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Do Financial Constraints Reduce Process Innovation? Evidence from Australian Firms*

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Accessing external finance for innovation is difficult. We study the effect of financial constraints on the probability of conducting process innovation, while also considering the role of past experience. We show a firm's optimal process innovation decision is a function of its previous decision and financial constraints, which naturally leads to a set of population moments for empirical testing with Australian microdata from 2006 to 2018. We find that if a firm did not conduct process innovation previously, financial constraints reduce its probability of process innovation by around 10 per cent. Whereas with previous process innovation, financial constraints reduce the probability by around 12 per cent.

I *Introduction*

Process innovations – innovations that enhance firm competitiveness by lowering costs and improving efficiency – are silent though prominent drivers of economic growth and productivity. Unfortunately, due to the uncertainty, complexity and specificity associated with innovation projects, information asymmetries arise and investors are often reluctant to provide capital at a reasonable price. This presents a problem as, unless firms are wealthy, firms must leave their innovation projects – which have acceptable rates of return at a 'normal' interest rate – on the shelf. In this paper we investigate both theoretically and empirically the impact of financial constraints on the probability a firm conducts process innovation. Moreover, we also consider how past innovating experience shapes this relationship.

Process innovation has often been considered a second-order innovative activity, the dull and unchallenging cousin of the more glamourous product innovation (Reichstein & Salter, 2006). With rising global competition, however, and the COVID-19 pandemic, new production techniques, new logistics methods and new supporting activities for business operations – all examples of process innovation – are becoming critical for firm survival. Previous studies exploring financial constraints and innovation, such as Canepa and Stoneman (2008) and Hajivassiliou and Savignac (2008), are unable to distinguish between the type of innovation conducted – or if they do, like Gorodnichenko and Schnitzer (2013), who exploit data from a sample of European countries – they find that innovation is a heterogeneous activity; that is, financial constraints have different impacts on product innovation and process innovation.

Our research makes three contributions to the literature. First, we add evidence to the nascent but growing literature exploring process innovation and financial constraints. We use novel Australian micro-data, namely the Australian

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Bureau of Statistics (ABS) Business Characteristics Survey (BCS) from 2006 to 2018, which, to the best of our knowledge, is one of the longest timeframes studied in this strand of literature.

Australia presents an interesting setting for such a study for four reasons. First, much of the finance innovation literature focuses on North American or European firms (Hall & Lerner, 2010; Kerr & Nanda, 2015), so insights into Australia provide additional perspectives and are particularly interesting for policymakers.[1] Second, innovation plays an important role in the Australian economy. For example, world development indicators data suggest that the correlation between research and development (R&D) expenditure (percentage of gross domestic product – GDP) and GDP *per capita* (constant 2015 US$) is as high as 0.6843 from 1996 to 2017 biennially. Third, Australia has well-established institutions promoting innovation. Its innovation system consists of a legal and regulatory framework, where advisory bodies and positions such as the chief scientist play an important role, promoting and supporting funding organisations (e.g., the Australian Research Council), and public and private research organisations (e.g., universities). Fourth, as identified by the Australian Innovation System Monitor, 'compared to other OECD countries, Australia has relatively modest proportions of (product and/or process) innovative businesses receiving public support for innovation or being engaged in public procurement contracts'.[2] The combination of demand for innovation funding (suggested by the high correlation between R&D expenditure and *per capita* GDP) and limited supply of public funding may hint at the existence of financial constraints in the Australian process innovation context, hence the importance of examining how financial constraints affect a firm's process innovation in Australia.

Second, and perhaps most importantly, we explore innovation dynamics and the way they shape the relationship between financial constraints and process innovation. Past innovating experience may be closely related to financial constraints; for instance, profits generated from past innovation may help finance subsequent innovation, and firms who have innovated in the past have proven ability to succeed and, therefore, may be looked upon favourably by financiers. Theoretically, we incorporate past innovating experience into the static framework from Gorodnichenko and Schnitzer (2013), and model a firm's decision to conduct process innovation with financial constraints. Profit maximisation yields an optimal decision on whether to innovate as a function of process innovation in the previous period, financial constraints, and a set of control variables. This decision naturally leads to a set of population moments, which we later test with the generalised methods of moments (GMM) estimator.

Third, when empirically testing our population moment conditions, we use a direct survey measure of financial constraints, and a novel approach to address an endogeneity problem this raises. Direct measures are advantageous, as compared with the other measures such as the cash flow–investment sensitivity, it avoids indirectly deducing financial constraints, and the survey methodology is standardised based on the guidelines set out by the OECD's *Oslo Manual*; this provides consistency and comparability. This direct measure, however, creates a particular endogeneity problem. That is, a large number of firms in the sample have no intention to innovate, and because all firms must respond to the survey, these firms report no process innovation and no financial constraints for innovation. This results in upward bias on the financial constraints coefficient in the regressions. To address this, following Hajivassiliou and Savignac (2008), we restrict the sample of firms to likely innovators – and similar to Gorodnichenko and Schnitzer (2013), we instrument the financial constraints variable.

Our econometric results show that financial constraints reduce the probability of conducting process innovation. Firms that innovated in the previous period are also more likely to continue innovating in the current period. Specifically, if a firm did not conduct process innovation in the previous year, financial constraints reduce the probability of conducting process innovation by around 10 per cent. Whereas if a firm did conduct process innovation in the previous period, financial constraints reduce the probability of process

[1] In Australia, several research papers have documented issues financing innovation (e.g., Alinejad *et al.*, 2015; Bakhtiari *et al.*, 2020). Empirically, however, the literature remains limited to the determinants of Australian innovators (Bhattacharya & Bloch, 2004; Rogers, 2004; Soriano *et al.*, 2019) and the role of the government in alleviating financial constraints (Xiang & Worthington, 2017; Bakhtiari, 2021).

[2] See https://www.industry.gov.au/data-and-publications/australian-innovation-system-monitor/.

innovation by around 12 per cent. These results suggest that Australia and other advanced economies can benefit from policies alleviating financial constraints for process innovation. Moreover, because firms that have innovated previously are likely to continue innovating, policies encouraging process innovation today have the added benefit of promoting continual process innovation in the future. In particular, our results suggest that grants and asset write-off schemes can play an important role in promoting process innovation. We also find that young firms, large firms, firms with government assistance, and firms that maintain or increase productivity and income have a higher likelihood of conducting process innovation. Alternately, vertical integration – as captured by foreign ownership and exporting status – has no statistically significant effect on the probability of process innovation. Our findings are robust to different specifications of the probability function, alternative estimation methods, alternative instruments for financial constraints, and estimations with subsamples.

The remainder of the paper is structured as follows. Section II reviews the literature. Section III outlines our theoretical framework. Section IV describes our econometric specification and data. Section V presents the results. Section VI concludes and provides policy recommendations.

II Literature Review

This study links two strands of research: one that investigates process innovation and one that explores the impacts of financial constraints, particularly on investment, R&D, and product innovation. In this section we review these two strands and highlight the gaps in the existing literature.

