robust to alternative index, the correlation of production index with loan-to-value-added in the industry sector.

3.2. Data and summary statistics

To show how the interaction of the firm needs for working capital and financial friction creates a linkage between real and financial sectors, we use the panel database of "*Annual Survey of Iranian Manufacturing Enterprises.*" This study is among the first to use this rich database and to understand firms' behavior in a developing country.

The Statistical Center of Iran has implemented an annual survey on manufacturing establishments[24] with 10 or more workers since 1972. The survey includes more than 100 fields of data in areas of employment, inventories, production, sales, expenditures, investment, R&D, IT, and management for each establishment. More than 15,000 enterprises covered in the database produce 70–80% of value-added of the industry sector in Iran. We focus on 2005–2011, the period that the dataset is available in the panel form. More details are in Appendix C.

Besides the detailed firm-level information of our database, the dominant form of financial frictions in Iran encourages us to select this country to test our theory and evaluate its importance. According to Mahmoudzadeh et al. (2016), financial repression, lack of contract enforcement, and weakness of secured lending and credit rating institutions lead Iranian banks to prefer quantity to price adjustments in loan contracts. This is compatible with the described situation in our analytical part. Furthermore, firms in developing countries like Iran have higher working capital needs relative to their rivals in the developed economies because of the status of macroeconomic and infrastructures (Chan, 2014).

[20] The idea is proposed and tested in literature from Kashyap, Lamont, and Stein (1994).

[21] For each year, firms are classified based on their size and industry. The growth rate of inventory in each group is considered as the benchmark growth rate for group members, and the scaled growth rate of inventory is the firm's growth rate minus the benchmark value.

[22] We repeat the exercise with different thresholds of 80, 66, 50 and 30%. The results of the first two were the same as reported regression. However, limiting the share of potentially constrained firms less than 50% present signs of mixing up two groups of firms. It could be a signal that more than half of the observations are financially constrained. The results are available in Table D1 of Appendix D.

[23] Mahmoudzadeh, Nili, and Nili (2016) construct a time-variant firm-specific financial constraint index by estimating the investment Euler equation and show that more than 80% of listed companies in Tehran Stock Exchange face credit constraint. The authors discuss that Iran has a bank-based financial market; more than 90% of official external finance is provided by the banking system. Thus, any contraction in credit access translates to a decrease in available financial resources. Moreover, financial repression imposed by government increases credit demand.

[24] The data on manufacturing enterprises with 10–49 workers for 14 of 31 provinces are collected by a sampling method, and the data related to the remaining provinces as well as manufacturing enterprises with 50+ workers are collected through a census. Sampling fraction is about 77%. Although firms are not identifiable, almost all enterprises belong to one-enterprise firms. More information is available on: http://www.amar.org.ir/Default.aspx?tabid=133.

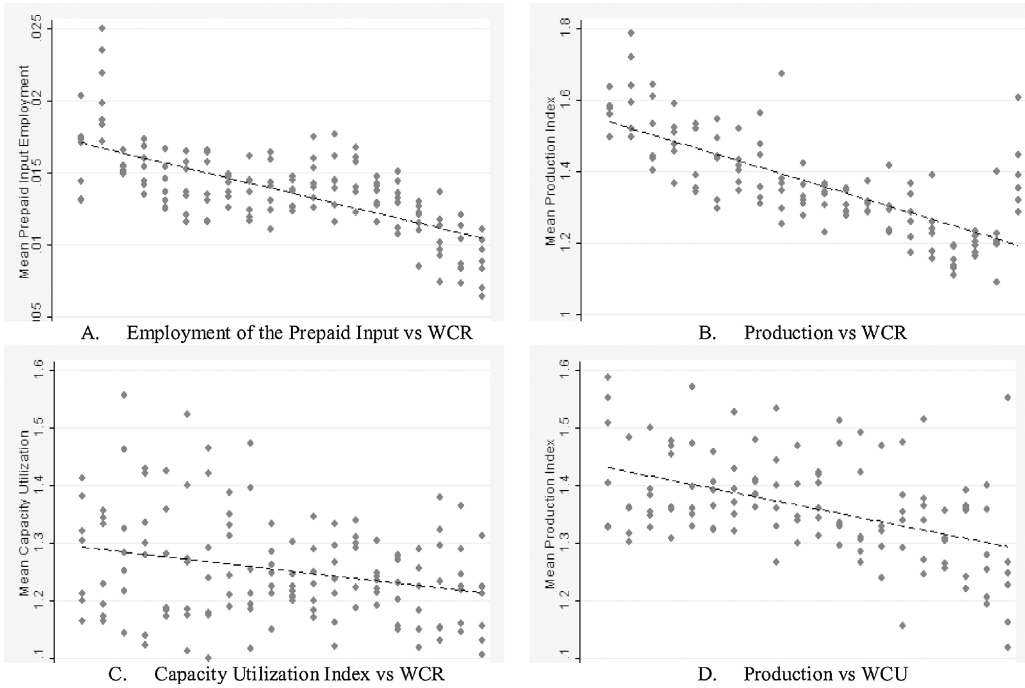

Fig. 2. Employment of prepaid input, production, and capacity utilization vs WCR and WCU.

Notes: Panels A–C demonstrate the relationship between firms' performance measures and WCR. In each year, firms are divided into twenty groups in order of WCR. Each point shows the mean of employment of prepaid input, capacity utilization and production for a single group in a single year. These figures display all group–year observations from 2005 to 2011. Panels D displays the relation between production measure and WCU. It is constructed in the same way, but uses the WCU index for grouping.

WCR is the median of lags of DIO, the ratio of the inventory of raw materials to sales. The proxy for WCU is WCU_Dispersion, the standard deviation of DIO among firms who are in the same industry and size group. Employment of the prepaid input is measured by the average expenditure of materials per unit of capital. CU_Btu is capacity utilization index based on Btu usage. Production-BB is the production index, the residual of an estimated production function using the Blundell and Bond method. See the details of definitions in Section 3.2 and Appendix B.

Table 1 provides the statistical summary of the sample distribution. We drop observations with negative or missing values for value-added, capital, and labor. To minimize the impact of outliers, we winsorize the top and bottom 0.75%[25] of the distributions of WCR and performance indices in each year.

Fig. 2 displays the relation between WCR and WCU with firms' performance measures based on variables defined in the previous section. The observed relation is consistent with our main hypotheses. It seems that in general, firms with higher prerequisites for working capital represent lower performance in the dimensions of employment of prepaid inputs (Panel A), production (Panel B) and capacity utilization (Panel C). In addition, being more uncertain about working capital, firms decrease their production (Panel D).

3.3. Estimation

We estimate the following reduced form regression equation, where subscripts i, s, and t refer to firm, industry, and time, respectively. Firm and time fixed effects and the vector of industry control variables are indicated by f_i, d_t, and $I_{s,t}$. $I_{s,t}$ contains industry's growth, inflation and working capital requirement.

$$\begin{gathered} Performance_{i,s,t} = c_0 + c_1.WCR_{i,s,t} + c_2.WCU_{i,s,t} + \mathbf{c}.\boldsymbol{I}_{s,t} + d_t + f_i + \varepsilon_{i,t} \\ Performance \in \left\{ employment\ of\ prepaid\ inputs,\ production,\ capacity\ utilization \right\} \end{gathered} \tag{11}$$

Based on our hypotheses about WCR impact on firms' performance variables (Hypotheses 1–3), the expected sign of c_1 in the Eq. (11) is negative. Regarding the negative effect of WCU on production, mentioned in Hypothesis 4, the expected sign of c_2 is also negative. To test our hypothesis about the different impacts of WCR on the constrained and unconstrained firms, we use two methods. First, we consider the interaction term between dummies for potentially unconstrained firms and performance measures, with an expected positive sign. Second, we estimate separate regressions for constrained and unconstrained firms. To have compatible results with our theoretical model, the absolute value of c_1 among potentially unconstrained firms must not be significantly greater than c_1 among potentially constrained firms.

To estimate Eq. (11), we need to take care of endogeneity of WCR and WCU, for which we apply the following methods. We use the fixed effect (FE) estimation to control for the time-invariant characteristics of firms, and the robust standard errors to consider heteroscedasticity and serial correlation of error terms. WCU is constructed at the industry-level, so it is exogenous for the firms.

To manage the possible simultaneity bias problem, we define WCR as the median of lagged values of DIO. Compared to indices based on average, median mitigates the impact of last observations on the index. Our introduced measure may also address concerns about low-frequency shocks that alternate the demand for firms. The richness of our database allows constructing DIO based on raw materials

[25] We change the winsorizing threshold to 1.5% of observations from top and bottom of our sample. The main results, reported in Table D2 in Appendix D, do not change.

instead of total inventories, which consequently reduces our concerns about low-frequency shocks from two points of view. First, we avoid using the inventory of work in process and finished goods, which are both more sensitive to demand shocks compared to the inventory of raw materials. In the framework of (s, S) inventory behavioral modes, fixed costs prevent continuous ordering of raw materials. This strategy of inventory managing reduces the correlation of raw materials and performance measures, e.g. production and employment. 2) Owing to the annual frequency of our data, the recognizable demand shock occurs per 12 months. However, the average duration of DIO is around two months from Table 1. This considerable difference weakens the relation between previous realizations of low frequency shocks and current WCR index, since the raw materials inventory circles about six times after any observed demand shock. To address the remaining concerns about endogeneity of the WCR index, we apply IV estimation in Section 3.4.2.

Considering these points, we design three main specifications for Eq. (11) reported in blocks of Table 2. Columns 1 and 2 express estimations for the full sample and columns 3 and 4 concentrate on subsamples of potentially constrained and unconstrained firms. The main regression is column 2, which focuses on the differential impact of WCR shocks on constrained and unconstrained firms.

Panel A is our benchmark experience. Although Panels B and C have the same variables and structure as Panel A, in Panel B, we control for the lag of the dependent variable and in Panel C, we drop industrial control variables and year fixed effects and add industry-year dummies. These dummies non-parametrically absorb all time-varying industry-level unobservable components. This specification that includes firms fixed effects and industry by period dummies is robust to all unobserved permanent determinants of firms' performance, all unobserved transitory factors common to potentially constrained and unconstrained firms within an industry, and all unobserved industry-specific shocks to performance.

3.3.1. Employment of prepaid inputs

We first test validity of Hypothesis 1, which claims higher requirement for working capital limits the employment of prepaid inputs in the constrained firms. In Table 2-Block 1, the dependent variable is materials expenditure per unit of capital. We start with Panel A with WCR as coefficient of interest. Column 1 demonstrates a significantly negative relation between WCR and cost of materials. This might be a sign of high share of constrained firms, since our theory predicts the negative relation among constrained firms.

To validate the hypothesis that the negative relation between WCR and performance variables comes from constrained firms, we construct a dummy variable for being unconstrained based on firms' scaled growth rates of raw materials. The interaction of WCR and the financially unconstrained dummy variable appears in column 2. The WCR negative impact on materials expenditure remains unaffected, and the coefficient of the interaction term is significantly positive, which indicates that the mentioned negative relation is significantly weaker among potentially unconstrained firms. To verify this result, we estimate the equation 11 on the potentially constrained and unconstrained firms separately in columns 3 and 4. We find that expectedly, the coefficient of WCR is significantly negative in column 3, and is insignificant among potentially unconstrained firms, which confirms our results in column 1.

Panels B and C of Table 2 have the same variables and structure as Panel A. In Panel B-Table 2, we control for the lag of Materials/K. In Panel C, we replace industrial control variables and year fixed effects with industry-year dummies. Comparing the outcomes in panels B and C with Panel A, we find that main results about WCR are robust to variation in control variables. The findings of Table 2-Block 1 conform to Hypothesis 1, that the ex-post effect of a working capital shock is a decline in the employment of prepaid inputs.

Though the impact of WCU on hiring of prepaid input is not part of the model, we consider it as an explanatory variable to investigate the empirical co-movements. The negative and significant coefficients of WCU in Panels A–C reveal that firms decrease their expenditure for materials when facing with higher uncertainty about working capital.

3.3.2. Production

Table 2B lock 2 reports the impact of WCR and WCU on production, in line with Hypotheses 2 and 4. Column 1 shows a significantly negative relation between production index and WCR, which indicates that firms with higher needs for working capital produce less. Which is consistent with studies that document the general effect of working capital on firm size, e.g., Uyar (2009).

Our study singles out the role of financial constraint. Based on Proposition 2(i), we expect no association between WCR and production in unconstrained firms. The positive and significant coefficient of interaction term between WCR and dummy variable for being financially unconstrained demonstrates that the negative impact of WCR on production is weaker when firms do not confront credit constraint. The comparison of coefficient of WCR in columns 3 and 4 reveals that WCR can only explain production variation in potentially constrained firms.

Hypothesis 4 predicts a negative relation between uncertainty about working capital and production in both groups of constrained and unconstrained firms. WCU has a negative significant effect on production based on columns 1–3, which provides compatible findings among all and potentially constrained firms. The fact that WCU just affects production in the potentially constrained firms may be a result of dynamic decision-making process which is not captured in our static model.

Panels B and C of Table 2-Block 2, have the same structure as their peers in Block 1. Comparing their outcomes with Panel A indicates that main inference about WCR and WCU are invariant to changes in control variables.

