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Discretely innovating: The effect of limited market contestability on innovation and growth

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Abstract

I consider the impact of market contestability on innovation and growth. To examine this I use discrete entry (i.e. an integer number of firms) as a tool to vary contestability in each sector of a disaggregated multi-sector endogenous growth model. Contestability affects entry, extending results beyond competition. As a result, sectors with lower contestability have lower innovation and sectors characterized by Cournot oligopoly have lower innovation than sectors characterized by Bertrand. The effect of contestability is in addition to the effects of competition. Entry requirements become a consideration for innovation and growth policy, particularly in small or isolated economies.

JEL classifications: O41; L13
Keywords: Innovation; contestability; Cournot; Bertrand; competition; endogenous growth

1 Introduction

The recent experience of the US economy is increasing market power (De Loecker and Eeckhout, 2017), concentration (Furman and Orszag, 2018) and rent seeking (Autor et al., 2017). Standard models of growth and innovation that assume free entry imply that market power is only temporary, as a reward for the cost and effort of developing and commercializing an innovation. If the market power that is won by developing technological improvements has increased, assuming free entry implies that potential entrants would also increase their efforts to develop innovations. But the contributions of innovation (Bloom et al., 2018; Gordon, 2016, 2018) and entrepreneurship (Decker et al., 2014, 2016, Hathaway and Litan, 2014; Guzman and Stern, 2016) to growth are declining along with shrinking dynamism in the labor market (Haltiwanger et al., 2013; Molloy et al., 2016). Economic output has shifted from the processing of material inputs to applying knowledge with increasing returns to scale as a result (Arthur, 1989). Many such markets are dominated by only a few firms or even only one. The standard free entry assumption is increasingly unreliable for understanding innovation and growth in modern economies that are characterized by market power, increasing returns to scale and concentration.

The *continuous* free entry assumption implies that entry, contestability and competition eliminate any profit and that each individual firm has no impact on the aggregate competitive environment. In the mathematics of general equilibrium models, profits equal zero and the aggregate economy is a continuous function that uses an integral to aggregate the economy-wide range of firms where each

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individual firm is infinitisimally small. The continuous free entry approach can also be approximated with a discrete function where there is an arbitrarily large number of firms and it is assumed that no individual firm can influence the aggregate market. For solving the optimisation problem, it means that firm profit is zero and that the firm's output has no impact on the economy-wide price index when differentiating. But real world markets are not the continuous functions assumed in growth models with infinitisimally small firms. Products are highly differentiated and firms directly compete with only a small discrete number of rivals with limited opportunity for entry to expand the number of firms. *Standard assumptions of continuous free entry are inadequate for understanding innovation and growth if markets are disaggregated with only a few discrete rivals able to contest and compete in each market. This article seeks to understand the effect on innovation and growth of relaxing continuous free entry assumptions in a disaggregated multi-industry endogenous growth model.*

If continuous free entry is inappropriate, then what is the alternative? Innovative entry often requires a specific factor of production which represents a *structural* barrier to entry and this factor attracts a premium for its scarcity. For example, Uber recently poached 40 researchers and scientists from Carnegie Mellon University offering "bonuses of hundreds of thousands of dollars and doubling the salaries to staff."[1] Market liberalization has removed many regulatory and trade barriers, but other barriers to entry may still hamper innovation. If firms require a minimum viable scale[2] for entry then the market may have capacity for only a few firms. This is expecially likely in small or isolated regions where the number of entrants may be limited by the resource base available and size of the market. Understanding the effect of contestability on entrepreneurship, innovation and growth is vitally important to developing policies that address declining economic dynamism. On this basis, the relationship between barriers to entry and growth or innovation would be clearer if contestability itself is a parameter of market structure in models of growth and innovation. To explore how contestability affects innovation and growth, I assume that the economy contains many sectors but each sector contains only a small *discrete* number of firms that only compete with other firms in their own sector. I allow entry, but I assume that additional entry will only occur if the marginal firm can recover the full cost of entry. To distinguish this tool from the standard "free entry" approach, I call this set of assumptions *"discrete entry"*. As a result, firms *may* earn a positive profit even in the long-run steady state if there is insufficient space in the market for an additional firm to meet this entry requirement. *Using discrete entry (i.e. only an integer number of firms is permitted) as a tool to model contestability, this article develops an understanding of how limited contestability affects innovation and how entrepreneurship, innovation and growth are nuanced by the mode of competition.*

I modify the endogenous growth model from Young (1998) by disaggregating utility into many sectors and only allowing entry to a sector if a discrete marginal firm is profitable. Yang and Heijdra's (1993) technique for solving the Dixit-Stiglitz model of monopolistic competition allows for market power by assuming a discrete number of firms such that firms account for their own effect on the price index. This is in contrast to the standard approach which treats the number of firms as a continuous variable or a discrete variable that is arbitrarily large, which implies that each firm is infinitesimally small and has no effect on the price index. Disaggregation into many sectors similar to Venables (1999) allows for a segmented market structure in an otherwise aggregate model of growth. Discrete entry combined with a *limit on one* factor of production required for entry (possibly out of many factors) enables only a limited number of firms to enter rather than an entirely contestable market with continuous free entry. The simplicity of this approach means that *the critical factor of production becomes a tool to calibrate the degree of contestability*, similar to Krugman's (1982) approach to studying comparative advantage or to the specific factor model of international trade (Jones, 1971; Samuelson, 1971). The discrete entry approach is also validated by its use elsewhere. For example, Desmet and Parente (2014) also apply Yang and Heijdra's (1993) techniques to consider how specialized workers can block technology adoption that could substitute their input. For analytical simplicity, I assume only a single factor of production and innovation (labor), but the model could encompass any number of factors of production so long as there is only one specific factor required for entry that is constrained such as a natural resource, access to a network, sector specific skills, entrepreneurial skills, access to finance or collateral, or any other scarce factor of production that is necessary for market participation. In this way, the model becomes a framework to examine the impact on innovation and growth from a limitation on any specific factor of production required for entry. To be clear, the discrete entry modelling tool assumes that only *one* factor required for entry is constrained. I use the ideas production function from Young (1998) but the approach could also be applied using any other ideas production function in the extensive Schumpeterian endogenous growth literature and give the same result.[3]

As a result, sectors with less contestability experience greater rent seeking, less innovation and greater inequality. This fits the observations of increasing market power (De Loecker and Eeckhout, 2017; Eeckhout et al., 2019), concentration (Furman and Orszag, 2018) and rent seeking (Autor et al., 2017) alongside declining innovation (Bloom et al., 2018; Gordon, 2016, 2018) and entrepreneurship (Decker et al., 2014, 2016, Hathaway and Litan, 2014; Guzman and Stern, 2016) *while the model with free entry does not*. Intuitively, barriers to contestability mean that participating firms are partially protected from the threat of a marginal entrant and the competitve pressure of other market participants provides only a weak incentive to develop innovations.