(i) Process Innovation

Several studies have linked process innovation with increased productivity (Huergo & Jaumandreu, 2004a; Parisi *et al*., 2006; Hall *et al*., 2009) and economic development (Hollander, 1965; Mankiw *et al*., 1992). Yet, despite its importance, process innovation has largely been overlooked. In a systematic review of the strategic management innovation literature, Keupp *et al*. (2012) find only 11 of the 342 articles analysed focus on process innovation. The neglect for process innovation arises for two reasons. First, compared with product innovation, process innovation is internally focused and is often unobservable. Second, the diffuse and elastic concept of process innovation makes measuring the phenomena quite difficult. Most innovation metrics, such as patents and R&D expenditure, were conceptualised for new product development (Arundel & Kabla, 1998; Brouwer & Kleinknecht, 1999).

Much of the existing literature focuses on determinants of process innovation. Utterback and Abernathy (1975) and Klepper (1996) investigate innovation at different stages of the product life cycle. They find the early stages of the product life cycle are dominated by product innovation, though as producers and users of a product gain experience firms turn to process innovation. In a related study, Cohen and Klepper (1996) examine the link between firm size and type of innovation. Both theoretically and empirically they find larger firms are more likely to be process innovators because of a cost-spreading advantage.

Studies have also explored the sources of process innovation. Parisi *et al*. (2006), using Italian firm-level data, show that R&D spending is positively associated with the introduction of new products, whereas fixed capital spending increases the likelihood of firms introducing process innovations. This result reflects an embodied knowledge hypothesis, which suggests that firms conduct process innovation by incorporating physical capital, such as advanced machinery or new technology, rather than by making intangible investments in R&D (Rouvinen, 2002). Along similar lines, Reichstein and Salter (2006) and Aliasghar *et al*. (2019) explore the importance of external knowledge sources for process innovation. They find that process innovators are likely to draw on knowledge from upstream partners such as suppliers, rather than from customers, universities and consultants.

The literature has examined the connection of process innovation to other types of innovation. Pisano (1997) finds that pharmaceutical firms that develop process innovations at the early stages of product development show better performance than those that leave process development for later stages. Consistent with this, Damanpour and Gopalakrishnan (2001) show that banks that simultaneously adopt product and process innovation have the greatest performance. In addition, process innovations are often accompanied by organisational innovations (new ways to organise business activities). For example, new technologies may result in firms adopting new business routines and reorganising internal or external relations (Hervas-Oliver *et al*., 2016).

Overall, despite the wide research on the adoption of process innovations, little attention has been paid to the role of financial constraints. Filling the gap, this study will investigate the impact of financial constraints on process innovation. As such, it links to the strand of research on financial constraints.

(ii) Financial Constraints

A large strand of literature is devoted to exploring the impacts of financial constraints, particularly on investment, R&D and product innovation. In general, a firm is considered financially constrained if it cannot carry out its desired activity (investment/R&D/innovation), at its desired scale and scope, due to a lack of financing availability or a very high cost of external finance (Hottenrott *et al*., 2015). Because this is not directly observable (up until recently), measuring this empirically has been challenging.

Early studies, devoted to linking financial constraints to firm investment, exploit the idea that a change in internal funds should not affect investment provided firms are not limited in their access to external funds (Fazzari *et al*., 1987).[3] In an Australian context, La Cava (2005) uses reductions in dividend payments as an indication of financial constraints and finds investment has a minimal response. Outside of Australia, studies have applied these cash flow–investment sensitivity measures to R&D – an input of innovation activities. Himmelberg and Petersen (1994) find a weak but statistically significant relationship between cash flow–investment sensitivity and R&D for German firms. Bond *et al*. (2005) perform a similar exercise except compare firms in Germany and the UK. They find German firms' investment and R&D are insensitive to cash flow, whereas firms in the UK partially respond.

Subsequent research, however, has challenged the cash flow–investment sensitivity as a sound indicator of financial constraints, which may partly explain the ambiguity of R&D response to cash flow. Kaplan and Zingales (1997, 2000), among others, argue that cash flow–investment sensitivity may not indicate the presence of financial constraints because (i) cash flow–investment sensitivity may not increase monotonically with financial constraints, (ii) investment opportunities may not be sufficiently controlled for and (iii) firms tend to smooth R&D over time; see Chichti and Mansour (2010) for a summary of the criticisms.

(iii) Financial Constraints and Innovation

Recently the increased availability of firm-level survey data on innovative activities has enabled researchers to directly explore the impact of financial constraints on innovation. Innovation surveys gather information on the types of innovation firms introduce and barriers they face. Firms are typically identified as financially constrained if they report some difficulty in access to external finance (usually reported on a scale or a yes/no). These direct measures avoid indirectly deducing financial constraints and are therefore advantageous. In addition, the survey methodology is standardised based on the guidelines set out by the OECD's *Oslo Manual*. This provides consistency and comparability unlike the indirect measures, such as cash flow–investment sensitivity (Moyen, 2004).

Canepa and Stoneman (2008) employ such a direct survey measure and conclude that financial factors reduce innovative activity in small, high-tech British firms. Because their survey data, however, combine product and process innovation into one category, little can be said about how each type of innovation is affected. Hajivassiliou and Savignac (2008) conduct a similar analysis among French firms, though find that the sign and magnitude of the financial constraints coefficient depends on the sample of firms chosen. The authors show that innovation and financial constraints are positively correlated in the full sample, but that correlation turns negative when the sample is restricted to firms they classify as likely innovators. This finding highlights an endogeneity problem that researchers must deal with when studying financial constraints using the direct survey measure. That is, the intention to innovate is highly correlated with the incidence of financial constraints. Similar to Hajivassiliou and Savignac (2008), we correct for this problem by classifying firms as likely innovators – those firms who have introduced an innovation, have an ongoing innovation, or have abandoned an innovation.

Few papers in the literature have looked at the impact of financial constraints specifically on process innovation. Gorodnichenko and Schnitzer (2013), the closest paper to our work, investigate the effect of financial constraints on

[3] Researchers using this approach group firms *a priori* into supposedly more and less constrained firms (based on theory). This allows researchers to observe more than an average effect.

product and process innovation in a sample of European countries from 2002 to 2005. Theoretically, they provide a powerful simplification of how financial constraints impact a firm's decision to innovate. And, empirically, using an instrument to correct for the endogeneity of financial constraints, they find that the negative effect of financial constraints is more severe for process innovation than for product innovation.

Our paper builds on and extends Gorodnichenko and Schnitzer's work in several ways. First, using rich Australian firm-level data from 2006 to 2018, we incorporate past innovating experience into their theoretical framework and into our empirical estimation. Recent studies have hinted at the possibility of persistence in innovative activity (e.g., Peters, 2009; Raymond *et al*., 2010; Ganter & Hecker, 2013). This is of particular interest as it is closely related to financial constraints. One explanation of innovation persistence – the resource constraint perspective – suggests that because innovating firms have trouble accessing external finance, profits generated from past innovation help finance subsequent innovation (Ganter & Hecker, 2013). Additionally, firms who have innovated in the past have proven ability to succeed and, therefore, may be looked upon favourably by financiers.[4] If this is the case, a failure to control for past innovation could underestimate the true effect of financial constraints on process innovation.[5]

Second, we use a different identification strategy. While we situate our theoretical framework within Gorodnichenko and Schnitzer (2013), we go on to generate a set of population moments, which we test empirically with the GMM estimator.

III Theoretical Framework

In this section we theoretically show how financial constraints and past innovation relate to a firm's profit-maximising decision to conduct process innovation. We extend the static model of Gorodnichenko and Schnitzer (2013) to incorporate past innovation, which subsequently generates a set of population moments for the empirical estimations.