3.3.3. Capacity utilization

To the best of our knowledge, theoretical and empirical relations between capacity utilization and working capital have not been mentioned in the literature. Block 3 of Table 2 validates the empirical merits of Hypothesis 3 where capacity utilization of the constrained firms fall as WCR rises. Negative and significant coefficients of WCR in columns 1–2 suggest that typically higher working capital decreases firms' capacity utilization. However, given column 4, the capacity utilization of potentially unconstrained firms does not vary with WCR. These findings are compatible with our inference in Hypothesis 3. This result is repeated in Panels B and C where lag of dependent variable and industry-year dummies were added correspondingly. The significant and negative sign of WCU in all regressions indicates that capacity utilization decreases when there is more uncertainty about working capital.

Table 2
Performance measures and working capital.

	Dependent variable	Block 1: Materials/K				Block 2: Production_BB				Block 3: CU_Btu			
		(1) All	(2) All	(3) Potentially constrained	(4) Potentially unconstrained	(1) All	(2) All	(3) Potentially constrained	(4) Potentially unconstrained	(1) All	(2) All	(3) Potentially constrained	(4) Potentially unconstrained
Panel A: main	WCR	−0.008***	−0.009***	−0.009***	−0.002	−0.312***	−0.378***	−0.385***	−0.045	−0.171**	−0.186**	−0.213***	−0.154
		(−10.278)	(−11.216)	(−10.339)	(−0.510)	(−5.238)	(−6.310)	(−5.613)	(−0.255)	(−2.373)	(−2.515)	(−2.794)	(−0.853)
	WCR*pot.		0.004***				0.272***				0.037		
	Unconstrained		(4.729)				(5.051)				(0.603)		
	WCU	−0.003***	−0.003***	−0.003***	−0.000	−0.103**	−0.105**	−0.188***	0.030	−0.166***	−0.169***	−0.140*	−0.240
		(−3.383)	(−3.429)	(−3.399)	(−0.112)	(−2.077)	(−2.108)	(−3.294)	(0.148)	(−2.722)	(−2.767)	(−1.928)	(−1.273)
	Industry vars.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Year & firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	F-test	51.952	44.196	39.427	4.267	6.920	8.760	6.098	1.389	12.596	10.151	9.415	2.523
	Observations	56,717	56,717	45,638	11,079	50,327	50,327	39,409	10,918	56,734	56,734	45,649	11,085
Panel B: lag of dep. variable	WCR	−0.006***	−0.007***	−0.007***	0.001	−0.534***	−0.606***	−0.577***	−0.206	−0.172**	−0.193**	−0.190**	−0.157
		(−7.733)	(−8.886)	(−7.729)	(0.215)	(−6.874)	(−7.937)	(−6.627)	(−1.055)	(−2.249)	(−2.509)	(−2.324)	(−0.867)
	WCR*pot.		0.004***				0.279***				0.049		
	Unconstrained		(4.918)				(5.036)				(0.810)		
	WCU	−0.003***	−0.003***	−0.003***	0.000	−0.117**	−0.118**	−0.106	−0.330	−0.156**	−0.158**	−0.098	−0.244
		(−3.433)	(−3.493)	(−3.762)	(0.164)	(−2.005)	(−2.018)	(−1.553)	(−1.382)	(−2.510)	(−2.557)	(−1.311)	(−1.289)
	Industry vars.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Year & firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Lag dep. var.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	F-test	48.626	41.757	41.526	5.598	65.525	52.823	30.150	5.314	12.411	10.140	10.442	2.571
	Observations	51,067	51,067	39,994	11,073	36,401	36,401	28,485	7916	50,957	50,957	39,882	11,075
Panel C: Ind. × year FE	WCR	−0.008***	−0.009***	−0.009***	−0.002	−0.315***	−0.372***	−0.377***	−0.084	−0.167**	−0.180**	−0.212***	−0.059
		(−10.352)	(−11.158)	(−10.278)	(−0.686)	(−5.276)	(−6.212)	(−5.465)	(−0.447)	(−2.329)	(−2.447)	(−2.825)	(−0.315)
	WCR*pot.		0.003***				0.266***				0.048		
	Unconstrained		(4.300)				(4.941)				(0.789)		
	WCU	−0.002***	−0.002***	−0.002***	−0.002	−0.109**	−0.107**	−0.183***	0.104	−0.108*	−0.109*	−0.093	0.013
		(−2.695)	(−2.684)	(−2.664)	(−0.697)	(−2.173)	(−2.132)	(−3.156)	(0.502)	(−1.714)	(−1.725)	(−1.251)	(0.071)
	Industry year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	F-test	9.947	10.068	–	–	2.777	3.078	–	–	2.582	2.611	–	–
	Observations	56,717	56,717	45,638	11,079	50,327	50,327	39,409	10,918	56,734	56,734	45,649	11,085

Notes: Columns report the result of regressing performance measures on WCR, WCU, and control variables. Materials/K is the average expenditure of materials per unit of capital. Production_BB is the residual of estimated production function using Blundell and Bond (2000)'s method. CU_Btu is the capacity utilization of firms based on Btu usage. WCR is the median of lags of DIO (the inventory of raw materials to sales). WCU is the standard deviation of DIO among firms who are in the same industry and size group. Pot. Unconstrained is a dummy variable for potentially unconstrained firms whose scaled growth rates of raw inventory is above 75% of observations. The remaining observations are considered to be potentially constrained. Industrial variables contain real growth of value-added, inflation, and WCR for industries defined at the 2-digit ISIC level. Columns (1) and (2) report the estimation results for the full sample. Columns (3) and (4) respectively report regression results on the selected samples of potentially constrained and potentially unconstrained firms. All panels use the fixed effect method, Panel B contains lag of dependent variable as explanatory variable. In Panel C, industrial control variables (industry's growth, inflation and WCR) and year fixed effects are replaced with industry-year dummies.

*** Denotes 1% significance.

** 5% significanc.

* 10% significance.

3.4. Robustness of results

This section provides robustness checks with respect to alternative definitions of dependent and explanatory variables and the estimation method. In Table 3, we inspect the strength of empirical findings by changing the definition of firms' performance measures. Table 4 reports the robustness tests with respect to alternative definitions of WCR, WCU, financial constraint, and IVs for WCR.

3.4.1. Firms' performance measures

Table 3 presents our assessments, using new indices for prepaid input, production, and capacity utilization as the dependent variables, respectively in Blocks 1–3. To measure the labor, we count the firm's labor cost, wage and nonwage bills, rather than its employment. The labor index is the ratio of real wage to capital, similar to what Hsieh and Klenow (2009) proposed. In Panels A–C, the effect of WCR on scaled real wage is significantly negative and more severe among potentially constrained firms as mentioned in Hypothesis 1.[26] However, the difference behavior of constrained and uncontained firms is only significantly observable by separating these two groups.

Block 2 presents our investigation of the impact of WCR and WCU on production, when we use real sale per capital as our measure. The findings are compatible with Hypotheses 2 and 4.

Block 3 uses an alternative definition for the capacity utilization, by dividing the ratio of the firms' electricity usage to capital stock by the benchmark value. For each firm, we use the median of electricity to capital as the benchmark. Although, WCR is not significant in columns 1 and 2, it explains variations of capacity utilization among constrained firms (column 5), which is compatible with our main prediction from Hypothesis 3. The inference of this hypothesis is that capacity utilization of unconstrained firm decreases as its prerequisites for prepayments increase.

3.4.2. Instrument variables for WCR

As mentioned in Section 3.2, firm-specific low-frequency shocks may cause a spurious empirical relation between WCR and firms' performance measures. We consider this problem by defining the WCR as the median of previous values of DIO and by defining DIO based on raw materials, which is less sensitive to demand shocks compare to total inventories. To address the remaining concerns about endogeneity of the WCR index, we apply IV estimation.[27] We introduce the producer price index (PPI) and Industry's WCR as instruments for DIO. We assume that the average ratio of raw materials inventory to sales among firms that are in the same industry is a suitable index for the intrinsic needs of working capital. Panel A of Table 4 reports the IV estimation results, which are almost similar to those of Table 2. We find that using IVs for the concept of WCR does not change the negative significant correlation of WCR with performance measures, compatible with Hypotheses 1–3.

3.4.3. Alternative definitions for WCR, WCU, and financial constraint

Panel B of Table 4 demonstrates that an alternation in the definition of WCR does not affect our empirical evidence about the negative impact of WCR and WCU on the employment of prepaid inputs, production, and capacity utilization. In this panel, WCR is measured as the median of lag values of DOI, the ratio of raw materials inventory to the cost of goods sold. In Table 2, DOI is as ratio of raw materials inventory to sales. By this alternative definition, which is common in the accounting literature, we also control for changes in the firms' markups.

In Panel C, we introduce an alternative definition for WCU constructed based on the volatility of input prices. For the indices of industry's relative price and wage, the standard deviations of observations in each year are computed as the uncertainty index about materials and wage expenditure.[28] We compute a weighted average of these uncertainty indices based on the benchmark share of materials and wages in each group.

Panel D shows the results of a new classification of constrained firms.[29] The production level of financially constrained firms commoves with their access to external finance, since access to credit releases their constraint and lack of loans distorts their production. Consequently, we expect a positive correlation between productions of these firms with financial access. We assume that the variation in the loan to the value of industrial sector is a suitable proxy for firms' access to finance. Correlation of the production index with loan to value added in the industry sector is our alternative classification index. We mark the three fourth of firms with the higher correlation as potentially constrained and the rest as potentially unconstrained. This method provides a firm-specific dummy variable for financial constraint.

Block 1 of Table 4 confirms our findings of the previous section about negative relations between WCR and employment of prepaid input among potentially constrained firms. Moreover, the outcomes approve insignificant correlation between these variables among unconstrained firms.

Block 2 of Table 4 reports the robustness test with respect to production as a performance measure. The outcomes of Panels B and C are compatible with our hypotheses about the influence of the first and second moments of WCR on the production index. In all panels, the estimated coefficients in columns 3 and 4 show that in general firms with higher needs for working capital produce less.

From Hypothesis 4, we expect a negative relation between WCU and production; except for Panel A, the coefficient of WCU is significantly negative in these specifications. Block 3 of Table 4 provides robustness checks of the impact of WCR on capacity utilization. The negative impact of WCR on capacity utilization does not change in either panel. This negative impact is more pronounced in potentially constrained firms, as projected in Hypothesis 3.

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[26] The negative empirical relation between WCU and employment of prepaid input does not repeat here. This is not a concern, since our theoretical model is silent about the effect of WCU on prepaid input. However, various behaviors of materials and labor need more investigations.

[27] The endogeneity C-test, suggested by Baum, Schaffer, and Stillman (2003), does not reject the null hypothesis that WCR_Med can be treated as exogenous. However, we report the results of using industry's WCR and PPI as IVs for DIO. Test results are available upon request.

[28] While firms transfer part of their input price variation to their sale price, uncertainty is computed based on relative price of input. Appendix B provides details of industry's relative price, wage, and the assigned weights.

[29] Dummies for unconstrained firms in the first and new classifications predict the same status for the firms with probability of 75%.

Table 3
Robustness checks with respect to alternative definitions of performance measures.

	Dependent variable	Block 1: Wage/K				Block 2: Sales/K				Block 3: CU_Electricity			
		(1) All	(2) All	(3) Potentially constrained	(4) Potentially unconstrained	(1) All	(2) All	(3) Potentially constrained	(4) Potentially unconstrained	(1) All	(2) All	(3) Potentially constrained	(4) Potentially unconstrained
Panel A: main	WCR	−0.001*	−0.001*	−0.001**	−0.000	−0.016***	−0.017***	−0.018***	0.000	−0.083	−0.110	−0.174**	0.324
		(−1.848)	(−1.770)	(−2.488)	(−0.341)	(−10.463)	(−11.452)	(−10.800)	(0.010)	(−1.136)	(−1.536)	(−2.141)	(1.514)
	WCR*Pot. Unconstrained		−0.000				0.007***				0.129*		
			(−0.095)				(5.556)				(1.863)		
	WCU	0.001***	0.001***	0.001***	0.002*	−0.004***	−0.004***	−0.005***	−0.003	−0.139**	−0.146***	−0.067	−0.415**
		(3.145)	(3.080)	(2.948)	(1.708)	(−3.466)	(−3.480)	(−3.673)	(−0.652)	(−2.515)	(−2.640)	(−1.010)	(−2.289)
	Industry vars.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Year & firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	F-test	319.554	246.914	268.539	55.251	70.832	58.783	59.408	4.813	14.560	15.962	9.839	4.965
	Observations	56,716	56,716	45,637	11,079	56,762	56,762	45,672	11,090	56,594	56,594	45,537	11,057
Panel B: lag of dep. variable	WCR	−0.001*	−0.001*	−0.001**	−0.000	−0.012***	−0.013***	−0.013***	0.006	−0.024	−0.049	−0.082	0.322
		(−1.797)	(−1.913)	(−2.207)	(−0.373)	(−7.955)	(−9.214)	(−8.629)	(0.911)	(−0.314)	(−0.675)	(−1.042)	(1.493)
	WCR*Pot. Unconstrained		0.000				0.007***				0.108		
			(1.084)				(5.792)				(1.504)		
	WCU	0.001***	0.001**	0.001*	0.001	−0.004***	−0.004***	−0.006***	−0.002	−0.151***	−0.159***	−0.078	−0.447**
		(2.671)	(2.542)	(1.852)	(1.491)	(−3.679)	(−3.705)	(−4.149)	(−0.470)	(−2.678)	(−2.822)	(−1.163)	(−2.460)
	Industry vars.	Yes	Yes	Yes	yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Year & firm FE	Yes	Yes	Yes	yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Lag dep.var.	Yes	Yes	Yes	yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	F-test	533.719	424.356	440.315	79.339	61.825	52.498	56.396	7.452	12.536	14.229	8.956	4.568
	Observations	51,060	51,060	39,987	11,073	50,964	50,964	39,877	11,087	50,804	50,804	39,761	11,043
Panel C: Ind. × year FE	WCR	−0.001	−0.001	−0.001**	0.000	−0.016***	−0.017***	−0.018***	−0.001	−0.085	−0.109	−0.175**	0.324
		(−1.492)	(−1.517)	(−2.146)	(0.061)	(−10.545)	(−11.557)	(−10.725)	(−0.117)	(−1.160)	(−1.522)	(−2.159)	(1.428)
	WCR*Pot. Unconstrained		0.000				0.007***				0.116*		
			(0.920)				(5.587)				(1.670)		
	WCU	0.001***	0.001***	0.002***	0.003***	−0.004***	−0.003***	−0.004***	−0.004	−0.129**	−0.129**	−0.075	−0.359**
		(4.012)	(4.037)	(4.116)	(2.660)	(−2.943)	(−2.904)	(−3.050)	(−0.818)	(−2.239)	(−2.255)	(−1.090)	(−2.004)
	Industry vars.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	F-test	41.574	40.627	–	–	8.443	8.775	–	–	2.802	3.180	–	–
	Observations	56,716	56716	45,637	11,079	56,762	56,762	45672	11,090	56,594	56,594	45,537	11,057