While continuous free entry leads to the same outcomes for both Cournot and Bertrand competition (as the number of firms tends to infinity), discrete entry implies differences between the two. The article compares these directly, holding all other factors constant. In particular, sectors characterized by Cournot oligopoly are less innovative than sectors characterized by Bertrand, but enable greater entry for the same degree contestability calibrated by the factor of production required for entry in the sector. Intuitively, in standard microeconomic theory, firms in sectors characterized by Cournot oligopoly respond to the threat of entry by accommodating the entrant to sustain higher mark-ups above marginal cost. In contrast, firms in sectors characterized by Bertrand competition respond aggressively to the threat of entry by reducing prices to deter entry. These standard responses also occur in the model in this article, but with innovation as an additional dimension of competition. While Cournot oligopoly accommodates additional competition with only a small increase in innovation investment due to greater competition, firms in sectors characterized by Bertrand oligopoly respond aggressively with a larger increase in innovation investment to deter entry. By accommodating additional entrants, Cournot enables a greater number of firms into the market since it has a less ambitious innovation investment requirement for entry compared to Bertrand.

The model developed and derived in this article adds to the existing literature on growth and innovation by examing relationships between innovation and contestability particularly with respect to the mode of competition, inequality and growth. Such an analysis is not possible with standard models that assume continuous free entry. The model is likely to apply to industries where competition is characterized by increasing returns to scale because these markets contain fewer firms such that a marginal innovative entrant is essentially blocked by the optimum size required to profitably compete in the market. As the cost of entry in the model is assumed to be innovation effort, the pure model applies most directly to industries where ideas form the basis of inputs. Many such markets are also characterized by other entry barriers such as network effects, leading to a dominant incumbent. For example, the market for internet search engines is dominated by Google and entry of a competing search algorithm is virtually impossible. Instead, competition occurs in related markets, rather than the core internet search engine market. As a result, Google's dominance of the market for search engines is not threatened by innovative entrants. Standard models of growth and innovation would imply a steady state of improving quality, multiple firms and constant change between technology leaders, yet internet search remains dominated by Google. Even when alternatives have entered, such as Microsoft's Bing, the innovative effort was insufficient to gain a competitve foothold. Instead, the discrete entry model developed here provides a tool to understand the impact on innovation and growth from such entry barriers, concentration and market power. The results also imply the important role for the type of oligopolistic competition in economic growth. In markets where capacity and output cannot be easily changed, it can be expected that Cournot competition would lead to several firms, but less innovation than would be predicted by the model with free entry or Bertrand competition. This would most readily apply with an extended model containing other factors of production for markets with increasing returns to scale due to large physical capital investments that limit changes in output and capacity. For example, mining, chemicals, petroleum, steel and car manufacturing are all industries that require a large capital outlay, where additional output is difficult to expand in response to competitive pressure. In markets where the source of increasing returns is knowledge, such that they require a significant knowledge capital base, output is more readily changed so Bertrand competition could be expected. This would imply greater innovation than Cournot, even if the market is dominated by only a few firms. For example, information and communication technology and their related industries such as fintech require significant knowledge capital, typically represented by patents, but firms can relatively easily expand output. Such a result might help to explain the pattern of innovative competition and rivalry in the market for smartphones, despite Samsung and Apple maintaining dominant market positions.

The article is set out as follows. A brief subsection explains the contribution relative to the existing literature. Section 2 fully specifies the model including preferences, innovation, the supply of labor and market entry. Section 3 derives equilibrium prices, wages and production, rates of innovation in each sector and economy-wide growth rates. Section 4 further analyses the model, discusses policy implications and describes a series of numerical examples to examine the relationship between contestability and innovation. Lastly, Section 5 provides some concluding remarks.

1.1 Related literature

Acemoglu and Cao (2015) is the most closely related research in terms of examining contestability, in which the market is contestable for entrants with a drastic innovation, but their results do not extend to incremental innovation or discrete entry. Klette and Kortum (2004) aim to understand the persistence of incumbent innovation. Economists have also long considered how rivalry affects innovation (Gilbert and Newbery, 1982; Fudenberg et al., 1983; Salant, 1984; Harris and Vickers, 1985; Reinganum, 1989). Innovations allow firms to deter entry by keeping ahead of rivals to escape entry or competition by innovating (Aghion et al., 2001; Acemoglu et al., 2006; Aghion et al., 2009; Griffith et al., 2009; Acemoglu and Akcigit, 2012; Acemoglu and Cao, 2015). Empirical research has typically focused on competition (Aghion et al., 2009, 2005). Models of competition and innovation that assume continuous free entry may overlook whether limited contestability affects innovation incentives. Often endogenous growth models use a distance to frontier approach (Acemoglu et al., 2006; Aghion et al., 2009) that requires additional investment for entrants to match frontier technology. While entry costs are typically thought of as barriers to entry, theoretical models still assume *free* entry where investors expect to earn a return for this otherwise arbitrary additional investment required for entry. Acemoglu and Akcigit (2012) find that an optimal intellectual property rights system should offer greater protection for technology leaders that are far ahead of rivals because this adds to the incentive for innovation to contest and expand the frontier. The model is also related to Atkeson and Burstein (2008) and Edmond et al. (2015) which examine competition and entry, although do not specifically consider the innovation implications. All of these models impose an essentially arbitrary cost for technology improvements, but otherwise consistently assume *continuous free* entry. Assuming free entry results in the implicit assumption that technological opportunity is available to any potential entrant, provided their investment is adequate. Such an assumption ignores the advice of Arrow (1962) that monopolists face a disincentive to innovate and disrupt the status quo (Shapiro, 2012). Empirical evidence also suggests that the important factor determining the relationship between market structure and innovation is the extent of technological *opportunity* (Scherer, 1967; Levin et al., 1985; Hashmi, 2013). On this basis, the limit on contestability in this article is more consistent with these empirical findings, because it considers such a limit on the extent of technological opportunity for potential entrants.

In terms of modelling techniques the most closely related article is Navas and Licandro (2011), which also uses Yang and Heijdra (1993) in a trade model to examine the relationship between competition and trade integration. However, by assuming free entry Navas and Licandro (2011) use conflicting assumptions in their interpretation of Yang and Heijdra (1993), that when corrected, imply the approach I use in this article with this additional impact on contestability. Specifically, Navas and Licandro (2011) assume that firms take account of their impact on the price index, but treating the number of firms as a continuous variable implies that each firm is infinitesimally small, which would imply that the firm does not account for its effect on the price index. To be clear, assuming that a firm accounts for its effect on the price index, is itself an assumption of a discrete number of firms. I correct for this conflicting assumption in the model here.