In each time period t, firms are engaged in three-stage activities. In stage 0 an exogenous shock to a firm's internal cash flow realises (e.g., due to late-paying customers), which may reduce the availability of internal funds for both innovation and production.

In stage 1 a firm has the opportunity to conduct process innovation at a fixed cost F_I; it must decide to either innovate ($\chi_t = 1$) or not ($\chi_t = 0$). Because process innovation activities are prone to information asymmetries (Akerlof, 1970; Stiglitz & Weiss, 1981; Myers & Majluf, 1984), agency problems (Jensen & Meckling, 1976), and they are difficult to collateralise (Brown *et al*., 2009; Mina *et al*., 2013), we assume that innovation must be financed with internal funds from positive cash flows.

In stage 2 the firm engages in production which also needs to be financed. The firm, however, can use internal or external funds. Because of information asymmetries and transaction costs, we assume external funding is more expensive than internal funds. That is, the opportunity cost of internal financing is normalised to 1 and the cost of obtaining external funds, γ, is greater than 1 ($\gamma > 1$). Consequently, a firm prefers to use internal finance for production but must switch to external sources if internal funds are not sufficient. It is assumed that, *a priori*, sufficient internal funds will be available with probability q while external finance will be required with probability $1 - q$.

Two kinds of events affect q. First, if the firm decides to innovate in stage 1, because it must use internal funds, there are fewer internal funds available for production in stage 2. In this situation the probability of having sufficient internal funds for production is reduced by δ_I. Second, the exogenous shock in stage 0 also reduces the probability of having sufficient

[4] Two other theories explaining innovation persistence are the sunk cost perspective and the competence-based perspective (Ganter & Hecker, 2013). The sunk cost perspective argues that R&D investment (e.g., facilities, and hiring and training specialised staff) is of long-term use that contributes to continuous innovation. If innovation ceases, these costs are mostly unrecoverable. This discourages exit and reduces the cost of future innovation activities. The competence-based perspective explains innovation persistence through knowledge accumulation and capability-building.

[5] Some studies of innovation persistence have tried to incorporate a financial constraint variable to test this theory. Peters (2009) uses credit rating to proxy for the availability of financial resources, whereas Ganter and Hecker (2013) and Raymond *et al*. (2010) both proxy financial constraint with size. As discussed above, direct measures of financial constraints are preferable as they avoid indirectly and incorrectly deducing financing constraint.

internal funds for production by δ_L. Firms have no control over the incidence of cash flow shocks.

Let π_{it} denote the profit of the firm in period t if no innovation takes place, where $i \in \{0, \gamma\}$ indexes the funding source. If $i = 0$, production is financed internally and $i = \gamma$, if it is financed with external funds ($\pi_{0t} = \pi_{\gamma t}$). Similarly, for $i \in \{0, \gamma\}$, let π^I_{it} denote the profit if the firm innovates, where $\pi^I_{it} > \pi_{it}$. The firm's expected per period profit *without* process innovation is:

$$E(\pi_t|\chi_t = 0) = (q_t - \delta_L)\pi_{0t} + (1 - q_t + \delta_L)\pi_{\gamma t}. \quad (1)$$

Recall if a firm decides to conduct process innovation, it must pay a fixed cost of F_I, which could be a facility or specialised equipment needed for the innovation. If a firm innovated in the previous period, however, some of the facilities can be utilised in the current period. As such, the associated fixed cost of innovation becomes $(1 - \theta\chi_{t-1})F_I$, where χ_{t-1} is a dummy variable equal to 1 if the firm innovated in the previous period and 0 otherwise; θ captures the fraction of cost saving due to the previous period's innovation.[6] The firm's expected per period profit is:

$$E\left(\pi^I_t|\chi_t = 1\right) = (q_t - \delta_L - \delta_I)\pi^I_{0t} + (1 - q_t + \delta_L + \delta_I)\pi^I_{\gamma t} - (1 - \theta\chi_{t-1})F_I. \quad (2)$$

Because innovation facilities can be used in the future, a firm's stage one decision on process innovation is dynamic. In each period t, the firm is faced with a state characterised by $(\chi_{t-1}, \lambda_t, \zeta_t)$, where λ_t is an index that captures all observed factors (e.g., age, size, and importantly, financial constraints), and ζ_t is an index that captures the influence from all factors unobserved to researchers (e.g., firm fixed effect and management capability). For brevity we slightly abuse notation by letting π_t and π^I_t represent $E(\pi_t|\chi_t = 0)$ and $E\left(\pi^I_t|\chi_t = 1\right)$, respectively. Accordingly, the firm's value function can be written as:

$$\nu(\chi_{t-1}, \lambda_t, \zeta_t) = \max_{\chi_t \in \{01\}} \chi_t \pi^I_t + (1 - \chi_t)\pi_t + \rho\nu(\chi_t, \lambda_{t+1}, \zeta_{t+1}), \quad (3)$$

where $\lambda_{t+1} = g_1(\lambda_t, \chi_t)$ and $\zeta_{t+1} = g_2(\zeta_t, \chi_t)$; g_1 and g_2 are transition functions; and ρ is the discount rate. Equation (3) suggests that in considering innovation, a firm does not maximise its current period static profit in isolation, but also includes the discounted value of next period's optimal decision.

Let $\nu_{1t} \equiv \pi^I_t + \rho\nu(1, g_1(\lambda_t, 1), g_2(\zeta_t, 1))$, the value if a firm chooses to innovate at time period t, and $\nu_{0t} \equiv \pi_t + \rho\nu(0, g_1(\lambda_t, 0), g_2(\zeta_t, 0))$, the value if it does not innovate at time period t. A firm's optimal decision on whether to conduct process innovation at time period t can then be written as $\chi_t = 1(\nu_{1t} > \nu_{0t})$, where $1(\bullet)$ is an indicator function. Taking the expectation of both sides with respect to the index ζ_t (unobserved), conditional on (χ_{t-1}, λ_t) gives us the following conditional population moments:

$$E(\chi_t|\chi_{t-1}, \lambda_t) = \text{Prob}(\chi_t = 1), \quad (4)$$

where Prob denotes a probability measure with respect to $\zeta_t|(\chi_{t-1}, \lambda_t)$.

Four remarks related to the empirical implementation of Equation (4) are warranted. First, it is likely that past innovation (χ_{t-1}) is correlated with the unobserved factor (ζ_t), for example, through the firm fixed effect. In Equation (4) we address this type of endogeneity by integrating out ζ_t, conditional on (χ_{t-1}, λ_t).[7] Second, Equation (4) follows from the theoretical modelling. In case one wishes to lay out an explicit estimation equation, Equation (4) implies $\chi_t = \text{Prob}(\chi_t = 1) + \epsilon_t$ where ϵ_t is an error term and $E(\epsilon_t|\chi_{t-1}, \lambda_t) = 0$ by construction. Third, Equation (4) is a dynamic model in that a firm's current period decision on innovation depends on its previous period decision. Fourth, Equation (4) implies a set of unconditional population moments and naturally leads to the GMM estimator, which is consistent and asymptotically normal under the usual regularity conditions (Hansen, 1982).

[6] More generally, if facilities of all previous periods can be used for innovation in the current period, the current period fixed cost of innovation is then $\left(1 - \sum^{\theta}\chi\right)F$. For simplicity and data availability, in our empirical estimations we assume only the previous period matters.