Notes: Columns report the result of regressing performance measures on WCR, WCU, and control variables. Wage/K is the real wage per unit of capital. Sales/K is the real sales per unit of capital. CU_Electricity is the capacity utilization of firms based on electricity usage. WCR is the median of lags of DIO (the inventory of raw materials to sales). WCU is the standard deviation of DIO among firms who are in the same industry and size group. Pot. Unconstrained is a dummy variable for potentially unconstrained firms whose production index correlation with industry's loan to value is less the 75% of observations. The remaining observations are considered to be potentially constrained. Industrial variables contain real growth of value-added, inflation and WCR for industries defined at the 2-digit ISIC level. Columns (1) and (2) report the estimation results for the full sample. Columns (3) and (4) respectively report regression results on the selected sample of potentially constrained and potentially unconstrained firms. All panels use the fixed effect method, Panel B contains lag of dependent variable as explanatory variable. In Panel C, industrial control variables (industry's growth, inflation and WCR) and year fixed effects are replaced with industry-year dummies.

*** Denotes 1% significance.

** 5% significance.

* 10% significance.

Table 4
Robustness checks with respect to alternative definitions of WCR and WCU.

	Dependent variable	Block 1: Materials/K				Block 2: Production_BB				Block 3: CU_Btu			
		(1) All	(2) All	(3) Potentially constrained	(4) Potentially unconstrained	(1) All	(2) All	(3) Potentially constrained	(4) Potentially unconstrained	(1) All	(2) All	(3) Potentially constrained	(4) Potentially unconstrained
Panel A: IV for WCR	WCR	−0.054***		−0.020***	0.016	−3.445***		−1.210**	−1.945	−2.412*		−0.652*	−2.190
		(−3.157)		(−2.700)	(0.765)	(−2.829)		(−2.110)	(−1.342)	(−1.916)		(−1.646)	(−1.420)
	WCR*Pot. Unconstrained												
	WCU	0.015		0.003	−0.002	0.991		0.182	0.234	0.622		0.067	−0.019
		(1.549)		(1.224)	(−0.591)	(1.488)		(0.931)	(0.860)	(1.465)		(0.299)	(−0.076)
	Hansen J.St	2.291		2.204	9.147	0.027		1.098	0.315	0.723		3.083	0.646
	Hansen J.Pv	0.130		0.138	0.002	0.869		0.295	0.575	0.395		0.107	0.422
	F-test	25.028		31.734	4.442	2.884		2.868	1.564	10.203		9.537	2.565
	Observations	52,684		40,815	5265	46,547		35,112	5118	52,696		40,818	5265
Panel B: definition of WCR	WCR	−0.006***	−0.006***	−0.007***	−0.002	−0.102**	−0.115**	−0.133***	−0.122	−0.124***	−0.164***	−0.153***	0.014
		(−11.819)	(−12.499)	(−11.056)	(−1.109)	(−2.381)	(−2.575)	(−2.901)	(−1.167)	(−3.652)	(−4.763)	(−3.832)	(0.158)
	WCR*Pot. Unconstrained		0.002***				0.036				0.135***		
			(5.071)				(1.040)				(4.407)		
	WCU	−0.003***	−0.003***	−0.003***	−0.000	−0.166***	−0.169***	−0.140*	−0.240	−0.106**	−0.109**	−0.191***	0.028
		(−3.271)	(−3.346)	(−3.322)	(−0.105)	(−2.720)	(−2.766)	(−1.927)	(−1.271)	(−2.138)	(−2.196)	(−3.356)	(0.142)
	F-test	55.211	46.028	41.092	4.350	12.650	10.243	9.529	2.574	5.583	7.537	4.426	1.377
	Observations	56,717	56,717	45,638	11,079	56,734	56,734	45,649	11,085	50,327	50,327	39,409	10,918
Panel C: definition of WCU	WCR	−0.009***	−0.009***	−0.010***	−0.005	−0.269***	−0.330***	−0.372***	−0.236	−0.212***	−0.231***	−0.253***	−0.122
		(−9.312)	(−10.205)	(−9.427)	(−1.209)	(−3.950)	(−4.867)	(−4.681)	(−0.997)	(−2.652)	(−2.851)	(−2.896)	(−0.630)
	WCR*Pot. Unconstrained		0.004***				0.251***				0.013		
			(4.266)				(4.029)				(0.193)		
	WCU	−0.004***	−0.004***	−0.004***	−0.010***	−0.133**	−0.137**	−0.159**	0.071	0.014	0.009	0.052	0.036
		(−4.120)	(−4.184)	(−4.192)	(−2.798)	(−2.028)	(−2.084)	(−2.102)	(0.226)	(0.183)	(0.118)	(0.612)	(0.137)
	F-test	33.976	30.113	25.531	3.535	5.108	6.866	4.653	1.342	10.534	8.494	8.701	2.313
	Observations	47,147	47,147	37,896	9251	41,691	41,691	32,567	9124	47,126	47,126	37,879	9247
Panel D: definition of Pot. Constraint	WCR	−0.008***	−0.008***	−0.008***	−0.008***	−0.312***	−0.321***	−0.310***	−0.166	−0.171**	−0.182**	−0.155*	−0.230
		(−10.278)	(−10.119)	(−8.997)	(−4.778)	(−5.238)	(−5.324)	(−4.703)	(−1.391)	(−2.373)	(−2.425)	(−1.894)	(−1.587)
	WCR*Pot. Unconstrained		0.000				0.163**				0.035		
			(0.026)				(2.206)				(0.436)		
	WCU	−0.003***	−0.003***	−0.003***	−0.000	−0.103**	−0.104**	−0.074	−0.106	−0.166***	−0.171***	−0.146**	−0.228*
		(−3.383)	(−3.379)	(−3.577)	(−0.181)	(−2.077)	(−2.098)	(−1.368)	(−1.038)	(−2.722)	(−2.762)	(−2.138)	(−1.665)
	F-test	51.952	40.467	36.362	23.033	6.920	5.918	76.623	160.738	12.596	10.677	15.679	2.397
	Observations	56,717	50,995	46,123	10,594	50,327	47,604	40,781	95,46	56,734	51,005	46,138	10,596

Notes: Columns report the results of regressing performance measures on WCR, WCU, and control variables. Columns (1) and (2) report the estimation results for the full sample. Columns (3) and (4) respectively report regression results on the selected sample of potentially constrained and potentially unconstrained firms. All panels use the fixed effect method, controls for firm and year fixed effects and industry level variables (industry's growth, inflation and WCR). Panel A uses PPI and industry-level WCR as IVs for DIO. Panel B uses the alternative definition of WCR, where WCR is the median of lags of DIO' (the inventory of raw materials to cost of goods sold). Panel B use the alternative definition of WCU, where WCU_Price is a weighted average of price and wage volatility. Panel D uses the alternative definition for financially unconstrained firms, where Pot. Constrained is a dummy variable for potentially unconstrained firms, defined as firms with lo whose scaled growth rates of raw inventory is above 75% of observations. The remaining observations are considered to be potentially constrained.
*** denotes 1% significance,
** 5% significance and,
* 10% significance. For more details, see the note of Table 2.

Based on the results of Tables 3 and 4, we can conclude that in general, empirical findings in support of our theoretical predictions about the negative impact of WCR on performance measures and negative influence of uncertainty on production are robust to changes in the definition of variables, financial constraint classification, and estimation methods.

4. Conclusion

Access to working capital is inevitable for production when the time mismatch between realization of payments and incomes is significant. While the main part of the literature emphasizes the first order impacts of working capital requirement activated by changes in the relative price of inputs, this paper concentrates on the real consequences of variations in the first and second moments of WCR in the presence of financial frictions. This paper links imperfect information about working capital requirement to the capacity utilization and consequently to the aggregate total factor productivity. The distinction here is that firms choose capital under limited information about the fraction of prepayment to prepaid input, while the ability to receive working capital loan is restricted through the limited enforceability of debt contracts.

Based on interaction of uncertain WCR and borrowing constraint, we introduce two mechanisms in our model. First, the probability of facing with high liquidity requirements and being financially constrained decreases the expected marginal product of capital and acts as a capital wedge. This effect would influence firms such that, they decrease their ex-ante investment of non-prepaid input, regardless of their degree of risk aversion. Second, the shadow prices of credit for constrained firms act as a labor wedge and changes the relative price of labor even in the interest rate-free context. This binding effect causes capacity underutilization among firms that reach credit ceiling and decreases their ex-post demand for prepaid inputs.

To assess the empirical merits of our theoretical predictions, we use the detailed panel database from Iran as a developing country, and a financial sector structure well matched with our theory. Based on the firm-level data from "*Annual Survey of Iranian Manufacturing Enterprises*" during 2005–2011, we verify the model predictions against observed regularities. We show that compatible with our propositions, the employment of prepaid inputs, production and capacity utilization are lower in firms with higher needs for working capital. This behavior is an outcome of the negative relations of WCR and performance in financially constrained firms. Furthermore, being more uncertain about working capital, firms decrease their production level. Our findings are robust with respect to changes in definitions of WCR and WCU, definition of constrained firms, performance measures, and estimation method.

Our model provides a proper framework to compare the impact of WCR on production in different levels of financial market conditions. Although the model clarifies the relation between working capital requirement and production level, future studies might address a number of limitations that exist in our research. First, we do not specify sources of heterogeneity in the working capital requirement. Moreover, since we have assumed a concave production technology, we have not considered the impact of non-convexities in production, e.g., via fixed costs or other indivisibilities. A dynamic model can explain additional mechanisms that may arise by uncertainties about working capital through investment. Lastly, we do not consider the effect of wealth accumulation by firms. Access to an internal source of fund, weakens the impacts originated by the lack of working capital loan. Investigating the real effects of uncertainty about working capital in a dynamic model may empower us to explain the observed empirical relations between WCU and firms' performance.

Appendix A. Proof details

Lemma A1. *There is a cut-off value for WCR* $(\bar{\mu})$ *equal to* ε/β *across all firms, which differentiates constrained and unconstrained firms.*[30]

Proof of Lemma A1. From problem 1 the first order condition with respect to h_i and Kahn–Taker condition for credit constraint are:

$$(1+\varepsilon\gamma_i)\,\beta A k_i^{\alpha} h_i^{\beta-1} = w\,(1+\mu_i\gamma_i) \tag{1-A}$$

$$\gamma_i\left(\varepsilon A k_i^{\alpha} h_i^{\beta} - \mu_i w h_i\right) = 0 \tag{2-A}$$

$$\overset{1-A}{\Rightarrow} A k_i^{\alpha} h_i^{\beta-1} = \frac{\mu_i w}{\varepsilon} \Rightarrow h_i = \left[\frac{\varepsilon}{\mu_i w} A k_i^{\alpha}\right]^{\frac{1}{1-\beta}} \overset{1-A}{\Rightarrow} (1+\varepsilon\gamma_i)\,\beta\frac{\mu_i w}{\varepsilon} = w\,(1+\mu_i\gamma_i) \Rightarrow \frac{1+\varepsilon\gamma_i}{1+\mu_i\gamma_i} = \frac{\varepsilon}{\mu_i\beta}$$

When WCR is greater than $\frac{\varepsilon}{\beta}$, the firm faces credit constraint and positive shadow price of credit, γ_i.

$$\Rightarrow \gamma_i\left(\varepsilon,\mu_i,\beta\right) = \begin{cases} 0 & \mu_i < \dfrac{\varepsilon}{\beta} \\ \dfrac{\mu_i\beta-\varepsilon}{\varepsilon\mu_i\left(1-\beta\right)} & \mu_i \geq \dfrac{\varepsilon}{\beta} \end{cases}$$

Lemma A2. *Uncertainty effect* (*i*) *lowers inputs demand as compared with a frictionless economy* (UE < 1). *This effect* (*ii*) *raised by financial market inefficiency* ($\frac{\partial \mathrm{UE}}{\partial \varepsilon} > 0$), *and* (*iii*) *intensified with uncertainty about WCR* [$\frac{\partial \mathrm{UE}}{\partial \sigma} < 0$, for $\mathrm{F}(\mu) \sim \mathrm{N}(\mathrm{m}, \sigma)$].[31]

Proof of Lemma A2. When there is uncertainty about WCR, firms' problem can be rewritten as problem 2. Producers decide about capital based on the expected profit at first, and then choose labor after realization of WCR. By rearranging the expressions of problem 2 we have:

[30] We assume that $\bar{\mu} < \mu_{max}$. Otherwise, credit constraint is never binding, which is not compatible with stylized facts of macro-finance literature.