Aghion et al. (2005) describe a relationship between technology-leading and following firms where competition discourages following firms from innovating, but encourages leading firms who are attempting to "escape competition". Escaping competition comes in two forms. Discrete entry eliminates the escape competition *for* the market effect by technology leading firms because the marginal firm is restricted from entry, but maintains the escape competition *in* the market effect. In this way the results relate to the upward sloping portion of the inverted U relationship between competiton and innovation. The model here is related to Desmet and Parente (2010) and Navas and Licandro (2011) whereby larger markets increase competition and innovation. In these models competition affects both the escape competition *for* the market effect and escape competition *in* the market effect, although there is no inverse U relationship because the escape competition in the market effect is always sufficiently dominant. In these models, a larger market supports increased product variety, increases the observed price elasticity of demand, reducing the size of a margin (competition in the market), but free entry requires innovation that uses all profits (competition for the market). Examining these results closer reveals a similar conclusion because both the number of participating firms and their size are also larger in the more contestable markets in order to amortise R&D costs over greater levels of production. However, free entry in both Desmet and Parente (2010) and Navas and Licandro (2011) means the effect on innovation is from competition only while the model here adds the additional dimension of contestability that further reduces innovation. Limited contestability enables those firms that are allowed to enter to maximise profits by innovating sufficiently to block the marginal firm. That is, *the contestability barrier introduced by assuming discrete entry eliminates the escape competition for the market effect*, reducing innovation further than these standard competition models with free entry, allowing firms to pay greater dividends to firm owners, reducing growth and increasing inequality.

The model also brings the discrete entry assumption and minimum viable scale from the industrial organisation literature (Bain, 1956; Reiss and Spiller, 1989; Berry, 1992) into aggregate models of growth in a similar way to how general equilibrium models of trade have already benefited from such insights (Eaton et al., 2013; Spencer and Brander, 1983; Brander and Spencer, 1985). The findings are consistent with research on the impact of deregulation which highlights how removal or simplification of regulatory barriers (Djankov et al., 2002; Bertrand and Kramarz, 2002; Alesina et al., 2005; Djankov, 2008) and trade liberalization (Tybout et al., 1991; Pavcnik, 2002; Melitz, 2003; Trefler, 2004; Melitz and Ottaviano, 2008; Verhoogen, 2008; Navas and Licandro, 2011) has stimulated investment.

2 Model specification

This section fully specifies the model. For simplicity, consumption is modeled as a representative consumer with a taste for variety in each sector. There are many sectors (indexed by i) and a small discrete number of varieties (indexed by j) in each sector. A single variety j in sector i is referred to as variety i, j. In each period, the quality leading firm produces variety i, j using a sector specific labor supply as a monopolist competing with other differentiated varieties in sector i and, if the firm is going to continue production in the following period, the firm purchases a sufficient quality improvement from entrepreneurial workers to be the quality leading firm in that variety in the following period. Participating firms pay a competitive wage to all workers and entrepreneurs also receive a dividend from monopoly profits.

2.1 Barriers to entry

Prior to specifying the model, consider the concept of modeling barriers to entry. In an economic modeling sense, *free* entry can be thought of as an expectation that potential entrepreneurs will pursue profitable opportunities and enter profitable segments of the market. This potential for entry means a market is contestable, even if entrants face varying entry costs. While these costs are sometimes referred to as barriers to entry, a *structural barrier to entry* represents a barrier to even the potential for additional entry or contestability. With this understanding of barriers to entry, the existing literature may be inadequate to understand the relationship between contestability and innovation. Therefore, the model does not assume free entry by a continuous array of firms and instead uses a simple discrete entry barrier that only allows market participation by an integer number of firms that meet a requirement for positive profits and uses the techniques of Yang and Heijdra (1993) to incorporate firm responses to market power.

The discrete entry barrier involves changing two assumptions about entry: (1) Only an integer number of firms may participate in each market; and (2) that one or more specific factor of production (out of possibly many) is *required* as part of the cost of entry. It is this factor of production that pins down the number of participants in each sector, such that once participation is determined, participating firms do not need to consider the threat of a marginal entrant. A third possible assumption is really a result of the first assumption: that the standard entry requirement of positive profits might not be binding, even in the long run. In the model here, the scarce factor of production is the sector specific labor supply. Innovations supplied by workers undertaking entrepreneurial effort is required for quality improvement and profitable entry. Entrepreneurs who find enough partners such that their collective entrepreneurial effort results in a sufficient quality improvement, receive a dividend as part of a firm's fixed cost, pinning down the number of firms to the number of entrepreneurial partnerships that achieve sufficient improvement.

As a result, the factor of production can be used to calibrate contestability and competition. Contestability is more than competition and more than simply the number of firms. While both competition and contestability are correlated with the number of firms, contestability is related to how easily one more firm can enter while competition is related to the overall magnitude of the number of firms. In this way, contestability is directly tied to the discrete entry assumption.[4]

2.2 Preferences

Constant elasticity of substitution (CES) utility by sector is nested in a Cobb-Douglas function with many sectors of only a few varieties each. The number of sectors is fixed, but the number of varieties in each sector is determined by sector parameters. The representative consumer has intertemporal preferences:

$$U = \sum_{t=0}^{\infty} \alpha^t \ln Q_t, \quad \alpha = 1/(1+\rho), \quad Q_t = \prod_{i=1}^{N} c_{i,t}^{\frac{1}{N}}. \tag{1}$$

where ρ represents the rate of time preference and Q_t is the Cobb-Douglas consumption of manufactured goods from N sectors in period t. Alternatively, Equation Q_t could be interpreted as a production function for a competitive final good sector which could serve as the numériare to aid empirical analysis. Varieties in different sectors are neither complements nor substitutes such that a change in the price of a variety in one sector has no effect on demand for varieties in other sectors and each sector has a constant expenditure share of $1/N$. Consumers have CES preferences between varieties (j) in the same sector (i):

$$c_{i,t} = \left[\sum_{j \in i} (A_{i,j,t} c_{i,j,t})^{\frac{\sigma_i - 1}{\sigma_i}} \right]^{\frac{\sigma_i}{\sigma_i - 1}}, \quad \sigma_i > 1 \forall i = 1, ..., N \tag{1a}$$

where $A_{i,j}$ represents the symmetric quality of variety j in sector i and the elasticity of substitution between varieties in the same sector is σ_i.

Intertemporal utility optimization implies the transversality condition and Euler equation $\frac{E_{t+1}}{E_t} = \frac{1+r}{1+\rho}$, where E_t is expenditure in period t and r is the rate of return on savings between period t and $t+1$. Rearranging gives $\frac{E_{t+1}}{1+r} = \frac{E_t}{1+\rho} = \alpha E_t$. Expenditure is normalized to $E_t = 1 \forall t$. The subscript t is suppressed where the time dimension is the same for all variables and its inclusion is unnecessary.