[7] This only requires that $\zeta_t \mid (\chi_{t-1}, \lambda_t)$ is integrable. The cost of doing so is that the marginal effects of (χ_{t-1}, λ_t) pick up both direct and indirect effects that operate through ζ_t. Other methods include, among others, those of Honoré and Weidner (2020). We thank an anonymous reviewer for pointing this out.

IV Empirical Implementation and Data

To operationalise Equation (4), we assume the probability of conducting process innovation, $\text{Prob}(\chi_t = 1)$, takes a logistic functional form, namely $\text{Prob}(\chi_t = 1) = \left(\exp\left(z_t'\beta\right)/\left(1+\exp\left(z_t'\beta\right)\right)\right)$, where z_t is a vector that contains past innovation (χ_{t-1}) and the observed characteristics (λ_t), and vector β contains the parameters to be estimated. Note $\text{Prob}(\chi_t = 1)$ is not a function of firm fixed effect, as it has been integrated out in Equation (4). The unconditional population moments, implied by Equation (4), are:

$$E\left[\left(\chi_{it} - \frac{\exp\left(z_{it}'\beta\right)}{1+\exp\left(z_{it}'\beta\right)}\right)z_{it}\right] = 0, \tag{5}$$

where we add the subscript i to index firms. Accordingly, their sample analogues are $g = \left(1/\sum_{t=1}^{T}|I_t|\right)\sum_{t=1}^{T}\sum_{i\in I_t}\left(\chi_{it} - \left(\exp\left(z_{it}'\beta\right)/\left(1+\exp\left(z_{it}'\beta\right)\right)\right)\right)z_{it}$ where I_t is the set of firms in time period t and T is the total number of time periods. The GMM estimator is then $\hat{\beta}_{\text{GMM}} = \text{argmin} g'Wg$ where W is a weighting matrix. Hansen (1982) establishes the consistency and asymptotic normality of the GMM estimator, under a set of usual regularity conditions. We implement the GMM estimator in Stata, using its 'gmm' command. Later for robustness we also explore alternative functional forms of $\text{Prob}(\chi_t = 1)$, such as linear and exponential functions of (χ_{t-1}, λ_t).

To fit the moment conditions, we use the Business Longitudinal Analysis Data Environment (BLADE). The BLADE is a collection of integrated, linked longitudinal datasets; it is the most comprehensive firm-level statistical asset in Australia.[8] Many researchers have used the BLADE to investigate Australian firms' innovation. For example, Majeed and Breunig (2021) explore the determinants of innovation novelty; Majeed *et al*. (2021) study the innovation characteristics of high-growth firms in Australia; and Soriano *et al*. (2019) examine the driving force of innovation in small businesses in the food industry in Australia. Unlike these studies, we focus on a particular type of innovation, process innovation, and investigate the influence of financial constraints. Our primary dataset in the BLADE is the Business Characteristics Survey (BCS). This is an annual ABS survey conducted on a rolling panel of firms. The survey is conducted *via* an online form or mail-out questionnaire and collects information on business characteristics, innovation practices and barriers, and use of information technology. We use 12 waves of the BCS, from 2006/07 to 2017/18.

Firms with 200 or more employees are a permanent part of the data. Every year, however, a new panel of firms with fewer than 200 employees are surveyed. Each panel runs for 5 years, meaning several panels are running in parallel (the samples for simultaneous panels are non-overlapping). Around 3,000 firms are included in each panel, though this can range from 2,000 to 5,000. Firms are randomly selected from the ABS Business Register (ABSBR) using stratification over employment size and industry.[9] Manufacturing and agriculture make up around 20 per cent of the sample, which is expected given the large contribution of the food industry to the Australian economy. Table S1 in Appendix S1 highlights the sample composition by industry and year.

(i) Identifying Process Innovators

The BCS asks firms to report on various types of innovation activity. These questions are aligned with the innovation definitions set out in the OECD's *Oslo Manual*, 3rd Edition (OECD/Eurostat, 2005), where the process innovation is defined as 'the implementation of a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software'.[10] Specifically for process innovation, each year firms are asked if they have introduced a new or

[8] See Hansell and Rafi (2018) for a discussion of firm-level analysis using the BLADE. For a list of BLADE research projects, see https://www.abs.gov.au/websitedbs/d3310114.nsf/home/statistical+data+integration+-+blade+research+projects/.

[9] Firms operating in sectors such as general government, public administration and safety, education and training, and financial asset investing and superannuation funds are not included.

[10] A fourth edition of this manual, released in 2018, breaks innovation into just two categories: product innovation and process innovation. Marketing and organisational innovations are now considered components of process innovations. Because the data cover the period 2006/07–2017/18, the innovation definitions are based on the third edition; hence, we exclude marketing and organisational innovations from our definition of process innovation.

significantly improved (i) method of manufacturing or producing goods or services, (ii) logistics, delivery or distribution method for goods and services, (iii) supporting activities for business operations, (iv) other operational processes or (v) none of the above. Firms can select multiple options. We classify a firm as a process innovator in each year ($\chi_t = 1$) if they responded yes to any of the first four options.

There are several strengths to this measure compared with using R&D expenditure or patent applications. First, as revealed in our literature review, firms tend to conduct process innovation by incorporating physical capital – such as advanced machinery or new technology – rather than by making intangible investments in R&D. Second, patent activity is unlikely to be observed as (i) most processes are highly context specific (new to the firm rather than new to the world) and (ii) in general, not all firms and industries use patents to protect innovations (Arundel & Kabla, 1998; Cohen *et al.*, 2000).

As with all measures of innovation, ours has its limitations. The measure does not account for the significance of the innovation, the number of new processes introduced, or the impact on subsequent business performance (for a further discussion of limitations, see Mohnen, 2019).[11] Self-reported qualitative measures are also by definition more prone to measurement error and cultural bias than R&D or patents (Gorodnichenko & Schnitzer, 2013). For instance, deciding what is 'significantly improved' is highly subjective.

(ii) Identifying Financial Constraints

The BCS collects information on barriers to innovation. In particular, one question asks firms to report yes or no if 'a lack of access to additional funds is a factor significantly hampering innovation'. We classify a firm as financially constrained if they respond with yes to this question. This measure of financial constraints directly captures the problems (and perceived problems) firms face when trying to finance innovation – unlike indirect measures such as cash flow sensitivity to investment. This self-reported binary measure, however, ignores the severity of financial constraints and is prone to measurement error. For instance, it is possible that a firm's innovation is non-viable and the financier's rejection on these grounds is being interpreted as difficulty in financing innovation. This is a problem with all survey data of this kind and cannot be overcome (Canepa & Stoneman, 2008).