[31] All statements hold true regardless of the distribution, though functional form of F must be specified for section (iii). We solve the model for Pareto distribution, which does not change the results. Main findings are robust and proofs are available upon request.

$$\max_k \int_{-\infty}^{\bar{\mu}} \left[Ak^{\alpha} \left[\frac{\beta}{w} Ak^{\alpha} \right]^{\frac{\beta}{1-\beta}} - w \left[\frac{\beta}{w} Ak^{\alpha} \right]^{\frac{1}{1-\beta}} \right] dF(\mu_i) + \int_{\bar{\mu}}^{\infty} \left[Ak^{\alpha} \left[\frac{\beta}{w} \frac{\bar{\mu}}{\mu_i} Ak^{\alpha} \right]^{\frac{\beta}{1-\beta}} - w \left[\frac{\beta}{w} \frac{\bar{\mu}}{\mu_i} Ak^{\alpha} \right]^{\frac{1}{1-\beta}} \right] dF(\mu_i) - rk$$

$$\max_k \left[F(\bar{\mu}) + \int_{\bar{\mu}}^{\infty} \left(\frac{\bar{\mu}}{\mu_i} \right)^{\frac{\beta}{1-\beta}} dF(\mu_i) \right] A^{\frac{1}{1-\beta}} \left(\frac{\beta}{w} \right)^{\frac{\beta}{1-\beta}} k^{\frac{\alpha}{1-\beta}} - w \left[F(\bar{\mu}) + \int_{\bar{\mu}}^{\infty} \left(\frac{\bar{\mu}}{\mu_i} \right)^{\frac{1}{1-\beta}} dF(\mu_i) \right] A^{\frac{1}{1-\beta}} \left(\frac{\beta}{w} \right)^{\frac{1}{1-\beta}} k^{\frac{\alpha}{1-\beta}} - rk$$

The first order condition of the mentioned problem with respect to k is:

$$\frac{\alpha}{1-\beta} \left[F(\bar{\mu}) + \int_{\bar{\mu}}^{\infty} \left(\frac{\bar{\mu}}{\mu_i} \right)^{\frac{\beta}{1-\beta}} dF(\mu_i) \right] A^{\frac{1}{1-\beta}} \left(\frac{\beta}{w} \right)^{\frac{\beta}{1-\beta}} k^{\frac{\alpha}{1-\beta}-1} - w \frac{\alpha}{1-\beta} \left[F(\bar{\mu}) + \int_{\bar{\mu}}^{\infty} \left(\frac{\bar{\mu}}{\mu_i} \right)^{\frac{1}{1-\beta}} dF(\mu_i) \right] A^{\frac{1}{1-\beta}} \left(\frac{\beta}{w} \right)^{\frac{1}{1-\beta}} k^{\frac{\alpha}{1-\beta}-1} = r$$

which can be solved for the optimal level of capital.

$$k = \left[A \left(\frac{\alpha}{r} \right)^{1-\beta} \left(\frac{\beta}{w} \right)^{\beta} UE^{1-\beta} \right]^{\frac{1}{1-(\alpha+\beta)}} \quad where \quad UE = F(\bar{\mu}) + \frac{1}{1-\beta} \int_{\bar{\mu}}^{\infty} \left[\left(\frac{\bar{\mu}}{\mu_i} \right)^{\frac{\beta}{1-\beta}} - \beta \left(\frac{\bar{\mu}}{\mu_i} \right)^{\frac{1}{1-\beta}} \right] dF(\mu_i)$$

The characteristics of UE are as follow:

i Define $g(\mu_i, \bar{\mu})$ as:

$$g(\mu_i, \bar{\mu}) = \frac{1}{1-\beta} \left[\left(\frac{\bar{\mu}}{\mu_i} \right)^{\frac{\beta}{1-\beta}} - \beta \left(\frac{\bar{\mu}}{\mu_i} \right)^{\frac{1}{1-\beta}} \right] = \frac{1}{1-\beta} \left(\frac{\bar{\mu}}{\mu_i} \right)^{\frac{1}{1-\beta}} \left[\frac{\mu_i}{\bar{\mu}} - \beta \right] \overset{\frac{\bar{\mu}}{\mu_i}<1,\ \frac{1}{1-\beta}>1}{\Longrightarrow} \left(\frac{\bar{\mu}}{\mu_i} \right)^{\frac{1}{1-\beta}} < 1 \text{ and } \left(\frac{\mu_i}{\bar{\mu}} - \beta \right) < (1-\beta)$$

$$\Rightarrow g(\mu_i, \bar{\mu}) < 1 \overset{g(\mu_i,\bar{\mu})<1}{\Longrightarrow} \int_{\bar{\mu}}^{\infty} g(\mu_i, \bar{\mu}) dF(\mu_i) < 1 - F(\bar{\mu}) \Rightarrow UE = F(\bar{\mu}) + \int_{\bar{\mu}}^{\infty} g(\mu_i, \bar{\mu}) dF(\mu_i) < 1 \Rightarrow UE < 1.$$

ii

$$\frac{\partial UE}{\partial \varepsilon} = \frac{\partial UE}{\partial \bar{\mu}} \frac{\partial \bar{\mu}}{\partial \varepsilon} = \frac{1}{\beta} \left[\frac{1}{1-\beta} \int_{\bar{\mu}}^{\infty} \left[\frac{\beta}{1-\beta} \frac{1}{\bar{\mu}} \left(\frac{\bar{\mu}}{\mu_i} \right)^{\frac{\beta}{1-\beta}} - \frac{\beta}{1-\beta} \frac{1}{\bar{\mu}} \left(\frac{\bar{\mu}}{\mu_i} \right)^{\frac{1}{1-\beta}} \right] dF(\mu_i) \right]$$

$$= \frac{1}{\beta(1-\beta)} \int_{\bar{\mu}}^{\infty} \frac{\beta}{1-\beta} \frac{1}{\bar{\mu}} \left(\frac{\bar{\mu}}{\mu_i} \right)^{\frac{1}{1-\beta}} \left[\frac{\mu_i}{\bar{\mu}} - 1 \right] dF(\mu_i) \overset{\mu_i \geq \bar{\mu}}{\Longrightarrow} \frac{\partial UE}{\partial \varepsilon} > 0.$$

iii

$$\overset{F(\mu) \sim N(m,\sigma)}{\Longrightarrow} UE = \Phi \left(\frac{\bar{\mu} - m}{\sigma} \right) + \int_{\bar{\mu}}^{\infty} g(\mu_i, \bar{\mu}) \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\mu_i - m)^2}{2\sigma^2}} d\mu_i = \int_{-\infty}^{\bar{\mu}} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\mu_i - m)^2}{2\sigma^2}} d\mu_i + \int_{\bar{\mu}}^{\infty} g(\mu_i, \bar{\mu}) \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\mu_i - m)^2}{2\sigma^2}} d\mu_i$$

$$\frac{\partial UE}{\partial \sigma} = \int_{-\infty}^{\bar{\mu}} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\mu_i - m)^2}{2\sigma^2}} [\frac{-1}{\sigma} + \frac{(\mu_i - m)^2}{\sigma^3}] d\mu_i + \int_{\bar{\mu}}^{\infty} g(\mu_i, \bar{\mu}) \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\mu_i - m)^2}{2\sigma^2}} [\frac{-1}{\sigma} + \frac{(\mu_i - m)^2}{\sigma^3}] d\mu_i$$

$$= \int_{-\infty}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\mu_i - m)^2}{2\sigma^2}} [\frac{-1}{\sigma} + \frac{(\mu_i - m)^2}{\sigma^3}] d\mu_i + \int_{\bar{\mu}}^{\infty} [g(\mu_i, \bar{\mu}) - 1] \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\mu_i - m)^2}{2\sigma^2}} [\frac{-1}{\sigma} + \frac{(\mu_i - m)^2}{\sigma^3}] d\mu_i$$

The first expression is equal to zero due to the following rule about moments of normal distribution:

$$if x \sim N\ E(x^p) = \begin{cases} 0 & p \text{ is odd} \\ \sigma^p (p-1)!! & p \text{ is even} \end{cases} \Rightarrow \int_{-\infty}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\mu_i - m)^2}{2\sigma^2}} \left[\frac{-1}{\sigma} + \frac{(\mu_i - m)^2}{\sigma^3} \right] d\mu_i = \frac{-1}{\sigma} + \frac{1}{\sigma^3} \left[\sigma^2 (2-1)!! \right] = 0$$

Hence, $\frac{\partial UE}{\partial \sigma}$ is reduced just to the second expression. The sign of $\frac{\partial UE}{\partial \sigma}$ depends on the sign of $\left[\frac{-1}{\sigma}+\frac{(\mu_i-m)^2}{\sigma^3}\right]$, which must be examined based on the relative size of $\bar{\mu}$ to $(m\pm\sigma)$, which are the roots of $\left[\frac{-1}{\sigma}+\frac{(\mu_i-m)^2}{\sigma^3}\right]$. In parts *a* to *c* we explore all possible cases and show that this expression is always positive.

a $\bar{\mu} > m+\sigma$

$$\frac{\partial UE}{\partial \sigma}=\frac{-1}{\sigma^2}\int_{\bar{\mu}}^{\infty}\left[1-g(\mu_i,\bar{\mu})\right]\left[(\mu_i-m)^2-\sigma^2\right]dF(\mu_i)\overset{[1-g(\mu_i,\bar{\mu})],\ \left[(\mu_i-m)^2-\sigma^2\right]>0}{\Rightarrow}\frac{\partial UE}{\partial \sigma}>0$$

b $m-\sigma<\bar{\mu}<m+\sigma$

$$\frac{\partial UE}{\partial \sigma}=\frac{-1}{\sigma^2}\left\{\int_{\bar{\mu}}^{m+\sigma}\left[1-g(\mu_i,\bar{\mu})\right]\left[(\mu_i-m)^2-\sigma^2\right]dF(\mu_i)+\int_{m+\sigma}^{\infty}\left[1-g(\mu_i,\bar{\mu})\right]\left[(\mu_i-m)^2-\sigma^2\right]dF(\mu_i)\right\}=M+N$$

$$M=\frac{-1}{\sigma^2}\int_{\bar{\mu}}^{m+\sigma}\left[1-g(\mu_i-\bar{\mu})\right]\left[(\mu_i-m)^2-\sigma^2\right]dF(\mu_i)\overset{\substack{\left[(\mu_i-m)^2-\sigma^2\right]<0\\ 0<[1-g(\mu_i,\bar{\mu})]<1}}{\Rightarrow}$$

$$M<\frac{1}{\sigma^2}\int_{\bar{\mu}}^{m+\sigma}\left[-(\mu_i-m)^2+\sigma^2\right]dF(\mu_i)=\Phi(1)-\Phi\left(\frac{\bar{\mu}-m}{\sigma}\right)-\frac{1}{\sigma^2}\int_{\bar{\mu}}^{m+\sigma}\left[(\mu_i-m)^2\right]dF(\mu_i)$$

$$N=\frac{-1}{\sigma^2}\int_{m+\sigma}^{\infty}\left[1-g(\mu_i,\bar{\mu})\right]\left[(\mu_i-m)^2-\sigma^2\right]dF(\mu_i)\overset{\substack{\left[(\mu_i-m)^2-\sigma^2\right]<0\\ 0<[1-g(\mu_i,\bar{\mu})]<1}}{\Rightarrow}$$

$$N<\frac{1}{\sigma^2}\int_{m+\sigma}^{\infty}\left[(\mu_i-m)^2-\sigma^2\right]dF(\mu_i)=1-\Phi(1)-\frac{1}{\sigma^2}\int_{m+\sigma}^{\infty}\left[(\mu_i-m)^2\right]dF(\mu_i)$$

By the assumption of normal distribution for WCR, with Φ as CDF and φ as PDF, we can write:

$$\frac{\partial UE}{\partial \sigma}=M+N<\Phi(1)-\Phi\left(\frac{\bar{\mu}-m}{\sigma}\right)-\frac{1}{\sigma^2}\int_{\bar{\mu}}^{m+\sigma}(\mu_i-m)^2dF(\mu_i)+1-\Phi(1)-\frac{1}{\sigma^2}\int_{m+\sigma}^{\infty}(\mu_i-m)^2dF(\mu_i)$$

$$=1-\Phi\left(\frac{\bar{\mu}-m}{\sigma}\right)-\frac{1}{\sigma^2}\int_{\bar{\mu}}^{\infty}(\mu_i-m)^2dF(\mu_i)=1-\Phi\left(\frac{\bar{\mu}-m}{\sigma}\right)-\int_{\frac{\bar{\mu}-m}{\sigma}}^{\infty}\left(\frac{\mu_i-m}{\sigma}\right)^2dF(\mu_i)$$