2.3 Labor

Following the approach of Krugman (1982) each industrial sector is assumed to have an exclusive labor supply L_i where workers inelastically provide one unit of labor per period. Workers undertake productive effort either as entrepreneurs or through employment in manufacturing. Workers are immobile between industry sectors,[5] but mobile between firms and mobile between entrepreneurship and manufacturing. This assumption implies workers' skills are industry-specific and it is difficult for workers to re-skill for employment in other sectors. Labor supply and entrepreneurship pin down the number of participants per sector and labor can therefore be used to calibrate contestability. An equivalent assumption may be placed on any other specific factor of production required for entry but for simplicity the model assumes labor is the only factor of production. Industries with a large labor supply will have a greater ability for firms to enter and contest the market. This allows a direct comparison of the level of contestability and innovation, without altering demand parameters such as elasticities.

In each industrial sector, the labor supply is given by $L_{i,t} = \sum_{j\varepsilon n_{i,t},n_{i,t+1}} l_{i,j,t}\ \forall i = 1,...,N$, where $l_{i,j,t}$ is labor employed in entrepreneurship and manufacturing in period t by the firm producing variety i, j and $n_{i,t}$ and $n_{i,t+1}$ are the discrete number of firms in sector i in periods t and $t+1$ respectively. Both n_t and n_{t+1} are required since manufacturing workers produce current versions and entrepreneurs produce quality improvements for production in the following period.

Production involves a fixed labor cost of $F_{i,j,t-1}$ in the period prior to production and a constant marginal labor cost of β. For all sectors $i = 1,2,...,N$ and varieties $j = 1,2,...,n_i$, the labor required by each firm in period t is:

$$\begin{array}{lcll} l_{i,j,t} & = & 0 & if\, c_{i,j,t} = 0\, and\, c_{i,j,t+1} = 0; \\ l_{i,j,t} & = & \beta c_{i,j,t} & if\, c_{i,j,t} > 0\, and\, c_{i,j,t+1} = 0; \\ l_{i,j,t} & = & F_{i,j,t} & if\, c_{i,j,t} = 0\, and\, c_{i,j,t+1} > 0; \\ l_{i,j,t} & = & F_{i,j,t} + \beta c_{i,j,t} & if\, c_{i,j,t} > 0\, and\, c_{i,j,t+1} > 0. \end{array} \tag{2}$$

where $c_{i,j,t}$ is the period t production of variety i, j at the existing quality level that was developed in the previous period $t-1$. In the steady state the number of varieties in each sector is unchanging such that the labor requirement for the average firm in sector i is $l_{i,j,t} = F_{i,j,t} + \beta c_{i,j,t}$ and the total labor requirement in sector i is $L_{i,t} = \sum_{j\varepsilon n_{i,t+1}} F_{i,j,t} + \sum_{j\varepsilon n_{i,t}} \beta c_{i,j,t}$.

In unsteady states, either too much labor is allocated to entrepreneurship or there is an opening for an additional firm to enter. If too much labor is allocated to entrepreneurship then firms make a loss which is repaid by entrepreneurs in reduced wages below the manufacturing wage. Workers would switch from entrepreneurship to manufacturing, as there are no barriers to working in manufacturing, decreasing manufacturing wages and reducing entrepreneurship losses, at least until wages equalise. If too few workers have chosen entrepreneurship then it is possible for a marginal firm to enter. This would enable some "lucky" few workers to switch to entrepreneurship by developing an innovation with an additional variety, leading to the steady state. These forces towards the steady state indicate the stability of the steady state.

2.4 Technology, entrepreneurship and innovation

Examining intra-firm rivalry within markets that contain only a small discrete number of firms requires using a knowledge production function where the number of firms can remain a small discrete number. This implies using the third generation Schumpeterian branch of endogenous growth (Young, 1998; Peretto, 1998; Dinopoulos and Thompson, 1998; Howitt, 1999) or a first generation quality ladders model (Grossman and Helpman, 1991; Aghion and Howitt, 1992). Product variety models (Romer, 1990; Jones, 1995) inevitably lead to infinitisimally small firms so would be inappropriate for the purpose of examining the effect of microeconomic market structures in aggregate models of growth. On this basis, innovation is modeled using the endogenous growth approach of Young (1998). This is a standard approach in third generation endogenous growth where quality or productivity improvements provide the engine of growth and variety innovations temper the scale effect, but the results would be comparable using any other Schumpeterian or quality ladders growth model. Entrepreneurship is considered more than R&D because entrepreneurs perform both research and commercialization roles. In this model entrepreneurs are self-employed to develop and commercialize an innovative quality improvement in each period for a firm to earn a profit in the subsequent period as remuneration for the entrepreneur's effort. Entrepreneurs can only develop a quality improvement if there is capacity in the market for a discrete firm to produce that product in the following period. As workers inelastically provide one unit of labor per period, for entrepreneurs to achieve a greater quality improvement requires additional effort from entrepreneurial partners. While the firm earns a monopoly profit, it is shared between the entrepreneurial workers who developed the quality improvement as a dividend in addition to the competitive wage. Therefore, entrepreneurs face a trade-off between sharing profits with additional partners or allowing additional rival firms to enter the market and diminish profit. For the purposes of this model, workers can only undertake effort in either entrepreneurship or manufacturing.[6]

Innovation occurs in the period prior to production. The entrepreneurial labor requirement to achieve the targeted quality level $A_{i,j,t}$ for variety i,j in period t and the fixed cost incurred *in the previous period* $t-1$ for production in period t is:

$$F_{i,j,t-1}(A_{i,j,t},\bar{A}_{i,j,t-1}) = \begin{cases} \gamma e^{\eta A_{i,j,t}/\bar{A}_{i,j,t-1}} & \text{if } A_{i,j,t} \geq \bar{A}_{i,j,t-1} \\ \gamma e^{\eta} & \text{otherwise} \end{cases} . \tag{3}$$

The parameters γ and η are constants used for calibration and the subscript t indicates the time period of the variable observation. $\bar{A}_{i,j,t-1}$ is an index of technological opportunity, representing the intertemporal spillover of knowledge available to entrepreneurs in period t-1 for developing improvements in variety i,j and innovations replace obsolete versions in the subsequent period. The technological opportunity index is simply the highest existing quality level for variety i,j. Each variety is symmetric within its sector such that all varieties in the same sector have the same quality level. The cost of innovation can be thought of as two components: a commercialization cost of γe^{η} irrespective of quality improvement and a research cost of $\gamma e^{\eta A_{i,t}/\bar{A}_{i,j,t-1}} - \gamma e^{\eta}$.