(iii) Control Variables

We control for several factors deemed important in the literature in vector Z_t:

- *Size* is the number of employees working for the business in the last pay period. Larger firms have more resources to innovate and can take advantage of scale economies (Cohen, 2010). Moreover, Cohen and Klepper (1996) find that the share of process R&D undertaken by firms rises with firm size. We expect this coefficient to be positive.
- *Age* is the number of years since founding. Two hypotheses are plausible: one suggests older firms have a better reputation, more credit history, and have accumulated knowledge necessary to innovate (positive effect); the other suggests established practices make older firms more resistant to innovation (negative effect) (Huergo & Jaumandreu, 2004b). Because the distributions of *Size* and *Age* are highly skewed, we take the natural logarithm of both variables.
- *Foreign* is a dummy variable equal to 1 if the firm has any degree of foreign ownership, and 0 otherwise. Foreign-owned firms have vertical linkages which promote transmission of technology and knowledge (Ayalew & Xianzhi, 2019). We expect a positive coefficient.
- *Exporter* is a dummy equal to 1 if the firm receives income from exporting goods or services, and 0 otherwise. Firms operating on the international market encounter fiercer competition, which encourages them to innovate (Becheikh *et al.*, 2006). Exposure to foreign firms and markets also facilitates the transfer of better foreign technology and practices.
- *Government assistance* is a dummy equal to 1 if the firm received any financial assistance from Australian government organisations, and 0 otherwise. Firms receiving government funding are more confident to seek financing and are less likely to experience financial constraints (Xiang & Worthington, 2017; Bakhtiari, 2021).
- *Collaboration* is a dummy equal to 1 if the business collaborated for innovation, and 0

[11] Every 2 years an extended innovation component is conducted in the BCS that gathers information on all these items; future research can explore this aspect.

otherwise. Collaborating firms have access to more financial resources and tend to outperform non-collaborating counterparts in terms of innovation output (Czarnitzki & Hottenrott, 2017).

- *Human capital* is a dummy equal to 1 if the firm identifies that a 'lack of skilled persons within the business' is not a factor hampering innovation, and 0 if it is. Cohen (2010) finds firms that lack qualified personnel receive less benefit from the transfer of technology. Growth theory also suggests that human capital increases the capacity to innovate, so we expect a positive coefficient.
- *Income* is a dummy equal to 1 if, compared with the previous year, income from the sales of goods or services stayed the same or increased, and 0 if it decreased. Because higher profitability increases funds available for innovation, we expect a positive relationship.
- *Cost of innovation* is a dummy equal to 1 if the firm identifies that the cost of innovation is a factor hampering innovation, and 0 otherwise. Firms that require larger capital investments are more likely to experience financial constraint. We expect a negative coefficient.[12]
- *Productivity* is a dummy equal to 1 if the firm reports productivity stayed the same or increased compared with the previous year, and 0 if it decreased. We expect a positive coefficient.
- *Share of part-time staff* is the share of part-time staff in the business. This is a proxy for capacity utilisation (CU) which is a strong predictor of innovations (Ayyagari *et al.*, 2011). Two hypotheses are plausible: one suggests that because firms are busy filling demand (high CU), they may be more interested in extending their current capacity than in innovating; the other suggests that if firms are already at capacity, then they may need to innovate.
- *Product innovation* is a dummy equal to 1 if a firm introduced a product innovation in the period, and 0 otherwise. If a firm introduces a product innovation, they may have less resources available to conduct process innovation. Alternatively, a product innovation may require a new accompanying process.

We also include industry dummies (based on the Industry Division 2006 Framework) as industry characteristics are likely to affect firm innovativeness and access to finance, and year dummies to control for time-variant macroeconomic factors impacting all firms.

Table 1 provides summary statistics for the variables used in our analyses. The mean firm size is around 230 employees, and the mean firm age is 23 years old. The high standard deviations of these variables suggest substantial variations in the sample.

Our process innovation and financial constraint proxies also both have means closer to zero, which indicates that only a small proportion of firms conduct process innovation or report financial constraints. We explore this finding further when discussing the endogeneity of financial constraint in Section IV(v).

(iv) Transition Probabilities

Based on evidence of persistence in innovative activity (see Section II), we expect firms who have innovated in the previous period ($\chi_{t-1} = 1$) to be more likely to innovate again in the current period ($\chi_t = 1$). Table 2 presents the average transition probabilities for process innovation. Firms that did not conduct process innovation in the previous period have a higher probability (85 per cent) of continuing not to innovate than to innovate (15 per cent). Similarly, firms that conducted process innovation in the previous period have a higher probability of continuing to innovate (55 per cent) than to stop innovating next period (45 per cent). These transitions confirm the importance of controlling for past innovating experience and provide preliminary evidence for the positive relationship between the previous period's innovation and current innovation. From here on, in our analyses, we refer to process innovation in $t - 1$ as past innovation.

(v) Addressing the Endogeneity of Financial Constraints

Studies using self-reported, survey measures of financial constraints such as Canepa and Stoneman (2008), Hajivassiliou and Savignac (2008) and Gorodnichenko and Schnitzer (2013) highlight a particular endogeneity problem. Namely, because innovating firms require more external finance and are therefore more likely to report

[12] Our proxies for human capital and cost of innovation are not ideal and may not fully remove possible variation in knowledge and cost of innovations across firms. Nevertheless, with the inclusion of these variables, one can presume the outsized differences in knowledge availability or costs of innovation have been addressed to a reasonable degree.

Table 1
Summary Statistics

	Observations	Mean	SD	Type
Variable				
Process innovation	140,877	0.246	0.431	Dummy
Financial constraint	139,396	0.173	0.379	Dummy
Controls				
Size	141,020	232.334	1081.236	Continuous
ln(Size)	135,186	2.722	2.248	Continuous
Age	139,538	22.779	25.592	Continuous
ln(Age)	135,933	2.680	1.016	Continuous
Foreign	139,559	0.113	0.317	Dummy
Exporter	140,092	0.160	0.367	Dummy
Government assistance	143,798	0.228	0.419	Dummy
Collaboration	107,054	0.148	0.356	Dummy
Human capital	143,798	0.847	0.360	Dummy
Income	127,107	0.654	0.476	Dummy
Cost of innovation	139,396	0.148	0.355	Dummy
Productivity	117,107	0.822	0.383	Dummy
Share of part-time staff	129,368	0.441	0.399	Continuous
Product innovation	140,866	0.229	0.420	Dummy
Instruments				
General business fc	139,069	0.143	0.350	Dummy
Share of general fc in industry–province	139,069	0.138	0.030	Continuous

Note: Missing values and extreme outliers have been removed.
Source: ABS BLADE, 2006–18.

Table 2
Process Innovation Transition Probabilities

		χ	
		$\chi = 0$	$\chi = 1$
χ_{t-1}	$\chi = 0$	0.85	0.15
	$\chi = 1$	0.45	0.55

Notes: Reported is the average transition probability for the four regimes $(\chi_{t-1}, \chi_t) = \{(0,0),(0,1),(1,0),(1,1)\}$ from $t = 2007$ to $t = 2018$. Appendix S1 discusses the computation of the transition matrix and reports the yearly transition probabilities used for the average calculation.
Source: ABS BLADE, 2006–18.