To compute above equation, consider that under the assumption of $z\sim N(0,1)$, we can calculate $\int_a^b z^2\frac{e^{-\frac{z^2}{2}}}{\sqrt{2\pi}}=\frac{-1}{\sqrt{2\pi}}\left\{-ze^{-\frac{z^2}{2}}\Big|_a^b+\int_a^b e^{-\frac{z^2}{2}}dz\right\}$.

$$\frac{\partial UE}{\partial \sigma}=M+N<1-\Phi\left(\frac{\bar{\mu}-m}{\sigma}\right)-\frac{1}{\sqrt{2\pi}}\left\{-z_ie^{-\frac{z_i^2}{2}}\Big|_{\frac{\bar{\mu}-m}{\sigma}}^{\infty}+\int_{\frac{\bar{\mu}-m}{\sigma}}^{\infty}dF(z_i)\right\}$$

$$=1-\Phi\left(\frac{\bar{\mu}-m}{\sigma}\right)-\frac{\bar{\mu}-m}{\sigma}\varphi\left(\frac{\bar{\mu}-m}{\sigma}\right)-1+\Phi\left(\frac{\bar{\mu}-m}{\sigma}\right)=-\frac{\bar{\mu}-m}{\sigma}\varphi\left(\frac{\bar{\mu}-m}{\sigma}\right)<0$$

c $\bar{\mu} < m - \sigma$

$$\frac{\partial UE}{\partial \sigma} = \frac{-1}{\sigma^2}\left\{\int_{\bar{\mu}}^{m-\sigma}[1-g(\mu_i,\bar{\mu})]\left[(\mu_i-m)^2-\sigma^2\right]dF(\mu_i) + \int_{m-\sigma}^{m+\sigma}[1-g(\mu_i,\bar{\mu})]\left[(\mu_i-m)^2-\sigma^2\right]dF(\mu_i)\right.$$
$$\left. + \int_{m+\sigma}^{\infty}[1-g(\mu_i,\bar{\mu})]\left[(\mu_i-m)^2-\sigma^2\right]dF(\mu_i)\right\} = O+P+N$$

$$O = \frac{-1}{\sigma^2}\int_{\bar{\mu}}^{m-\sigma}\left[1-g\left(\mu_i,\bar{\mu}\right)\right]\left[(\mu_i-m)^2-\sigma^2\right]dF(\mu_i) \overset{\substack{\left[(\mu_i-m)^2-\sigma^2\right]>0 \\ 0<[1-g(\mu_i,\bar{\mu})]<1}}{\Rightarrow} M < \frac{-1}{\sigma^2}\int_{\bar{\mu}}^{m+\sigma}\left[(\mu_i-m)^2-\sigma^2\right]dF(\mu_i)$$
$$= \Phi(1) - \Phi\left(\frac{\bar{\mu}-m}{\sigma}\right) - \frac{1}{\sigma^2}\int_{\frac{\bar{\mu}-m}{\sigma}}^{1}(\mu_i-m)^2 dF(\mu_i) = \Phi(1) - \Phi\left(\frac{\bar{\mu}-m}{\sigma}\right) - \frac{1}{\sqrt{2\pi}}\left\{-z_i e^{-\frac{z_i^2}{2}}\Big|_{\frac{\bar{\mu}-m}{\sigma}}^{1} + \int_{\frac{\bar{\mu}-m}{\sigma}}^{1} dF(z_i)\right\}$$
$$= \Phi(1) - \Phi\left(\frac{\bar{\mu}-m}{\sigma}\right) + \varphi(1) - \varphi\left(\frac{\bar{\mu}-m}{\sigma}\right) - \Phi(1) + \Phi\left(\frac{\bar{\mu}-m}{\sigma}\right) = \varphi(1) - \varphi\left(\frac{\bar{\mu}-m}{\sigma}\right)$$

$$P = \frac{-1}{\sigma^2}\int_{m-\sigma}^{m+\sigma}[1-g(\mu_i,\bar{\mu})]\left[(\mu_i-m)^2-\sigma^2\right]dF(\mu_i) \overset{\substack{\left[(\mu_i-m)^2-\sigma^2\right]<0 \\ 0<[1-g(\mu_i,\bar{\mu})]<1}}{\Rightarrow} M < \frac{1}{\sigma^2}\int_{m-\sigma}^{m+\sigma}\left[-(\mu_i-m)^2+\sigma^2\right]dF(\mu_i)$$
$$= \Phi(1) - \Phi(-1) - \frac{1}{\sigma^2}\int_{m-\sigma}^{m+\sigma}\left[(\mu_i-m)^2\right]\mathrm{d}F(\mu_i)$$

$$\frac{\partial UE}{\partial \sigma} = O+P+N < \varphi(1) - \varphi\left(\frac{\bar{\mu}-m}{\sigma}\right) + \Phi(1) - \Phi(-1) - \frac{1}{\sigma^2}\int_{m-\sigma}^{m+\sigma}(\mu_i-m)^2 dF(\mu_i) + 1 - \Phi(1) - \frac{1}{\sigma^2}\int_{m+\sigma}^{\infty}(\mu_i-m)^2 dF(\mu_i)$$
$$= \varphi(1) - \varphi\left(\frac{\bar{\mu}-m}{\sigma}\right) + \Phi(1) - \frac{1}{\sigma^2}\int_{m-\sigma}^{\infty}(\mu_i-m)^2 dF(\mu_i) = \varphi(1) - \varphi\left(\frac{\bar{\mu}-m}{\sigma}\right) + \Phi(1) - \int_{m-\sigma}^{\infty}\left(\frac{\mu_i-m}{\sigma}\right)^2 dF(\mu_i)$$
$$= \varphi(1) - \varphi\left(\frac{\bar{\mu}-m}{\sigma}\right) + \Phi(1) - \frac{1}{\sqrt{2\pi}}\left\{-z_i e^{-\frac{z_i^2}{2}}\Big|_{-1}^{\infty} + \int_{-1}^{\infty} dF(z_i)\right\}$$
$$= \varphi(1) - \varphi\left(\frac{\bar{\mu}-m}{\sigma}\right) + \Phi(1) + \varphi(1) - 1 + \Phi(-1) = -\varphi\left(\frac{\bar{\mu}-m}{\sigma}\right) < 0$$

Thus, based on the negative sign of $\frac{\partial UE}{\partial \sigma}$ in cases *a* to *c*, the derivative of uncertainty effect with respect to variance is negative.

Proof of Proposition 2. To compute production derivatives, based on Eq. (3), $ln\left(y_{s,i}\right)$ is:

$$ln(y_i) = \begin{cases} \dfrac{1}{1-\left(\alpha+\beta\right)} ln\left(A\left(\dfrac{\alpha}{r}\right)^{\alpha}\left(\dfrac{\beta}{w}\right)^{\beta}\right) + \dfrac{\alpha}{1-\left(\alpha+\beta\right)} ln(UE) & \mu_i \le \bar{\mu} \\ \dfrac{1}{1-\left(\alpha+\beta\right)} ln\left(A\left(\dfrac{\alpha}{r}\right)^{\alpha}\left(\dfrac{\beta}{w}\right)^{\beta}\right) + \dfrac{\alpha}{1-\left(\alpha+\beta\right)} ln(UE) + \dfrac{\beta}{1-\beta} ln\left(\dfrac{\bar{\mu}}{\mu_i}\right) & \mu_i > \bar{\mu} \end{cases}$$

where the first part, $\frac{1}{1-(\alpha+\beta)} ln\left(A\left(\frac{\alpha}{r}\right)^{\alpha}\left(\frac{\beta}{w}\right)^{\beta}\right)$, is equal to the logarithm of firm's production level in a frictionless economy, and does not change with financial market conditions and WCR.

$$\text{i}\ \frac{\partial y_i}{\partial \mu_i}=\begin{cases} y_i\left\{\dfrac{\alpha}{1-(\alpha+\beta)}\dfrac{\partial \text{UE}}{\partial \mu_i}\dfrac{1}{\text{UE}}\right\} & \mu_i\le\bar{\mu}\\ y_i\left\{\dfrac{\alpha}{1-(\alpha+\beta)}\dfrac{\partial \text{UE}}{\partial \mu_i}\dfrac{1}{\text{UE}}-\dfrac{\beta}{1-\beta}\dfrac{\ln(\mu_i)}{\partial \mu_i}\right\} & \mu_i>\bar{\mu}\end{cases} \quad \frac{\partial \text{UE}}{\partial \mu_i}\xRightarrow{}=0 \begin{cases}0 & \mu_i\le\bar{\mu}\\ -\dfrac{\beta y_i}{(1-\beta)}\cdot\dfrac{1}{\mu_i} & \mu_i>\bar{\mu}\end{cases}\Rightarrow\frac{\partial y_i}{\partial \mu_i}\le 0$$

$$\text{ii}\ \frac{\partial y_i}{\partial \sigma}=y_i\cdot\frac{\alpha}{1-(\alpha+\beta)}\cdot\frac{1}{\text{UE}}\cdot\frac{\partial UE}{\partial \sigma}\xRightarrow{\frac{\partial UE}{\partial \sigma}<0}\frac{\partial y_i}{\partial \sigma}<0$$

$$\text{iii}\ \frac{\partial y_{s,i}}{\partial \varepsilon}=\begin{cases} y_i\{\dfrac{\alpha}{1-(\alpha+\beta)}\dfrac{\partial \text{UE}}{\partial \varepsilon}\dfrac{1}{\text{UE}}\} & \mu_i\le\bar{\mu}\\ y_i\{\dfrac{\alpha}{1-(\alpha+\beta)}\dfrac{\partial \text{UE}}{\partial \varepsilon}\dfrac{1}{\text{UE}}+\dfrac{\beta}{1-\beta}\dfrac{ln(\bar{\mu})}{\partial \varepsilon}\} & \mu_i>\bar{\mu}\end{cases}=\begin{cases} y_i\cdot\dfrac{\alpha}{1-(\alpha+\beta)}\cdot\dfrac{1}{\text{UE}}\cdot\dfrac{\partial UE}{\partial \varepsilon} & \mu_i\le\bar{\mu}\\ y_i\cdot\{\dfrac{\alpha}{1-(\alpha+\beta)}\cdot\dfrac{1}{\text{UE}}\cdot\dfrac{\partial UE}{\partial \varepsilon}+\dfrac{1}{1-\beta}\cdot\dfrac{1}{\bar{\mu}}\} & \mu_i>\bar{\mu}\end{cases}\xRightarrow{\frac{\partial UE}{\partial \varepsilon}>0}\frac{\partial y_i}{\partial \varepsilon}>0$$

$$\frac{\partial^2 y_i}{\partial \varepsilon\partial \mu_i}=\begin{cases}0 & \mu_i\le\bar{\mu}\\ -\dfrac{\beta}{(1-\beta)}\cdot\dfrac{1}{\mu_i}\cdot\dfrac{\partial y_i}{\partial \varepsilon} & \mu_i>\bar{\mu}\end{cases}\Rightarrow\frac{\partial y_i}{\partial \mu_i}\le 0=\begin{cases}0 & \mu_i\le\bar{\mu}\\ -\dfrac{\beta}{(1-\beta)}\cdot\dfrac{1}{\mu_i}\cdot\left[\dfrac{\alpha}{1-(\alpha+\beta)}\cdot\dfrac{1}{\text{UE}}\cdot\dfrac{\partial UE}{\partial \varepsilon}+\dfrac{1}{1-\beta}\cdot\dfrac{1}{\bar{\mu}}\right] & \mu_i>\bar{\mu}\end{cases}.$$

$$\xRightarrow{\frac{\partial UE}{\partial \varepsilon}>0}\frac{\partial^2 y_i}{\partial \varepsilon\partial \mu_i}\le 0$$

Proof of Proposition 3. We can easily show that marginal productivity of capital is lower for constrained firms owing to lower level of employment.

$$mpk_u=\frac{\alpha}{1-\beta}A^{\frac{1}{1-\beta}}\left(\frac{\beta}{w}\right)^{\frac{\beta}{1-\beta}}k^{\frac{\alpha}{1-\beta}-1}-w\frac{\alpha}{1-\beta}A^{\frac{1}{1-\beta}}\left(\frac{\beta}{w}\right)^{\frac{1}{1-\beta}}k^{\frac{\alpha}{1-\beta}-1}$$

$$mpk_{c,i}=\frac{\alpha}{1-\beta}A^{\frac{1}{1-\beta}}\left(\frac{\beta}{w}\right)^{\frac{\beta}{1-\beta}}k^{\frac{\alpha}{1-\beta}-1}\left(\frac{\bar{\mu}}{\mu_i}\right)^{\frac{\beta}{1-\beta}}-w\frac{\alpha}{1-\beta}A^{\frac{1}{1-\beta}}\left(\frac{\beta}{w}\right)^{\frac{1}{1-\beta}}k^{\frac{\alpha}{1-\beta}-1}\left(\frac{\bar{\mu}}{\mu_i}\right)^{\frac{1}{1-\beta}}$$

$$\frac{mpk_{c,i}}{mpk_u}=\frac{1}{1-\beta}\left[\left(\frac{\bar{\mu}}{\mu_i}\right)^{\frac{\beta}{1-\beta}}-\beta\left(\frac{\bar{\mu}}{\mu_i}\right)^{\frac{1}{1-\beta}}\right]=g(\mu_i,\bar{\mu})<1\Rightarrow\frac{mpk_{c,i}}{mpk_u}<1$$