Dividends from monopoly profits may provide entrepreneurs with greater earnings than manufacturing workers as discrete entry creates a barrier to employment as entrepreneurs, with manufacturing wages falling until the labor market clears. In models that extend this approach to other critical factors of production, this premium would accrue to whomever controls the relevant factor of production required for entry.[7]

To facilitate the potential for new varieties not produced in the previous period and to maintain symmetry, if there is capacity for an additional profitable firm, it is assumed that the index of technological opportunity is an average of quality levels for its sector: $\bar{A}_{i,j,t-1} = \frac{\sum_{j \in n_{i,t-1}} A_{i,j,t-1}}{n_{i,t-1}}$. Alternatively, if an incumbent acquired an innovation that was an insufficient improvement (for any arbitrary reason) such that a marginal discrete firm could profitably enter, the new disequilibrium would result in negative profits for some firms because entrepreneurs would have to fund the market clearing manufacturing wage out of their own wages. Therefore, some entrepreneurial workers would prefer higher incomes by offering their labor in manufacturing rather than entrepreneurship reducing the productivity improvement target of entrants below that required to maximise profits. This disequilibrium would be corrected when an unprofitable firm would inevitably exit the market and any remaining entrepreneurs would join other participating firms and increase their productivity improvement target back to a profit maximising level. This characteristic can be thought of as the market having partially free entry, but the extent of contestability is determined by the availability of the entry-limiting factor of production. It is this mechanism that blocks the marginal entrant and limits market participation to a discrete number of firms. As a result, the entry decision for a new variety matches the quality improvement decision for any existing variety. Since both quality improvements and new varieties imply the exact same entry decision, there is no need to distinguish how entrepreneurial effort is allocated across new or existing varieties.

3 Equilibrium and the steady state

Equilibrium follows from optimization of CES sectors using techniques adapted from Yang and Heijdra (1993). All model variables are solved as functions of the number of firms and subsequently the number of entrants is solved and defined. This completes the model. As a result of discrete entry, profits are positive, but extracted by entrepreneurs appropriating all profit in the entrepreneurial "dividend" rather than by competitive pressure under a free entry condition. Usually in CES models, assuming free entry means both Cournot and Bertrand competition yield the same results, because the function is continuous or the number of firms is assumed to be very large. However, with discrete entry, outcomes differ by the mode of competition because each firm is not infinitesimally small. Both Cournot and Betrand equilibria are derived.

3.1 Equilibrium

Consumers allocate expenditure across sectors and varieties subject to the budget constraint $\sum_{i\in N} P_i c_i \leq E$, where P_i is the price index of sector i (to be defined in Equation 4a), c_i is demand for all varieties in sector i (defined by Equation 1a) and E is expenditure. From Cobb-Douglas utility between sectors, expenditure per sector is $c_i P_i = \frac{E}{N}$, such that the consumer spends a $\frac{1}{N}$ share of her expenditure on varieties in each sector i. Utility optimization finds that the direct demand function (for determining equilibrium in a sector characterized by Bertrand oligopoly) for each variety i, j is given by:

$$c_{i,j} = \frac{E}{N} A_{i,j}^{\sigma_i - 1} P_{i,j}^{-\sigma_i} P_i^{\sigma_i - 1} \tag{4}$$

where $P_{i,j}$ and $A_{i,j}$ are the price and quality level of variety i, j respectively. P_i is the sector i index of price and quality defined by the budget constraint and derived as:

$$P_i = \left[\sum_{j\in i,} A_{i,j}^{\sigma_i - 1} P_{i,j}^{1-\sigma_i} \right]^{\frac{1}{1-\sigma_i}}. \tag{4a}$$

Alternatively, utility optimization finds that the inverse demand function (for determining equilibrium in a sector characterized by Cournot oligopoly) for each variety i, j is given by:

$$P_{i,j} = A_{i,j}^{\frac{\sigma_i - 1}{\sigma_i}} c_{i,j}^{\frac{-1}{\sigma_i}} \frac{E}{N} \left[c_i^{\frac{\sigma_i - 1}{\sigma_i}} \right]^{-1}, \tag{5}$$

where c_i is a consumption index defined byconsumer preferences (Equation 1a).

The earnings in period $t-1$ for each entrepreneur in sector i who developed the current quality level $A_{i,j,t}$ is

$$y_{i,E,t-1} = w_{i,t-1} + \frac{d_{i,t}}{(1+r_t)}$$

where $w_{i,t-1}$ is the sector i wage of workers in period $t-1$ in order to clear the sector i labor market and $d_{i,t}$ is the sector specific dividend for entrepreneurs received in the following period.

The usual free entry condition, which implies that profits diminish to zero due to the competitive pressure of free entry, does not apply. In contrast to standard models with free or continuous entry, with the discrete entry barrier, firms permitted entry may make positive profit but all profit is paid to entrepreneurs through a dividend, over and above the standard manufacturing wage paid to all workers, including entrepreneurs. The free entry condition is modified to an alternative "entrepreneurial dividend condition" such that *entrepreneurs appropriate all profit and dividends are always positive*. Dividends are determined by the firm's profit function:

$$\pi_{i,j,t} = \frac{(P_{i,j,t} - \beta w_{i,t}) c_{i,j,t}}{(1+r_t)} - w_{i,t-1} F_{i,j,t-1} = \frac{d_{i,t}}{(1+r_t)} F_{i,j,t-1} \geq 0, \tag{5a}$$

subject to demand and discrete entry. The initial entrepreneur determines whether to hire further entrepreneurs in order to increase effort to achieve a greater quality improvement. The optimization decision requires that these initial entrepreneurs attempt to maximize their income from both wages and dividends. Rearranging the firm's profit function (Equation 5a) and substituting entrepreneurial earnings, entrepreneurs make innovation and production choices that maximize earnings such that the firms output, wage, innovation and pricing decisions are governed by the optimization problem:

$$\max y_{i,E,t-1} = \frac{(P_{i,j,t} - \beta w_{i,t})\, c_{i,j,t}}{(1+r_t)\, F_{i,j,t-1}} \tag{5b}$$

subject to market demand.Workers will choose to be entrepreneurs if dividends are positive and an entrepreneurship opportunity is available either as a partner to develop an improvement in an existing variety or by creating a new variety if there is capacity for a profitable marginal firm. If no entrepreneurial opportunity is available, remaining workers are employed in manufacturing to clear the labor market.