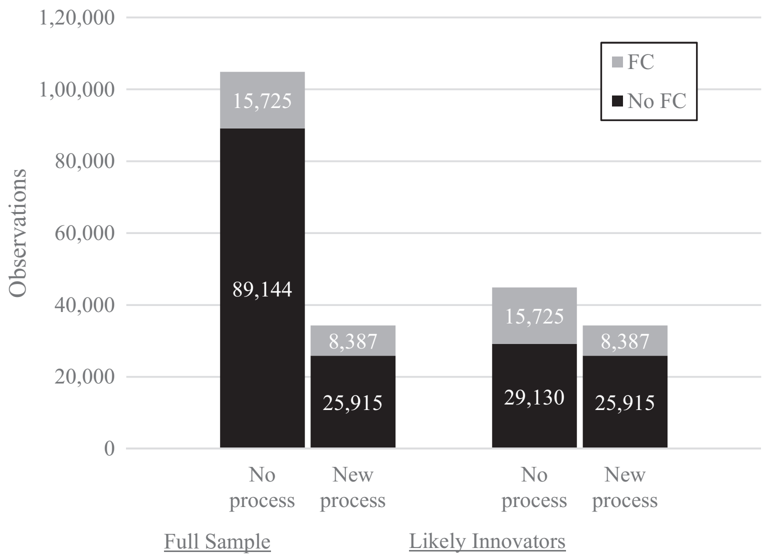
financial constraints for innovation – if the sample contains a lot of firms which *do not* intend to innovate (firms less likely to report financial constraints for innovation) – this positive correlation (no innovation, no constraints) induces upward bias on the estimate of the financial constraints coefficient. In other words, if a firm responds with no to our financial constraints question – meaning access to additional funds is not a problem for innovation – it may be because the firm had no intention to innovate. Therefore, one cannot use the proportions of yes and no responses as a clear indicator of whether a firm has been hampered or not in its innovation activity (Canepa & Stoneman, 2008).

Figure 1 explores our process innovation variable and financial constraints variable in conjunction. The first two columns highlight process innovation and financial constraints observations in the full sample. Column 1 confirms the finding of previous papers; that is, there is a large group of observations (89,144) that do not conduct process innovation and report no financial constraints for innovation. To weed out the firms in this category that have no intention to innovate, we use an instrumental variable and restrict the sample to firms considered likely innovators.[13]

The instrument we select must be correlated with financial constraints but should not directly

[13] The likely innovators include firms that have done any kind of previous innovation. See below for a full definition of likely innovators.

FIGURE 1
Process Innovation and Financial Constraints: Full Sample and Likely Innovators



Source: ABS BLADE, 2006–18.

influence process innovation. The instrument we use, *General business fc*, is a dummy equal to 1 if the firm identifies that a 'lack of access to additional funds' is a factor hampering general business activities, and 0 otherwise. Note this is very similar to the question used to identify financial constraints for innovation. This variable, however, likely satisfies the exclusion criteria; that is, it is correlated with financial constraints for innovation (0.72 correlation), and it is only indirectly related to process innovation through our financial constraints variable. If a firm has difficulty raising funds for general business activities, it will have difficulty raising funds for innovation, and this, in turn, reduces process innovation.

That said, firms that are struggling to access funds for general business activities are likely to undertake process innovation, to cut costs and support their bottom line, suggesting a potential direct link to process innovation.[14] If this is the case, we shall observe that, conditional on financial constraints for innovation, firms' probability of process innovation if they are faced with *General business fc* shall be substantially higher than if they are not. That is, $\text{Prob}(\chi = 1|gfc = 1, fc = 0) > \text{Prob}(\chi = 1|gfc = 0, ,fc = 0.)$ and $\text{Prob}(\chi = 1|gfc = 1, fc = 1) > \text{Prob}(\chi = 1|gfc = 0, fc = 1)$ where gfc represents *General business fc* and fc denotes financial constraints for innovation. From the data, we can non-parametrically estimate these probabilities as relative frequencies. For the full sample, $\text{Prob}(\chi = 1|gfc = 1, fc = 0) = 0.2603$, $\text{Prob}(\chi = 1|gfc = 0, fc = 0) = 0.2239$, $\text{Prob}(\chi = 1|gfc = 1, ,fc = 1.) = 0.3479$, and $\text{Prob}(\chi = 1|gfc = 0, fc = 1.) = 0.3471$. Hence, when $fc = 1$, the difference in probabilities is almost 0, while the difference is small (0.0365) when $fc = 0$. In the sample of likely innovators, $\text{Prob}(\chi = 1|gfc = 1, fc = 0.) = 0.4478$, $\text{Prob}(\chi = 1|gfc = 0, fc = 0.) = 0.4712$, $\text{Prob}(\chi = 1|gfc = 1, fc = 1) = 0.3479$, and $\text{Prob}(\chi = 1|gfc = 0, fc = 1 \quad) = 0.3471$. We observe that when $fc = 0$, the difference in probabilities is even negative. Therefore, firms with *General business fc* appear not to conduct process innovation to cut costs and support their bottom line.

[14] We thank an anonymous reviewer for pointing this out.

Later for robustness we also explore alternative instruments. The additional instrument is the per cent of firms that report general business financial constraints in each industry–province excluding the firm (provinces are the Australian states), *Share of general fc in industry–province*. To compute this variable, we count the number of firms that report *General business fc* within each industry, in each Australian state (e.g., the number of generally constrained mining firms in Queensland); we exclude the individual firm's response from this count.[15] We then divide this count by the total number of firms in the industry–province minus one to exclude the firm. Access to capital in the firm's industry–province is likely to reflect innovation financing conditions for the firm. Moreover, this instrument only indirectly affects process innovation through financial constraints for innovation.

Due to the sheer volume of firms which report no process innovation and no financial constraints (Fig. 1, column 1), this instrument alone may not be sufficient to remove the upward bias on the financial constraints coefficient. We follow Hajivassiliou and Savignac (2008) and restrict the sample to firms that are likely innovators. A firm is classified as a likely innovator if in year t they fall into any of the following categories: (i) they have introduced a new process, product, marketing or organisational innovation, (ii) they have an ongoing process, product, marketing or organisational innovation in development, (iii) they have abandoned development of a process, product, marketing or organisational innovation or (iv) they have responded that they are financially constrained for innovation. Figure 1 (columns 3 and 4) present the composition of the restricted likely innovator sample. The number of observations in the no process innovation, no financial constraint category (column 3) now decreases significantly; all other categories remain the same. We report results for both the full sample and the restricted sample.

V Empirical Results

(i) Main Findings

We begin our empirical analysis by only including in z_t whether a firm conducts process innovation in the previous year (χ_{t-1}) and our measure of financial constraints; this is the minimum specification. We then gradually add control variables to test sensitivity to different specifications.

Table 3 reports the full-sample estimation results: column (1) reports the minimum specification, columns (2) and (3) add control variables, column (4) adds in year dummies, and column (5) uses both year and industry dummies. In all five specifications using the full-sample, process innovation in the previous year (χ_{t-1}) is positive and statistically significant at the 1 per cent level. Consistent with our theory, this indicates that firms who innovated in the previous period have a higher likelihood to innovate in the current period. At the same time, though, the financial constraints coefficient is positive and statistically significant, which suggests that financial constraints increase the probability of process innovation. This incoherent positive effect is somewhat unsurprising, however, given the endogeneity of financial constraints discussed in Section IV(v).[16] There are too many firms which have no intention to innovate, and therefore report no innovation and no financial constraints for innovation (Fig. 1, column 1). This leads to upward bias on the financial constraints coefficient.

Table 4 reports the estimation results for the same five specifications except using the preferred likely innovator sample. The point estimates and significance of past innovation remain similar, although now the coefficient of financial constraints is negative and statistically significant at the 1 per cent level. This indicates that financial constraints do in fact reduce the probability of firms conducting process innovation.