The profit function is:

$$\pi_i=\begin{cases} y_{u,i}\left[1-\alpha.UE-\beta\right] & \mu_i\le\bar{\mu}\\ y_{c,i}\left[1-\alpha.UE.\left(\dfrac{\bar{\mu}}{\mu_i}\right)^{\dfrac{-\beta}{1-\beta}}-\beta\dfrac{\bar{\mu}}{\mu_i}\right] & \mu_i>\bar{\mu}\end{cases}$$

Since α, β and UE are less than one, $1-\alpha.UE-\beta>0$, unconstrained firms' return is always positive. Although for all constrained firms return is a decreasing function of WCR, there is a threshold level, μ_0, that specifies firms' loss or profit. The μ_0 is computable based on $\alpha.UE.\left(\frac{\bar{\mu}}{\mu_0}\right)^{\frac{-\beta}{1-\beta}}+\beta\frac{\bar{\mu}}{\mu_0}=1$. Firms whose WCR is below μ_0 gain positive return. Higher need for working capital causes a loss; however, these firms do not exit from the market since the loss is less than the capital rent.

$$\frac{\pi_i}{y_i}=\begin{cases}\left[1-\alpha.UE-\beta\right]>0 & \mu_i\le\bar{\mu}\\ \left[1-\alpha.UE.\left(\dfrac{\bar{\mu}}{\mu_i}\right)^{\dfrac{-\beta}{1-\beta}}-\beta\dfrac{\bar{\mu}}{\mu_i}\right]>0 & \mu_0>\mu_i>\bar{\mu}\\ \left[1-\alpha.UE.\left(\dfrac{\bar{\mu}}{\mu_i}\right)^{\dfrac{-\beta}{1-\beta}}-\beta\dfrac{\bar{\mu}}{\mu_i}\right]<0 & \mu_i>\mu_0\end{cases}$$

Lemma A3. *Affected by the uncertainty and aggregate binding effects, the aggregate production level* (i) *is lower compared with a frictionless economy. The difference between production in mentioned two economies decreases by* (ii) an improvement in financial market conditions($\frac{\partial Y}{\partial \varepsilon}>0$), and ($iii$) *being more certain about working capital* [$\frac{\partial Y}{\partial \sigma}<0$, *for* $F(\mu)\sim N(m,\sigma)$].

Proof of Lemma A3

i It is easy to show that aggregate production in a frictionless economy is equal to $\left[A\left(\frac{\alpha}{r}\right)^{\alpha}\left(\frac{\beta}{w}\right)^{\beta}\right]^{\frac{1}{1-(\alpha+\beta)}}$.

$$Y=\int_{-\infty}^{\bar{\mu}}\left[A\left(\frac{\alpha}{r}\right)^{\alpha}\left(\frac{\beta}{w}\right)^{\beta}\right]^{\frac{1}{1-\left(\alpha+\beta\right)}}UE^{\frac{\alpha}{1-\left(\alpha+\beta\right)}}dF\left(\mu_i\right)+\int_{\bar{\mu}}^{\infty}\left[A\left(\frac{\alpha}{r}\right)^{\alpha}\left(\frac{\beta}{w}\right)^{\beta}\right]^{\frac{1}{1-\left(\alpha+\beta\right)}}UE^{\frac{\alpha}{1-\left(\alpha+\beta\right)}}\left(\frac{\bar{\mu}}{\mu_i}\right)^{\frac{\beta}{1-\beta}}dF\left(\mu_i\right)$$

$$=\left[A\left(\frac{\alpha}{r}\right)^{\alpha}\left(\frac{\beta}{w}\right)^{\beta}\right]^{\frac{1}{1-\left(\alpha+\beta\right)}}.UE^{\frac{\alpha}{1-\left(\alpha+\beta\right)}}\left\{F\left(\bar{\mu}\right)+\int_{\bar{\mu}}^{\infty}\left(\frac{\bar{\mu}}{\mu_i}\right)^{\frac{\beta}{1-\beta}}dF\left(\mu\right)\right\}$$

$$BE_Y=F(\bar{\mu})+\int_{\bar{\mu}}^{\infty}(\frac{\bar{\mu}}{\mu_i})^{\frac{\beta}{1-\beta}}dF(\mu)\overset{(\frac{\bar{\mu}}{\mu_i})<1,\frac{\beta}{1-\beta}>0}{\Rightarrow}BE_Y<1\Rightarrow Y_s<[A(\frac{\alpha}{r})^{\alpha}(\frac{\beta}{w})^{\beta}]^{\frac{1}{1-(\alpha+\beta)}}$$

ii $$\frac{\partial BE_Y}{\partial\varepsilon}=\frac{\partial BE_Y}{\partial\bar{\mu}}\frac{\partial\bar{\mu}}{\partial\varepsilon}=\frac{1}{\beta}\int_{\bar{\mu}}^{\infty}\frac{\beta}{1-\beta}\frac{1}{\bar{\mu}}\left(\frac{\bar{\mu}}{\mu_i}\right)^{\frac{\beta}{1-\beta}}dF\left(\mu_i\right)>0$$

$$\frac{\partial Y}{\partial\varepsilon}=Y.\left[\frac{\alpha}{1-\left(\alpha+\beta\right)}\cdot\frac{1}{UE}\cdot\frac{\partial UE}{\partial\varepsilon}+\frac{1}{BE_Y}\frac{\partial BE_Y}{\partial\varepsilon}\right]\overset{\frac{\partial UE}{\partial\varepsilon},\frac{\partial BE_Y}{\partial\varepsilon}>0}{\Rightarrow}\frac{\partial Y}{\partial\varepsilon}>0$$

iii The steps of demonstrating that aggregate binding effect is a decreasing function in uncertainty ($\frac{\partial BE_Y}{\partial\sigma}<0$), is just similar to $\frac{\partial UE}{\partial\sigma}<0$, mentioned in the part iii of Proposition 2.

$$\frac{\partial Y}{\partial\sigma}=Y.\left[\frac{\alpha}{1-\left(\alpha+\beta\right)}\cdot\frac{1}{UE}\cdot\frac{\partial UE}{\partial\sigma}+\frac{1}{BE_Y}\frac{\partial BE_Y}{\partial\sigma}\right]\overset{\frac{\partial UE}{\partial\sigma},\frac{\partial BE_Y}{\partial\sigma}<0}{\Rightarrow}\frac{\partial Y}{\partial\sigma}<0$$

Lemma A4

i *ATFP differs from aggregate productivity level due to misallocation of inputs.*
ii *ATFP rises with an improvement in financial market conditions* ($\frac{\partial \mathrm{ATFP}}{\partial\varepsilon}>0$)
iii *ATFP decreases with WCU* ($\frac{\partial \mathrm{ATFP}}{\partial\sigma}<0$, *for* $\mathrm{F}(\mu)\sim\mathrm{N}(\mathrm{m},\sigma)$).

Proof of Lemma A4

i Aggregate labor and capital inputs are defined as follows:

$$K=\int_{-\infty}^{\infty}kdF\left(\mu_i\right)=k$$

$$H=\int_{-\infty}^{\bar{\mu}}\left[\frac{\beta}{w}Ak^{\alpha}\right]^{\frac{1}{1-\beta}}dF\left(\mu_i\right)+\int_{\bar{\mu}}^{\infty}\left[\frac{\beta}{w}\frac{\bar{\mu}}{\mu_i}Ak^{\alpha}\right]^{\frac{1}{1-\beta}}dF\left(\mu_i\right)=\left[\frac{\beta}{w}Ak^{\alpha}\right]^{\frac{1}{1-\beta}}\left[F\left(\bar{\mu}\right)+\int_{\bar{\mu}}^{\infty}\left(\frac{\bar{\mu}}{\mu_i}\right)^{\frac{1}{1-\beta}}dF\left(\mu_i\right)\right]=\left[\frac{\beta}{w}Ak^{\alpha}\right]^{\frac{1}{1-\beta}}.BE_H$$

where $BE_H = F(\bar{\mu}) + \int_{\bar{\mu}}^{\infty} \left(\frac{\bar{\mu}}{\mu_i}\right)^{\frac{1}{1-\beta}} dF(\mu)$, thus:

$$TFP = \frac{Y}{K^{\alpha}H^{\beta}} = A \times \frac{F(\bar{\mu}) + \int_{\bar{\mu}}^{\infty} \left(\frac{\bar{\mu}}{\mu_i}\right)^{\frac{\beta}{1-\beta}} dF(\mu_i)}{\left[F(\bar{\mu}) + \int_{\bar{\mu}}^{\infty} \left(\frac{\bar{\mu}}{\mu_i}\right)^{\frac{1}{1-\beta}} dF(\mu_i)\right]^{\beta}} = A \times \frac{BE_Y}{[BE_H]^{\beta}}$$

ii

$$\frac{\partial TFP}{\partial \varepsilon} = \frac{\partial TFP}{\partial \bar{\mu}} \cdot \frac{\partial \bar{\mu}}{\partial \varepsilon} = \frac{TFP}{\beta}\left[\frac{\partial BE_Y}{\partial \bar{\mu}} \cdot \frac{1}{BE_Y} - \beta \frac{\partial BE^H}{\partial \bar{\mu}} \cdot \frac{1}{BE_H}\right]$$

$$= \frac{TFP}{\beta}\left[\frac{1}{BE_Y} \cdot \frac{\beta}{1-\beta} \cdot \frac{1}{\bar{\mu}} \int_{\bar{\mu}}^{\infty} \left(\frac{\bar{\mu}}{\mu_i}\right)^{\frac{\beta}{1-\beta}} dF(\mu_i) - \frac{\beta}{BE_H} \cdot \frac{1}{1-\beta} \cdot \frac{1}{\bar{\mu}} \int_{\bar{\mu}}^{\infty} \left(\frac{\bar{\mu}}{\mu_i}\right)^{\frac{1}{1-\beta}} dF(\mu_i)\right]$$

$$= \frac{TFP}{\bar{\mu}\left(1-\beta\right)}\left\{\frac{BE_Y - F(\bar{\mu})}{BE_Y} - \frac{BE_H - F(\bar{\mu})}{BE_H}\right\} = \frac{TFP.F(\bar{\mu})}{\bar{\mu}\left(1-\beta\right)}\left\{\frac{1}{BE_H} - \frac{1}{BE_Y}\right\} \overset{BE_Y \geq BE_H}{\Rightarrow} \frac{\partial TFP}{\partial \varepsilon} > 0$$

$$\frac{\partial TFP}{\partial \sigma} = \frac{TFP}{BE_Y}\left[\frac{\partial BE_Y}{\partial \sigma} - \beta \frac{\partial BE^H}{\partial \sigma} \cdot \frac{BE_Y}{BE_H}\right] \overset{BE_Y \geq BE_H}{\Rightarrow} \frac{\partial TFP}{\partial \sigma} < \frac{TFP}{BE_Y}\left[\frac{\partial BE_Y}{\partial \sigma} - \beta \frac{\partial BE^H}{\partial \sigma}\right]$$

$$\frac{\partial BE_Y}{\partial \sigma} = \int_{\bar{\mu}}^{\infty} \left[\left(\frac{\bar{\mu}}{\mu_i}\right)^{\frac{\beta}{1-\beta}} - 1\right] \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\mu_i - m)^2}{2\sigma^2}} \left[\frac{-1}{\sigma} + \frac{(\mu_i - m)^2}{\sigma^3}\right] d\mu_i$$

$$\frac{\partial BE_H}{\partial \sigma} = \int_{\bar{\mu}}^{\infty} \left[\left(\frac{\bar{\mu}}{\mu_i}\right)^{\frac{1}{1-\beta}} - 1\right] \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\mu_i - m)^2}{2\sigma^2}} \left[\frac{-1}{\sigma} + \frac{(\mu_i - m)^2}{\sigma^3}\right] d\mu_i$$

$$\left[\frac{\partial BE_Y}{\partial \sigma} - \beta \frac{\partial BE^H}{\partial \sigma}\right] = \int_{\bar{\mu}}^{\infty} \left\{\left[\left(\frac{\bar{\mu}}{\mu_i}\right)^{\frac{\beta}{1-\beta}} - 1\right] - \beta\left[\left(\frac{\bar{\mu}}{\mu_i}\right)^{\frac{1}{1-\beta}} - 1\right]\right\} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\mu_i - m)^2}{2\sigma^2}} \left[\frac{-1}{\sigma} + \frac{(\mu_i - m)^2}{\sigma^3}\right] d\mu_i$$

$$= \int_{\bar{\mu}}^{\infty} \left\{\left[\frac{\left(\frac{\bar{\mu}}{\mu_i}\right)^{\frac{\beta}{1-\beta}} - \beta\left(\frac{\bar{\mu}}{\mu_i}\right)^{\frac{1}{1-\beta}}}{1-\beta}\right] - 1\right\} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\mu_i - m)^2}{2\sigma^2}} \left[\frac{-1}{\sigma} + \frac{(\mu_i - m)^2}{\sigma^3}\right] d\mu_i$$

$$= \int_{\bar{\mu}}^{\infty} [g(\mu_i, \bar{\mu}) - 1] \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\mu_i - m)^2}{2\sigma^2}} \left[\frac{-1}{\sigma} + \frac{(\mu_i - m)^2}{\sigma^3}\right] d\mu_i = \frac{\partial UE}{\partial \sigma} < 0 \Rightarrow \frac{\partial TFP}{\partial \sigma} < 0$$

Appendix B. Variable definitions

32. Capital stock

Replacement value of capital stock is constructed using the perpetual inventory method (PIM) (Blundell, Bond, Devereux, & Schiantarelli, 1992). For each firm, we choose the starting value equal to the market value of capital[32] in the first observation in our sample period, adjusted for the previous year's inflation. Thereafter, the capital of future years is obtained by the perpetual inventory formula.

$$K_{i,s,t} = \left(1-\delta\right) K_{i,s,t-1} + \frac{I_{i,s,t}}{P_t}$$

[32] We construct the capital item by adding the stock of machinery, durable gadgets, office equipment, vehicles, constructions and installations, and computer software.