In sectors characterized by Cournot oligopoly, entrepreneurs maximize income subject to inverse demand by choosing output and quality on the basis of the willingness of consumers to pay to clear the market. Differentiating Equation 5b with respect to the decision variables of output and quality respectively, the first order conditions for maximizing entrepreneurial income in a market characterized by Cournot oligopoly are given by:

$$\frac{\partial y_{i,E,t-1}}{\partial c_{i,j,t}} = \frac{P_{i,j,t} - \beta w_{i,t}}{(1+r_t)\, F_{i,j,t-1}} + \frac{c_{i,j,t}}{(1+r_t)\, F_{i,j,t-1}} \frac{\partial P_{i,j,t}}{\partial c_{i,j,t}} = 0 \tag{6}$$

and

$$\frac{\partial y_{i,E,t-1}}{\partial A_{i,j,t}} = \frac{c_{i,j,t}}{(1+r_t)} \left(\frac{\frac{\partial P_{i,j,t}}{\partial A_{i,j,t}} F_{i,j,t-1} - (P_{i,j,t} - \beta w_{i,t}) \frac{\partial F_{i,j,t-1}}{\partial A_{i,j,t}}}{(F_{i,j,t-1})^2} \right) = 0. \tag{7}$$

Rearranging 6 gives equilibrium Cournot prices:

$$P_{i,j,t} = \frac{1}{\left(1 + \frac{c_{i,j,t}}{P_{i,j,t}} \frac{\partial P_{i,j,t}}{\partial c_{i,j,t}}\right)} \beta w_{i,t} \tag{8}$$

where $\frac{c_{i,j,t}}{P_{i,j,t}} \frac{\partial P_{i,j,t}}{\partial c_{i,j,t}}$ represents the elasticity of demand with respect to price, evaluated using inverse demand. Symmetry in each sector means the inverse demand function (Equation 5) for variety i, j can also be written as $P_{i,j} = \frac{E}{N} A_{i,j}^{\frac{\sigma_i - 1}{\sigma_i}} c_{i,j}^{\frac{-1}{\sigma_i}} \left(A_{i,j}^{\frac{\sigma_i - 1}{\sigma_i}} c_{i,j}^{\frac{\sigma_i - 1}{\sigma_i}} + (n_i - 1) A_{i,k}^{\frac{\sigma_i - 1}{\sigma_i}} c_{i,k}^{\frac{\sigma_i - 1}{\sigma_i}} \right)^{-1}$, where variety i,k represents each of the other symmetrical varieties in sector i. Differentiating this inverse demand function with respect to consumption of variety i, j, simplifying and substituting the differential and the inverse demand function to find the elasticity of substitution, the equilibrium price of variety i, j is evaluated as a function of the number of entrants by substituting the elasticity into Equation 8:

$$P_{i,j}(n_i) = \left(\frac{n_i \sigma_i}{(n_i - 1)(\sigma_i - 1)} \right) \beta w_i, \qquad n_i \geq 2. \tag{8a}$$

As competition increases with the number of firms n_i, the price of a firm's own variety has less effect on the industry index until the familiar CES pricing rule is reached $P_{i,j} = \beta w_i \left(\frac{\sigma_i}{\sigma_i - 1} \right)$ which is the result of the standard model with *continuous free entry* where n effective tends to infinity as each firm becomes infinitesimally small. In the case of $n_i = 1$ the firm would receive the same revenue irrespective of price due to Cobb-Douglas utility between sectors because consumers allocate a specific portion of expenditure on that sector. This limitation therefore requires that $n \geq 2$. To include the $n = 1$ scenario would require the upper-level of the utility function to be an alternative such as a CES function. For simplicity, the Cobb-Douglas version is used to aid intuition and there is no loss of generality for the conclusions drawn because this article is concerned with situations other than pure monopoly.

The labor used in manufacturing in sector i simply equals the number of units consumed multiplied by the marginal labor cost per unit (β). Dividing consumer expenditure in sector i by the symmetrical price per unit and multiplying by β finds the labor requirement in sector i is $l_{i,m,t} = \frac{E_t}{NP_{i,j,t}}\beta$. Labor employed as entrepreneurs in period t equals the number of entrants in the coming period multiplied by the symmetric investment in quality improvement per firm, $l_{i,I,t} = n_{i,t+1}F_{i,j,t}$. Labor market clearing requires that the total specialized sectoral labor supply is employed. Total labor in each sector is therefore equal to

$$L_{i,t} = n_{i,t+1}F_{i,j,t} + \frac{E_t}{NP_{i,j,t}}\beta. \tag{9}$$

It is assumed that wages are not affected by the market power of employers.[8] However, wages are affected by competition in product markets as this determines workers' alternative employment opportunities as entrepreneurs.

Substituting Cournot prices finds that the labor employed in sector i, characterized by Cournot oligopoly, is given by: $L_{i,t} = n_{i,t+1}F_{i,t} + \frac{E_t(n_{i,t}-1)(\sigma_i-1)}{Nn_{i,t}\sigma_i w_{i,t}}$. Solving for Cournot manufacturing wages gives:

$$w_{i,t} = \frac{E_t\,(n_{i,t}-1)\,(\sigma_i-1)}{Nn_{i,t}\sigma_i\,(L_{i,t}-n_{i,t+1}F_{i,t})}. \tag{10}$$

Notably manufacturing wages decline as competition increases. While this seems counterintuitive, this result is because both the level of competition (n) and wages (w) are a result of the constraint on supply of labor. This becomes clear once the model is solved for the equilibrium number of firms.

In sectors characterized by Bertrand oligopoly, entrepreneurs maximize income subject to direct demand (Equation 4) by choosing price and quality on the basis of quantity demanded at that price and quality in order to clear the market. Differentiating Equation 5b with respect to the decision variables of price and quality respectively, the first order conditions for maximizing entrepreneurial income in a market characterized by Bertrand oligopoly are given by:

$$\frac{\partial y_{i,E,t-1}}{\partial P_{i,j,t}} = \frac{c_{i,j,t}}{(1+r_t)\,F_{i,j,t-1}\,(A_{i,j,t})} + \frac{(P_{i,j,t}-\beta w_{i,t})}{(1+r_t)\,F_{i,j,t-1}}\frac{\partial c_{i,j,t}}{\partial P_{i,j,t}} = 0 \tag{11}$$

and

$$\frac{\partial y_{i,E,t-1}}{\partial A_{i,j,t}} = \frac{(P_{i,j,t}-\beta w_{i,t})}{(1+r_t)}\left(\frac{\frac{\partial c_{i,j,t}}{\partial A_{i,j,t}}F_{i,j,t-1} - c_{i,j,t}\frac{\partial F_{i,j,t-1}}{\partial A_{i,j,t}}}{(F_{i,j,t-1})^2}\right) = 0. \tag{12}$$