We can now answer one of our key questions: If a firm has innovated in the past, how do financial constraints affect the probability of process innovation? Using the point estimates in the baseline specification (Table 4, column 1), if a firm *did not* conduct process innovation in the previous year, financial constraints reduce the probability of conducting process innovation by around 10 per cent. Whereas if a firm *did* conduct process innovation in the previous

[15] Let the dummy variable $_{fc}$ denote the general business financial constraint of firm i in industry j, province k and time t, which takes a value of 0 if a firm reports no constraint. Then the percentage of firms that report general business financial constraint in each industry–province excluding the firm itself ($_{s}$) is $_{s} = \left(\sum 1\left(_{fc} > 0\right)/\left(|_{I}| - 1\right)\right)$, where $_{I}$ is the set of firms in industry j, province k and time t; $|_{I}|$ is its cardinality; 1 (•) is the indicator function, taking a value of 1 if $_{fc} > 0$. Note that $_{s}$ contains firm-level variation.

[16] Hajivassiliou and Savignac (2008) and Chundakkadan and Sasidharan (2020) obtain similar results.

Table 3
Full Sample Estimation Results

	(1)	(2)	(3)	(4)	(5)
Constant	−1.8542***	−2.2339***	−2.3707***	−2.3457***	−2.5694***
	(0.0087)	(0.0139)	(0.0194)	(0.0225)	(0.0298)
Past process innovation	1.9577***	1.5950***	1.4200***	1.4074***	1.3953***
	(0.0092)	(0.0084)	(0.0081)	(0.0081)	(0.0081)
Financial constraint	0.4568***	0.4892***	0.1825***	0.1636***	0.1850***
	(0.0118)	(0.0117)	(0.0136)	(0.0136)	(0.0136)
ln(Size)		0.2040***	0.1961***	0.1937***	0.1954***
		(0.0019)	(0.0019)	(0.0019)	(0.0021)
ln(Age)		−0.0836***	−0.0637***	−0.0618***	−0.0622***
		(0.0040)	(0.0039)	(0.0039)	(0.0040)
Foreign		−0.0118	−0.0313***	−0.0382***	−0.0768***
		(0.0085)	(0.0085)	(0.0084)	(0.0086)
Exporter		0.2560***	0.0790***	0.0722***	0.0339***
		(0.0076)	(0.0075)	(0.0075)	(0.0084)
Government assistance		0.1844***	0.1775***	0.1773***	0.1557***
		(0.0076)	(0.0074)	(0.0074)	(0.0076)
Collaboration		1.0279***	0.7122***	0.7035***	0.7065***
		(0.0067)	(0.0066)	(0.0066)	(0.0066)
Human capital			−0.2720***	−0.2649***	−0.2712***
			(0.0083)	(0.0083)	(0.0083)
Income			0.0834***	0.0776***	0.0757***
			(0.0082)	(0.0082)	(0.0082)
Cost of innovation			0.3744***	0.3838***	0.3771***
			(0.0088)	(0.0087)	(0.0087)
Productivity			0.1508***	0.1502***	0.1702***
			(0.0119)	(0.0119)	(0.0119)
Share of part-time staff			−0.2359***	−0.2388***	−0.1502***
			(0.0095)	(0.0095)	(0.0099)
Product innovation			1.2956***	1.2793***	1.3093***
			(0.0075)	(0.0075)	(0.0077)
Year dummies				Yes	Yes
Industry dummies					Yes
Observations	87,542	66,670	57,027	57,027	57,027

Notes: ***Significant at 1 per cent, **significant at 5 per cent, *significant at 10 per cent. Reported are the estimates of Equation (5) (GMM estimator, where the probability of conducting process innovation takes a logistic functional form) using the full sample. Financial constraint is instrumented with *General business fc*, which is a dummy equal to 1 if the firm identifies that a 'lack of access to additional funds' is a factor hampering general business activities, and 0 otherwise. Robust standard errors are shown in parentheses.

period, financial constraints reduce the probability of conducting process innovation by around 12 per cent.[17] These results indicate that policies to alleviate financial constraints for process innovation are beneficial, and that firms who have innovated in the past may require more ongoing financial support than non-repeat innovators to continue innovating. We expand on policy implications in Section VI.

There are also several interesting findings regarding the control variables in Table 4. First, *size* has a positive effect on process innovation, which indicates larger firms are more likely to engage in process innovation; this is consistent with Cohen and Klepper (1996) who find larger firms are more likely to be process innovators because of a cost-spreading advantage. Second,

[17] These probabilities were obtained by differentiating $\text{Prob}(_\chi = 1) = \exp(_z\beta)/(1+\exp(_z\beta))$, where $_z$ only includes process innovation in the previous period and financial constraints. Note that it could be that previous non-process innovators are further behind the technology frontier than previous process innovators, hence they have a greater need to process innovate and therefore a greater determination to find a way around financial constraints nonetheless to process innovate, resulting in a smaller marginal effect of financial constraints.

TABLE 4
Likely Innovator Estimation Results

	(1)	(2)	(3)	(4)	(5)
Constant	−0.7000***	−1.2368***	−1.4855***	−1.4090***	−1.6361***
	(0.0070)	(0.0125)	(0.0183)	(0.0210)	(0.0279)
Past process innovation	1.4550***	1.2888***	1.2154***	1.2226***	1.2092***
	(0.0073)	(0.0073)	(0.0075)	(0.0075)	(0.0074)
Financial constraint	−0.5200***	−0.1902***	−0.2592***	−0.2641***	−0.2450***
	(0.0116)	(0.0117)	(0.0135)	(0.0135)	(0.0135)
ln(Size)		0.1336***	0.1393***	0.1368***	0.1408***
		(0.0018)	(0.0018)	(0.0018)	(0.0019)
ln(Age)		−0.0472***	−0.0395***	−0.0390***	−0.0432***
		(0.0036)	(0.0037)	(0.0037)	(0.0037)
Foreign		0.0000	−0.0106	−0.0135*	−0.0575***
		(0.0077)	(0.0080)	(0.0079)	(0.0081)
Exporter		0.1714***	0.0613***	0.0535***	0.0092
		(0.0069)	(0.0071)	(0.0071)	(0.0079)
Government assistance		0.1487***	0.1463***	0.1430***	0.1118***
		(0.0068)	(0.0069)	(0.0069)	(0.0070)
Collaboration		0.5865***	0.4519***	0.4559***	0.4606***
		(0.0063)	(0.0064)	(0.0064)	(0.0064)
Human capital			−0.1639***	−0.1555***	−0.1633***
			(0.0080)	(0.0080)	(0.0080)
Income			0.1083***	0.0997***	0.0971***
			(0.0077)	(0.0078)	(0.0077)
Cost of innovation			0.2782***	0.2903***	0.2791***
			(0.0084)	(0.0084)	(0.0083)
Productivity			0.1403***	0.1393***	0.1643***
			(0.0112)	(0.0112)	(0.0112)
Share of part-time staff			−0.2438***	−0.2295***	−0.1318***
			(0.0089)	(0.0089)	(0.0092)
Product innovation			0.7369***	0.7279***	0.7628***
			(0.0068)	(0.0067)	(0.0069)
Year dummies				Yes	Yes
Industry dummies					Yes
Observations	50,655	44,824	39,511	39,511	39,511

Notes: ***Significant at 1 per cent, **significant at 5 per cent, *significant at 10 per cent. Reported are estimates of Equation (5) (GMM estimator, where the probability of conducting process innovation takes a logistic functional form) using the likely innovators (defined in Section IV(v)). Financial constraint is instrumented with *General business fc*. Robust standard errors are shown in parentheses.

younger firms are more likely to introduce process innovations than older firms; this suggests that established practices may make older firms more resistant to process innovation. Third, both foreign ownership and exporting status have no statistically significant effect on the probability of conducting process innovation; this suggests that vertical linkages to foreign firms may not be as important for process innovation than for other innovation types.