To deflate the nominal values of investment[33] ($I_{i,s,t}$) and capital ($K_{i,s,t}$), we use the gross fixed capital indices[34] (P_t) for the manufacturing and mining sectors from national accounts. The depreciation rates for the building and machinery items (δ) are respectively considered 2.5 and 5% as computed by Tamassoki (2005). Subscripts of *i,s* and *t* represent firm, industry and time dimensions.

1. Production index

We use two proxies for the production index.

1 *Production_BB*: to construct the production index, we apply the method of Blundell and Bond (2000) to estimate the production function, and use the residuals to compute adjusted production. Consider the Cobb–Douglas production function:

$$y_{i,s,t} = \beta_l l_{i,s,t} + \beta_k k_{i,s,t} + \gamma_t + \left(\eta_i + \nu_{i,s,t} + m_{i,s,t}\right),$$

$$\nu_{i,s,t} = \rho\nu_{i,s,t-1} + e_{i,s,t}|\rho| < 1, \quad m_{i,s,t}, e_{i,s,t} \sim MA(0)$$

where $y_{i,s,t}$, $l_{i,s,t}$ and $k_{i,s,t}$ are respectively the logarithm of firm's value-added,[35] labor[36] and capital stock. γ_t is the year dummy variable, η_i is unobserved time-invariant firm specific effect, $\nu_{i,s,t}$ is the productivity shock and $m_{i,s,t}$ is serially uncorrelated measurement errors. We estimate the production function based on this method, using the second to fourth lags of dependent variable as instruments for the difference equation. In addition, we use the time dummies and sectors' inflation as instruments for the difference and level equations. As the estimation was in logarithmic form, we introduce the exponential form of estimated residuals as the production index.

2 *Sales/K*: we use real sale per capital as an alternative measure that represents firm's activity. To consider the level of firm's size on sales, we divide the real sales (deflated with PPI in the 2-digit industry) with capital.

Working capital requirement (WCR)

We construct a firm-level measure of WCR by the concept of days inventory outstanding (DIO), the ratio of the end of period raw materials inventory to the sale, which indicates how many times on average, a firm turns its inventory into sales. To solve the endogeneity problem that may arise by using the current value of DIO as an independent variable in firms' performance regression, we quantify WCR as the median of previous values of DIO, for each firm-year,

As an alternative index, WCR is defined as the median of lag values of DOI'. DOI' is the ratio of raw materials inventory to the cost of goods sold. By this alternative definition, which is common in accounting literature, we have also controlled for changes in the firms' markups.

Industry's WCR

For each industry-year, the ratio of total raw materials to total sales is considered as WCR in the industry level.

37. Industry's relative price

To construct the input prices for the 2-digit industries,[37] we compute the weighted average price of all activities that are considered as inputs for an industry in the Input–Output table. We define activities and their weights based on the Input–Output table 2011 provided by Islamic Parliament Research Center of Iran. The monthly PPIs (constant 2004) gathered from the Central Bank of Iran. For each industry, we define the relative price as the ratio of computed input price to the appropriate PPI.

$$m_{s,t} = relative\,raw\,material\,price_{s,t} = \Sigma_{u=1}^{71}\alpha_u \frac{PPI_{u,t}}{PPI_{s,t}}, \quad \alpha_u \in IO\ (IO\,has\,71\,activities)$$

38. Industry's relative wage

Quarterly wage indices (constant 2004) for the 2-digit industries are received from the *Large Manufacturing Enterprises Survey*[38] implemented by the Central Bank of Iran. The relative wage is computed by dividing this index by the appropriate PPI.

$$w_{s,t} = relative\,wage\,price_{s,t} = \frac{WI_{s,t}}{PPI_{s,t}}$$

[33] Investment in each item of capital is defined as the sum of purchased capital, built or repaired capital inside the establishment, built or repaired capital outside the establishment, minus sold or transferred capital.

[34] We construct the index by dividing current value of gross fixed capital in manufacturing and mining to the constant value of this item (2004 = 100) from national account.

[35] For each establishment, value added is defined as output minus input. Output is the sum of produced ware and capital-goods by establishment, revenues from industrial services, revenues from instalment and setting-up the produced items, changes in value of goods in progress and the value of those goods that are sold without any modification. Input is the sum of expenditures on raw materials, fuel and payments for industrial services.

[36] Labor is the number of workers in each establishment.

[37] PPI and IO tables do not provide more details about industry classifications.

[38] This survey includes about 2000 large enterprises with more than 100 workers. Though our panel dataset is composed of enterprises with 10 or more workers, the only available wage index with higher frequency than annual is the one extracted from *Large Manufacturing Enterprises Survey*.

1. *Working capital uncertainty (WCU)*

We use two measures of uncertainty about working capital based on dispersion of WCR and the price volatility of inputs.

1. *WCU_Dispersion*: for each year, firms are classified based on their size[39] and industry. We consider the standard deviation of DIO in each group as the WCU index for all group members.
2. *WCU_Price*: for the indices of industry relative price and wage, the standard deviations of observations in each year are computed as the uncertainty index about materials and wage expenditure in that industry. A weighted average of these uncertainty indices is computes based on the benchmark share of materials and wage in each group. Groups are defined based on size and industry as above. For each group, we compute the average share of materials (wage[40]) as the benchmark share of materials (wage) for that firm.

$$w\_share_{s,t} = \frac{\sum_{i=1}^{n_s} wage_{\,i,s,t}}{\sum_{i=1}^{n_s} wage_{i,s,t} + raw\ material_{\,i,s,t}}$$

$$m\_share_{s,t} = \frac{\sum_{i=1}^{n_s} raw\ material_{\,i,s,t}}{\sum_{i=1}^{n_s} wage_{i,s,t} + raw\ material_{\,i,s,t}}$$

$$WCU_{i,s,t} = \left[w\_share_{s,t}.var\left(w_{s,t}\right) + m\_share_{s,t}.var\left(m_{s,t}\right) + 2.w\_share_{s,t}.m\_share_{s,t}.covar\left(w_{s,t}, m_{s,t}\right)\right]^{1/2}$$

1. *Prepaid inputs' employment*

1. *Materials/K*: the raw materials and fuel costs divided by capital stock is our main proxy that displays the employed level of prepaid inputs. We deflate the numerator with industry's input price index.
2. *Wage/K*: to measure the labor input, we count the firms' labor cost, consists of wage and nonwage bills, rather than its employment, as mentioned by Hsieh and Klenow (2009). The index is the ratio of real wage to capital. To deflate the wage, we use the wage price index from Central Bank of Iran.

1. *Capacity utilization*

1. *CU_Btu*: capacity utilization index is constructed by dividing the ratio of the firms' Btu usage to capital stock to the benchmark value. For each firm, the median of Btu usage to capital is considered as the benchmark.
2. *CU_Electricity*: we scaled the ratio of the firms' Electricity usage to capital stock to the benchmark value. For each firm, the median of electricity usage to capital is considered as the benchmark.

1. *Financial constraint index*

While we are not able to compute the common continuous indexes, we use the ex-ante classification of the observations based on two specified characteristics of constrained firms.

1. Firms are sorted based on the scaled growth rate on raw materials inventory. For each year, we mark three quarters of firms with the lower normal growth rate as potentially constrained and the rest as potentially unconstrained. This method gives us a time-variant firm specific dummy variable for financial constraint.
2. We assume that variation in the loan to the value of industrial sector is a suitable proxy for firms' variation in access to finance. Correlation of production index with loan to value added in the industry sector is our alternative classification index. We mark the three quarter of firms with the higher correlation as potentially constrained and the rest as potentially unconstrained. This method provides us a firm-specific dummy variable for financially constrained.

Industry's real sales growth rate

We consider the growth rate of total sales of industry computed from *Annual Survey of Iranian Manufacturing Enterprises*, deflated by the proper PPI, as industry's real sale growth rate.

Industry's Inflation

The growth rate of proper PPI deflator for the 2-digit industry from the Central bank of Iran is used as an index for industry inflation

Appendix C. An introduction to database: "*Annual Survey of Iranian Manufacturing Enterprises*"

[39] Size groups are defined based on number of workers. Firms with 10–49, 50–399 and more than 400 workers are considered as small, medium and large, respectively.
[40] Wage consists of wage and non-wage payments to workers.

Table C1
Summary Statistics of the Main Variables By Year.

year		Add-Value (million $)	Labor (1000 person)	Capital (million $)	Raw Inv. (Million $)	Energy (million Btu)	Wage (million $)	Expend (million $)
2005	Observation	16,966	16,966	16,966	16,832	16,966	16,953	16,953
	Sum	220	1068	31,350	8581	735	117	315
	Mean	0.01	0.06	1.84	0.51	0.04	0.01	0.02
	CV	13.60	3.89	14.35	13.13	23.33	7.33	15.27
2006	Observation	12,737	12,737	12,734	12,737	12,737	12,726	12,726
	Sum	254	1002	36,041	9954	821	120	354
	Mean	0.02	0.08	2.83	0.78	0.06	0.01	0.03
	CV	11.79	3.73	12.02	11.48	19.42	6.97	12.19
2007	Observation	15,463	15,460	14,206	15,351	15,463	15,446	15,449
	Sum	288	1158	45,423	14,073	931	144	445
	Mean	0.02	0.07	3.19	0.91	0.06	0.01	0.03
	CV	12.19	3.65	11.25	8.94	18.73	7.60	11.34
2008	Observation	14,773	14,773	12,803	14,619	14,773	14,759	14,759
	Sum	275	1197	50,343	19,794	1010	156	447
	Mean	0.02	0.08	3.94	1.35	0.07	0.01	0.03
	CV	11.42	3.59	10.72	14.10	18.24	8.14	11.40
2009	Observation	14,038	13,863	11,016	12,486	14,038	13,850	14,026
	Sum	280	1182	51,487	18,421	1030	61	747
	Mean	0.02	0.09	4.68	1.48	0.07	0.00	0.05
	CV	12.51	3.91	10.10	9.89	16.65	7.93	19.62
2010	Observation	13,574	13,231	10,029	11,741	13,574	13,221	13,564
	Sum	284	1179	53,890	20,366	1380	59	705
	Mean	0.02	0.09	5.38	1.73	0.10	0.00	0.05
	CV	13.66	4.17	10.23	8.02	19.44	7.99	16.97
2011	Observation	13,939	13,258	9707	11,442	13,939	13,244	13,922
	Sum	279	1186	55,149	25,286	1490	69	775
	Mean	0.02	0.09	5.69	2.21	0.11	0.01	0.06
	CV	12.00	4.23	9.21	9.75	20.72	10.81	20.74

Notes: "*Annual Survey* of Iranian *Manufacturing Enterprises*" from 2005 to 2011. To compute the values in Dollar, we calculate the real values of value added (Add-Value), capital stock (Capital), raw materials inventory (Raw Inv.), payments to labor (Wage) and sum of materials and fuels expenditure (Expend). Except for payments to labor, we use PPI (2004 = 100) to deflate the current values. We deflate payments to labor with wage index for the 2-digit industries (2004 = 100) from *Large Manufacturing Enterprises Survey*. The real values converted to the U.S. Dollar based on the official exchange rate of 2004, which was 8740 Rails (Iranian Currency).

Table C2
SHARE of main variables in the 2-digit industry in 2011.