Rearranging 11 gives the equilibrium Bertrand price rule:

$$P_{i,j,t}\left(\frac{c_{i,j,t}}{P_{i,j,t}}\frac{1}{\frac{\partial c_{i,j,t}}{\partial P_{i,j,t}}} + 1\right) = \beta w_{i,t} \tag{13}$$

where $\frac{c_{i,j,t}}{P_{i,j,t}}\frac{1}{\frac{\partial c_{i,j,t}}{\partial P_{i,j,t}}}$ is the elasticity of demand with respect to price, evaluated using direct demand. While it seems familiar with Cournot prices, elasticities are not constant with a discrete number of firms, despite using CES demand. With discrete firms and symmetry in each sector, the direct demand function can be written as $c_{i,j}\,(n_i) = \frac{E}{N}A_{i,j}^{\sigma_i-1}P_{i,j}^{-\sigma_i}\left[P_{i,j}^{1-\sigma_i}A_{i,j}^{\sigma_i-1} + (n_i-1)\,P_{i,k}^{1-\sigma_i}A_{i,k}^{\sigma_i-1}\right]^{-1}$. Differentiating this direct demand function with respect to the price of variety i,j, simplifying and substituting the differential and the direct demand function to find the elasticity of substitution, the equilibrium price of variety i,j is evaluated as a function of the number of entrants by substituting the elasticity into Equation 13:

$$P_{i,j}(n) = \left(\frac{\sigma_i n_i - (\sigma_i-1)}{(n_i-1)\,(\sigma_i-1)}\right)\beta w_i, \qquad n \geq 2. \tag{13a}$$

As with Cournot, when competition increases with the number of firms n_i, the price of a firm's own variety has less effect on the industry index until the familiar CES pricing rule $P_{i,j} = \beta w_i\left(\frac{\sigma_i}{\sigma_i-1}\right)$ is also reached with Bertrand which is the result of the standard model with *continuous free entry* where n effective tends to infinity as each firm becomes infinitesimally small. The limitation that $n \geq 2$ still applies due to Cobb-Douglas preferences between sectors.

Substituting Bertrand prices into Equation 9 finds that the labor employed in sector i, characterized by Bertrand oligopoly, is given by $L_{i,t} = n_{i,t+1}F_{i,t} + \frac{E_t(n_{i,t}-1)(\sigma_i-1)}{N(\sigma_i n_i-(\sigma_i-1))w_{i,t}}$. Rearranging, Bertrand manufacturing wages are given by:

$$w_{i,t} = \frac{E_t\left(n_{i,t}-1\right)\left(\sigma_i-1\right)}{N\left(\sigma_i n_i-\left(\sigma_i-1\right)\right)\left(L_{i,t}-n_{i,t+1}F_{i,t}\right)}. \tag{14}$$

As above, manufacturing wages decline as competition increases because both the level of competition (n) and wages (w) are a result of the constraint on supply of labor. This becomes clear once the model is solved for the equilibrium number of firms.

3.2 Innovation

After manufacturing costs, all remaining future profits are paid in dividends to entrepreneurs in return for their efforts to develop the innovation. Workers are mobile between employment in manufacturing or entrepreneurship and there are no barriers to workers offering their labor for manufacturing. However, workers face a barrier to employment as an entrepreneur since opportunities either require a partnership with additional entrepreneurs or the capacity for an additional firm. Therefore, dividends must be positive, such that entrepreneurs' earnings are never less than the wages of manufacturing workers, because workers employed as entrepreneurs would switch to the manufacturing role if dividends were negative, but the reverse process may not be possible.

In a significant departure from Yang and Heijdra (1993), these techniques are adapted to also determine innovation. If the market is characterized by Cournot, it is assumed that profit maximization involves the joint optimization of quality improvement and output given consumers' willingness to pay for higher quality products and to clear the market. Alternatively, if the market is characterized by Bertrand, it is assumed that profit maximization involves the joint optimization of quality improvement and prices based on consumers' quantity demanded in response to higher quality products and proposed prices.

Rearranging the second first order condition (Equation 7) for markets characterized by Cournot competition yields that the entrepreneur's income-maximizing quality-improvement target is:

$$A_{i,j,t} = \overline{A}_{i,j,t-1}\frac{\left(\sigma_i-1\right)\left(n_{i,t}-1\right)}{\eta\left(n_{i,t}+\left(\sigma_i-1\right)\right)}. \tag{15}$$

The income-maximizing quality-improvement target increases as competition increases with the number of firms n_i. As in Young (1998) parameters are assumed such that there is always growth in the fully contestable market. That is $\frac{\sigma_i-1}{\eta} > 1$. As a result, the entrepreneurial effort required per firm is:

$$F_{i,j,t-1} = \begin{cases} \gamma e^{\frac{\left(\sigma_i-1\right)\left(n_{i,t}-1\right)}{n_{i,t}+\left(\sigma_i-1\right)}} & \text{for}\, n_{i,t} > \frac{(\eta+1)(\sigma_i-1)}{(\sigma_i-1)-\eta} \\ \gamma e^{\eta} & \text{otherwise.} \end{cases} \tag{15a}$$

As n_i increases, the quality improvement target and investment in innovation tends towards the results in the continuous free entry model in Young (1998). Substituting the research cost into Equation 5b and taking the revenue of all firms in sector i as symmetric, the income of entrepreneurs in period $t-1$ from both wages and future dividends in sectors characterized by Cournot competition is equal to:

$$y_{i,E,t-1} = \begin{cases} \frac{(n_{i,t}+\sigma_i-1)\alpha E_{t-1}}{N n_{i,t}^2 \sigma_i \gamma e^{\frac{\left(\sigma_i-1\right)\left(n_{i,t}-1\right)}{n_{i,t}+\left(\sigma_i-1\right)}}} & \text{for}\, n_{i,t} > \frac{(\eta+1)(\sigma_i-1)}{(\sigma_i-1)-\eta} \\ \frac{(n_{i,t}+(\sigma_i-1))\alpha E_{t-1}}{N n_{i,t}^2 \sigma_i \gamma e^{\eta}} & \text{otherwise.} \end{cases} \tag{16}$$

Workers will enter the labor market as entrepreneurs, either with partners in an existing variety or a new variety, until adding additional entrepreneurial effort or a marginal firm would result in entrepreneurial income falling below the manufacturing wage.

Substituting the Cournot manufacturing wage and entrepreneurial income (Equations 10 and 16 respectively), the positive dividend requirement can be rearranged to $L_{i,t} \geq \left(\frac{(n_{i,t}-1)(\sigma_i-1)n_{i,t+1}^2}{n_{i,t}(n_{i,t+1}+\sigma_i-1)\alpha} + n_{i,t+1} \right) F_{i,t}$. In the steady state, the number of firms is unchanging such that the largest integer $n_i \geq 2$ that satisfies

$$L_i \geq n_i \left(\frac{(n_i-1)(\sigma_i-1)}{(n_i+\sigma_i-1)\alpha} + 1 \right) F_i \tag{17}$$

implicitly defines the steady state number of firms in a sector characterized by Cournot competition. The Cournot model is now complete. The n_i which satisfies Equation 17 can be used to solve for any variable in Cournot competition using equations 8a, 10, 15 and 16.