Fourth, government assistance and collaboration for innovation increase the probability of conducting process innovation.

Fifth, the negative coefficient of *Human capital* suggests that better access to skilled workers reduces process innovation; this, however, is unexpected and arises because mainly innovating firms are going to report that access to skilled workers is a problem for innovation.[18]

Sixth, an increase in income from the previous period increases the probability of process innovation.

[18] We discuss the limitation of this proxy in Section IV(iii).

Seventh, the estimation results show that firms who report the cost of innovation as a barrier have a higher probability of conducting process innovation. Similar to the human capital proxy, this result arises because mainly innovating firms are going to report that the cost of innovation is an issue. Alternatively, if product innovation is more expensive than process innovation, firms who indicate that innovation costs are high may revert to the cheaper innovation option – process innovation.

Eighth, maintaining or increasing productivity from the previous year increases the probability of conducting process innovation. Ninth, our proxy for capacity utilisation, the share of part-time staff, is negative suggesting that firms busy filling demand (high CU) may be more interested in extending their current capacity than in implementing new processes. Finally, conducting product innovation increases the probability of conducting process innovation highlighting a complementary relation between the two.

(ii) Robustness Checks

In this section we conduct nine robustness checks: (i) explore alternative functional forms of Prob$(\chi_t = 1)$, (ii) estimate our model using a maximum likelihood estimator, (iii) use an additional instrument, (iv) estimate the minimal model with time and industry dummies, (v) estimate the model with a continuous income variable, (vi) estimate the model with lagged control variables, (vii) estimate the model by firm size (small and medium-sized enterprises (SMEs) versus large firms), (viii) estimate the model by high and low growth firms and (ix) controlling for market size and measure the income by firms' turnover.

Previously we assumed that the probability a firm innovates, Prob$(\chi_t = 1)$, takes a logistic functional form. Table S3 in Appendix S1 reports the estimation results using alternative functional forms (only on the likely innovator restricted sample), namely linear and exponential probability functions. Across all specifications, past process innovation remains positive and statistically significant. Similarly, the coefficient of financial constraints remains statistically significant and negative. Despite the slight differences in point estimates, these tests show our results are robust to alternative specifications.

We also check if we obtain similar results using maximum likelihood estimation (MLE) instead of GMM. Table S4 (columns 1 and 2) in Appendix S1 presents the maximum likelihood estimation results for a logit probability model using the sample of likely innovators (for these estimations we assume the right-hand side variables are exogenous). We find that in both the minimal and full specifications the sign of point estimates are in line with those using the GMM estimator in Table 4.

We include an additional instrumental variable, *Share of general fc in industry–province*, in our main model (Eqn 5). Columns (3) and (4) in Table S4 in Appendix S1 estimate Equation (5) with both instruments – *General business fc* and *Share of general fc in industry–province*. In both the minimal and full specifications, past innovation remains statistically significant and positive. Similarly, the financial constraints coefficient remains negative and significant, with the point estimates being very similar to that in Table 4.

Table S5 in Appendix S1 reports the estimation results for robustness checks (4)–(8). Comparing with Table 4, we observe that the point estimates are largely in line with those of Table 4. In particular, the sign of estimated coefficients of lagged process innovation and financial constraints remain unchanged. Table S6 in Appendix S1 reports the estimation results where we control for market size and measure the income by firms' turnover, which is deflated by the consumer price index obtained from World Development indicators. Similarly, the sign and the coefficients of lagged process innovation and financial constraints does not change. Overall, these robustness tests provide further evidence to support our main finding that financial constraints reduce the probability of conducting process innovation.

VI Conclusions

Investment in process innovation is an important, silent driver of economic growth. Yet, it is one of the most difficult types of investment to finance. Due to the presence of high uncertainty and information asymmetries – investors are often reluctant to provide capital at a reasonable price. In this paper, we investigate the impact of financial constraints on a firm's decision to conduct process innovation, while also considering the role of past innovating experience.

Theoretically, we incorporate past innovating experience into the static framework from Gorodnichenko and Schnitzer (2013) and show a firm's optimal decision on process innovation is a function of past innovation, financial constraints, and a set of control variables. This decision naturally implies a set of population moments, which we use in the empirical estimations. Drawing on Australian microdata from 2006 to 2018 – namely the BCS – we test our theoretical predictions. We employ a direct survey measure of financial constraints – and to address the endogeneity problem this raises – we restrict the sample to likely innovators and instrument the financial constraints variable.

Our econometric results reveal that financial constraints reduce the probability a firm conducts process innovation. Firms that innovate in the previous period are also more likely to continue innovating in the current period. Specifically, if a firm *did not* conduct process innovation in the previous year, financial constraints reduce the probability of conducting process innovation by around 10 per cent. Whereas if a firm *did* conduct process innovation in the previous period, financial constraints reduce the probability of conducting process innovation by around 12 per cent.

(i) Policy Implications

Our results suggest that Australia and other advanced economies can benefit from policies alleviating financial constraints for process innovation. Moreover, because firms that have innovated previously are likely to continue innovating, policies encouraging process innovation today have the added benefit of promoting continual process innovation in the future. In particular, our analyses indicate that grants and asset write-off schemes can be effective policies for removing financial constraints for process innovation. First, as revealed in our literature review, firms tend to conduct process innovation by incorporating physical capital – such as advanced machinery or new technology – rather than by making intangible investments in R&D. Second, if information asymmetries were leading to excessive costs of finance, one would expect that firms who have innovated in the past – those who have reduced information asymmetry by proving ability to succeed – to be impacted less by financial constraints. This, however, does not appear to be the case (at least for Australia – a country with well-developed capital markets), as we find that past process innovation does not reduce the effect of financial constraints on the probability of present innovation.[19] In fact, because firms who have innovated in the past suffer more from financial constraints than non-repeat innovators, ongoing financial assistance for these firms is important for continual process innovation. That said, the procedure/criteria for grants and asset write-off schemes need to be well targeted.[20]

(ii) Future Research

Process innovation – once considered a second-order innovative activity – is accelerating to the forefront of policy discussion due to the COVID-19 pandemic. Future research can continue exploring the financing of process innovation as questions regarding the impact of financial constraints on different types or quality of process innovation remain unanswered. In this study, we use survey information that firms self-report to measure financial constraints. In addition, for future research, one can use alternative measures that can be computed from administrative data (e.g., the investment–cash flow sensitivity), and combine them with the self-reported measure. Besides, as more innovation panel data become available, researchers can not only continue to explore the dynamics of innovation (possibly using longer lags) but can also explore the dynamics of financial constraints.

Conflicts of Interest

Authors declare no conflicts of interest.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Sample composition by industry and year.

Table S2. Yearly transition probability matrices.

Table S3. Robustness checks: linear and exponential probability.

Table S4. Robustness checks: maximum likelihood estimator and additional instrument.

Table S5. Additional robustness checks.

Table S6. Additional robustness checks 2.

[19] For countries with less developed capital markets, Gorodnichenko and Schnitzer (2013) indicate that policies reducing information asymmetries can be beneficial.

[20] We thank an anonymous reviewer for pointing this out.

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