		Add-Value (million $)	Labor (1000 person)	Capital (million $)	Raw Inv. (million $)	Energy (million Btu)	Wage (million $)	Expend (million $)
15. Manufacture of food products & beverages	Obs. (%)	18.73	19.04	21.04	18.47	18.73	19.06	18.75
	Sum (%)	6.68	15.18	9.88	9.05	4.49	7.31	8.24
16. Manufacture of tobacco products	Obs. (%)	0.01	0.02	0.02	0.02	0.01	0.02	0.01
	Sum (%)	0.46	0.63	0.41	0.84	0.02	1.37	0.10
17. Manufacture of textiles	Obs. (%)	7.65	7.60	6.62	8.27	7.65	7.61	7.66
	Sum (%)	2.57	6.34	3.36	2.80	0.97	4.17	1.52
18. Manufacture of wearing apparel, dressing, & dyeing of fur	Obs. (%)	1.15	1.15	1.10	1.06	1.15	1.15	1.15
	Sum (%)	0.28	0.62	0.12	0.15	0.03	0.40	0.13
19. Tanning & dressing of leather, manufacture of luggage, . . .	Obs. (%)	1.02	0.94	0.70	0.90	1.02	0.94	1.02
	Sum (%)	0.20	0.52	0.13	0.26	0.03	0.28	0.11
20. Manufacture of wood, & of products of wood & cork, . . .	Obs. (%)	0.97	1.00	1.17	1.09	0.97	1.00	0.97
	Sum (%)	0.43	0.58	0.35	0.46	0.23	0.53	0.28
21. Manufacture of paper & paper products	Obs. (%)	2.25	2.27	2.44	2.35	2.25	2.27	2.26
	Sum (%)	0.64	1.59	0.71	1.36	0.77	1.32	0.44
22. Publishing, printing & reproduction of recorded media	Obs. (%)	1.38	1.35	1.09	1.07	1.38	1.35	1.38
	Sum (%)	0.31	0.86	0.32	0.77	0.06	0.47	0.13
23. Manufacture of coke, refined petroleum products, & nuclear fuel	Obs. (%)	0.85	0.89	0.97	0.91	0.85	0.89	0.85
	Sum (%)	2.49	2.13	7.18	7.92	9.73	0.90	42.39
24. Manufacture of chemicals & chemical products	Obs. (%)	6.54	6.53	7.33	6.78	6.54	6.54	6.54
	Sum (%)	21.97	9.65	27.80	14.66	29.13	12.10	11.20
25. Manufacture of rubber & plastics products	Obs. (%)	6.36	6.16	5.68	6.42	6.36	6.17	6.37
	Sum (%)	2.62	4.63	2.39	3.24	0.77	3.21	1.64
26. Manufacture of other non-metallic mineral products	Obs. (%)	20.45	20.52	17.84	19.89	20.45	20.55	20.48
	Sum (%)	12.30	13.09	12.82	6.92	23.22	12.67	2.41
27. Manufacture of basic metals	Obs. (%)	4.22	4.34	4.96	4.47	4.22	4.35	4.22
	Sum (%)	14.10	10.16	18.94	17.74	25.64	11.15	10.53
28. Manufacture of fabricated metal products, except machinery, etc	Obs. (%)	7.58	7.45	6.86	7.18	7.58	7.46	7.59
	Sum (%)	3.19	5.90	2.26	3.98	0.59	5.16	1.51
29. Manufacture of machinery & equipment n.e.c.	Obs. (%)	6.77	6.68	6.96	6.83	6.77	6.68	6.77
	Sum (%)	2.54	6.43	2.74	6.11	0.69	3.71	1.36
30. Manufacture of office, accounting, & computing machinery	Obs. (%)	0.25	0.26	0.31	0.22	0.25	0.26	0.25
	Sum (%)	0.22	0.46	0.21	0.19	0.02	0.33	0.14
31. Manufacture of electrical machinery & apparatus n.e.c.	Obs. (%)	3.25	3.29	3.85	3.48	3.25	3.29	3.25
	Sum (%)	2.26	4.31	1.69	4.07	1.31	2.62	1.22
32. Manufacture of radio, television, & communication equipment, . . .	Obs. (%)	0.53	0.54	0.67	0.52	0.53	0.54	0.53
	Sum (%)	0.86	0.58	0.34	0.49	0.02	0.97	0.19
33. Manufacture of medical, precision & optical instruments, etc.	Obs. (%)	1.09	1.08	1.30	1.07	1.09	1.08	1.09
	Sum (%)	0.73	1.06	0.29	0.53	0.06	0.92	0.32
34. Manufacture of motor vehicles, trailers, & semi-trailers	Obs. (%)	4.66	4.72	4.71	4.91	4.66	4.73	4.66
	Sum (%)	23.81	12.29	6.95	16.52	1.66	27.55	15.07
35. Manufacture of other transport equipment	Obs. (%)	1.03	1.00	1.28	1.01	1.03	1.00	1.03
	Sum (%)	1.02	1.41	0.58	1.18	0.12	2.02	0.79
36. Manufacture of furniture, manufacturing n.e.c.	Obs. (%)	3.14	3.07	2.92	2.99	3.14	3.07	3.14
	Sum (%)	0.47	1.56	0.51	0.67	0.18	0.80	0.29
37. Recycling	Obs. (%)	0.12	0.11	0.18	0.10	0.12	0.00	0.00
	Sum (%)	0.00	0.03	0.02	0.00	0.00	0.00	0.00
Total	Obs.	13,939	13,258	9707	11,442	13,939	13,244	13,922
	Sum	279	1186	55,149	25,286	1490	69	775
	Mean	0.02	0.09	5.69	2.21	0.11	0.01	0.06
	CV	12.00	4.23	9.21	9.75	20.72	10.81	20.74

Notes: "*Annual Survey* of Iranian *Manufacturing Enterprises*" 2011.

Appendix D. More robustness checks

Table D1 shows that changes in the thresholds of defining potentially unconstrained firms do not change our main findings about the negative impact of WCR and WCU on the performance of constrained firms. Nevertheless, when the share of potentially constrained firms is less than 50%, the coefficient of WCR is significant, even among potentially unconstrained firms. However, the impact is weaker compared to potentially constrained ones.

Table D1
Change in the threshold level to classify potentially constrained firms.

		30% as Pot. Cons.			50% as Pot. Cons.			66% as Pot. Cons.			80% as Pot. Cons		
		Potentially constrained	Potentially unconstrained	All	Potentially constrained	Potentially unconstrained	All	Potentially constrained	Potentially unconstrained	All	Potentially constrained	Potentially unconstrained	All
Panel A: Materials/K	WCR	−0.010***	−0.008***	−0.008***	−0.010***	−0.005***	−0.009***	−0.009***	−0.004*	−0.009***	−0.009***	0.001	−0.009***
		(−3.493)	(−8.053)	(−9.753)	(−8.537)	(−3.756)	(−11.247)	(−10.130)	(−1.746)	(−11.279)	(−10.135)	(0.269)	(−10.844)
	WCR*Pot. Unconstrained			−0.003***			0.002***			0.003***			0.003***
				(−4.390)			(4.096)			(4.116)			(4.056)
	WCU	−0.006***	−0.003***	−0.003***	−0.003***	−0.002*	−0.003***	−0.003***	−0.001	−0.003***	−0.003***	0.001	−0.003***
		(−2.596)	(−2.849)	(−3.373)	(−2.824)	(−1.655)	(−3.450)	(−3.582)	(−0.551)	(−3.424)	(−3.455)	(0.420)	(−3.462)
	F-test	5.949	32.907	45.965	23.537	11.312	45.940	34.539	7.503	45.154	42.397	3.094	43.231
	Observations	14802	41915	56717	34319	22398	56717	41898	14819	56717	47940	8777	56717
Panel B: Production_BB	WCR	−0.441**	−0.243***	−0.293***	−0.454***	−0.288***	−0.400***	−0.428***	−0.064	−0.382***	−0.373***	0.275	−0.364***
		(−2.546)	(−3.244)	(−4.814)	(−5.254)	(−3.175)	(−6.449)	(−6.020)	(−0.448)	(−6.379)	(−5.685)	(1.043)	(−6.098)
	WCR*Pot. Unconstrained			−0.119***			0.168***			0.228***			0.275***
				(−2.586)			(4.263)			(4.905)			(4.173)
	WCU	−0.264*	−0.125**	−0.104**	−0.113	−0.147	−0.105**	−0.135**	−0.116	−0.103**	−0.159***	−0.104	−0.106**
		(−1.859)	(−2.050)	(−2.089)	(−1.476)	(−1.597)	(−2.121)	(-2.185)	(−0.806)	(−2.076)	(−2.919)	(−0.401)	(−2.122)
	F-test	2.305	4.267	9.111	4.231	3.632	8.970	5.769	1.837	8.505	6.247	1.357	7.816
	Observations	14630	35697	50327	28230	22097	50327	35718	14609	50327	41667	8660	50327
Panel C: CU_Btu	WCR	−0.004	−0.195**	−0.170**	−0.239**	−0.213	−0.181**	−0.212***	−0.129	−0.187**	−0.198***	0.149	−0.186**
		(−0.019)	−2.163)	(−2.308)	(−2.433)	(−1.635)	(−2.403)	(−2.596)	(−0.968)	(−2.523)	(−2.583)	(0.687)	(−2.528)
	WCR*Pot. Unconstrained			−0.024			0.009			0.030			0.055
				(-0.420)			(0.215)			(0.556)			(0.734)
	WCU	0.068	−0.218***	−0.167***	−0.123	−0.243**	−0.169***	−0.155**	−0.295**	−0.170***	−0.170**	−0.124	−0.169***
		(0.393)	(−3.117)	(−2.743)	(−1.343)	(−2.425)	(−2.769)	(−1.993)	(−2.250)	(−2.785)	(−2.400)	(−0.486)	(−2.770)
	F-test	1.863	9.286	11.767	4.759	5.843	10.193	8.936	2.782	10.449	10.166	2.171	10.167
	Observations	14802	41932	56734	34330	22404	56734	41909	14825	56734	47952	8782	56734

Notes: Columns report the results of FE regressing performance measures on WCR, WCU, and control variables. Pot.Unconstrained is a dummy variable for potentially unconstrained firms whose scaled growth rates of raw inventory is above 50, 66 and 80% of observations. The rest observations are considered as potentially constrained. Industrial variables contain real growth of value-added, inflation, and WCR for industries defined at the 2-digit ISIC level. For more details see the note of Table 2.

*** Denotes 1% significance.

** 5% significance.

* 10% significance.

Table D2
Performance measures and working capital by defining outliers as 3% of observations.

		Block 1: Materials/K				Block 2: Production_BB				Block 3: CU_Btu			
		(1) All	(2) All	(3) Potentially constrained	(4) Potentially unconstrained	(1) All	(2) All	(3) Potentially constrained	(4) Potentially unconstrained	(1) All	(2) All	(3) Potentially constrained	(4) Potentially unconstrained
Panel A: main	WCR	−0.008***	−0.009***	−0.009***	−0.001	−0.455***	−0.513***	−0.473***	−0.383	−0.130	−0.150*	−0.147*	−0.044
		(−8.598)	(−9.159)	(−8.176)	(−0.424)	(−5.764)	(−6.373)	(−5.618)	(−1.373)	(−1.599)	(−1.787)	(−1.712)	(−0.173)
	WCR*Pot. Unconstrained		0.004***				0.264***				0.007		
			(4.637)				(3.620)				(0.112)		
	WCU	−0.004***	−0.004***	−0.004***	0.001	−0.267***	−0.260***	−0.366***	−0.017	−0.223***	−0.230***	−0.224***	−0.253
		(−4.128)	(−4.245)	(−4.044)	(0.165)	(−3.410)	(−3.319)	(−4.140)	(-0.054)	(−3.060)	(−3.149)	(−2.606)	(−0.978)
	Industry vars.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Year & firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	F-test	59.666	49.777	43.264	4.700	8.565	7.621	8.428	1.604	14.020	11.405	10.258	3.011
	Observations	56,709	56,709	45,630	11,079	50,323	50,323	39,405	10,918	56,726	56,726	45,641	11,085
Panel B: lag of dependent variable	WCR	−0.005***	−0.006***	−0.006***	0.002	−0.660***	−0.731***	−0.680***	−0.156	−0.096	−0.120	−0.078*	−0.053
		(−5.659)	(−6.359)	(−5.145)	(0.573)	(−6.049)	(−6.653)	(−5.945)	(−0.409)	(−1.080)	(−1.316)	(−1.839)	(−0.204)
	WCR*Pot. Unconstrained		0.004***				0.328***				0.007		
			(4.737)				(4.425)				(0.122)		
	WCU	−0.004***	−0.004***	−0.005***	0.001	−0.330***	−0.319***	−0.300***	−0.840**	−0.211***	−0.218***	−0.195**	−0.253
		(−4.186)	(−4.328)	(−4.448)	(0.373)	(−3.549)	(−3.430)	(−2.853)	(−2.105)	(−2.795)	(−2.892)	(−2.157)	(−0.982)
	Industry vars.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Year & firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Lag Dep.Var.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	F-test	57.316	48.281	47.021	6.553	98.754	77.412	47.562	6.171	13.770	11.366	12.104	3.018
	Observations	51,056	51,056	39,983	11,073	36,401	36,401	28,485	7916	50,952	50,952	39,877	11,075
Panel C: variation in control variables	WCR	−0.008***	−0.009***	−0.009***	−0.002	−0.451***	−0.500***	−0.460***	−0.389	−0.123	−0.140*	−0.143*	−0.031
		(−8.398)	(−8.875)	(−7.907)	(−0.483)	(−5.676)	(−6.177)	(−5.390)	(−1.337)	(−1.521)	(−1.673)	(−1.685)	(−0.119)
	WCR*Pot. Unconstrained		0.003***				0.259***				0.017		
			(4.258)				(3.545)				(0.284)		
	WCU	−0.003***	−0.003***	−0.003***	−0.001	−0.272***	−0.267***	−0.356***	0.010	−0.167**	−0.170**	−0.174*	0.039
		(−3.497)	(−3.530)	(−3.271)	(−0.396)	(−3.366)	(−3.302)	(−3.861)	(0.030)	(−2.196)	(−2.242)	(−1.946)	(0.149)
	Industry vars.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Year & firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	F-test	11.241	11.324	–	–	2.403	2.454	–	–	2.867	2.914	–	–
	Observations	56,709	56,709	45,630	11,079	50,323	50,323	39,405	10,918	56,726	56,726	45,641	11,085

Notes: See notes for Table 2.
*** Denotes 1% significance.
** 5% significance.
* 10% significance.

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