Similarly, rearranging the second first order condition (Equation 12) for markets characterized by Bertrand competition finds that the entrepreneur's earnings-maximizing quality target is:

$$A_{i,j,t} = \overline{A}_{i,j,t-1} \frac{(\sigma_i-1)(n_{i,t}-1)}{\eta n_{i,t}}. \tag{18}$$

The income-maximizing quality-improvement target increases as competition increases with the number of firms n_i. For $\sigma_i > 2\eta + 1$, Bertrand competition results in growth for any level of $n_i \geq 2$. For $1 < \sigma_i < 2\eta + 1$, the supply of labor must be large enough that $n_i > \frac{\sigma_i-1}{(\sigma_i-1)-\eta}$ for growth to occur. Therefore, the entrepreneurial effort required per firm is:

$$F_{i,j,t-1} = \begin{cases} \gamma e^{\frac{(\sigma_i-1)\left(n_{i,t}-1\right)}{n_{i,t}}} & \text{for } n_{i,t} > \frac{\sigma_i-1}{(\sigma_i-1)-\eta} \\ \gamma e^{\eta} & \text{otherwise.} \end{cases} \tag{18a}$$

Similar to Cournot innovation, as n_i increases, the innovation target and investment in innovation tends toward the competitive level found in Young (1998). Substituting the cost of innovation into Equation 5b and taking the revenue of all firms in sector i as symmetric, the income of entrepreneurs in period $t-1$ from both wages and future dividends in sectors characterized by Bertrand oligopoly is:

$$y_{i,E,t-1} = \begin{cases} \frac{\alpha E_{t-1}}{N(\sigma_i n_{i,t}-(\sigma_i-1))\gamma e^{\frac{(\sigma_i-1)\left(n_{i,t}-1\right)}{n_{i,t}}}} & \text{for } n_{i,t} > \frac{\sigma_i-1}{(\sigma_i-1)-\eta} \\ \frac{\alpha E_{t-1}}{N(\sigma_i n_{i,t}-(\sigma_i-1))\gamma e^{\eta}} & \text{otherwise.} \end{cases} \tag{19}$$

Substituting Bertrand manufacturing wages and entrepreneurial income (Equations 14 and 19), the positive dividend requirement can be rearranged such that $L_{i,t} \geq \left(\frac{(n_{i,t}-1)(\sigma_i-1)(\sigma_i n_{i,t+1}-(\sigma_i-1))}{\alpha(\sigma_i n_{i,t}-(\sigma_i-1))} + n_{i,t+1} \right) F_{i,t}$. With a constant number of firms in the steady state, the largest integer $n_i \geq 2$ that satisfies

$$L_i \geq \frac{(n_i-1)(\sigma_i-1)+\alpha n_i}{\alpha} F_i \tag{20}$$

implicitly defines the steady state number of firms in a sector characterized by Bertrand. In the non-growth scenario for Bertrand competition, the number of firms can be explicitly defined as the largest integer $n_i \geq 2$ which satisfies:

$$n_i \leq \frac{\alpha L_i + (\sigma_i-1)\gamma e^{\eta}}{((\sigma_i-1)+\alpha)\gamma e^{\eta}} \tag{20a}$$

The Bertrand model is now also complete. The n_i which satisfies Equation 20 (or for $n_i < \frac{\sigma_i-1}{(\sigma_i-1)-\eta}$ also satisfies Equation 20a) can be used to solve for any variable in Bertrand competiton using equations 13a, 14, 18 and 19.

3.3 Steady-state growth

The measure of growth for the economy as a whole is the rate at which total output increases. In this model, total output is made up of two components: production of manufactured goods and production of quality-improving innovations. Output increases at the rate that real incomes increase because all profits are the income of workers and real income reflects what incomes are worth in consumption.

Real wages are defined by $\omega_{i,t} = \frac{w_{i,t}}{P}$, where P describes the aggregate price index such that it recognizes the changes in costs and quality across all sectors. Since nominal wages are unchanging in the model, real wages are increasing at the rate that the economy-wide price index declines. So far, price indices have been defined for each sector only. The aggregate price index describes the overall cost of living. It is the P that buys one unit of Q,

$$P = \frac{1}{N}\prod_{i=1}^{N}\left(P_i^{\frac{1}{N}}\right), \tag{21}$$

where P_i is each sector's price index given by Equation 4a.

The rate of technology improvement is the discrete derivative of $A_{i,j}$. The growth rate of technology in a Cournot sector is therefore:

$$g_{i,A} = \frac{A_{i,j,t} - A_{i,j,t-1}}{A_{i,j,t-1}} = \frac{\varepsilon(\sigma_i - 1)(n_i + \varepsilon - 1)}{\eta(\sigma_i(\varepsilon + 1) + n_i - 1)} - 1 \tag{21a}$$

and the growth rate of technology in a Bertrand sector is:

$$g_{i,A} = \frac{\varepsilon(\sigma_i - 1)(n_i + \varepsilon - 1)}{\eta(n_i + \varepsilon)} - 1. \tag{21b}$$

Taking the discrete derivative of P_i with respect to time, the sector i price index is falling at a rate of $(g_{i,A})^{\sigma-1}\frac{1}{1-\sigma}$ with the exact rate depending on the mode of competition. Aggregating price indices across all sectors, the growth rate of consumption/output is given by the rate that the aggregate price index declines:

$$g_Q = \frac{1}{N(1-\sigma)}\prod_{i=1}^{N}(g_{i,A})^{\sigma-1} \tag{21c}$$

Since the other portion of economic output, innovation, is constant in this model, the growth rate of total output for each sector is the growth rate of consumption of each sector multiplied by the proportion of the specialized workforce employed in manufacturing. As each sector represents an equal $1/N$ share of the value of total consumption, GDP growth is the average growth rate of all sectors. GDP growth depends upon the specific make-up of the economy. In particular, the form of competition in each market, the size of each specialized labor supply and the level of contestability. These factors determine the share of employment in innovation or manufacturing and the rate of technology improvement in each sector.

4 Analysis

While the main analytical results of the model are shown in section 3, this section provides analysis and discussion of particular aspects of interest.

4.1 Cournot versus Bertrand Innovation

In comparable markets with the same parameters, the difference between quality targets for sectors characterized by Cournot or Bertrand oligopoly converges to zero as the number of firms tends to infinity. Similarly, Cournot and Bertrand models converge towards the equal outcomes as σ tends toward one. However, with the discrete entry requirement used to model limited contestability, the relationship between innovation targets for Cournot and Bertrand competition is not so clear, given that varieties are substitutes ($\sigma > 1$). A direct comparison between the quality targets cannot be made because the number of firms is implicitly defined by the size of each specialized labor type L_i and the number of firms differs between Cournot and Bertrand markets.

Specifically, Cournot reduces the innovation investment required for entry such that the scarce factor of production can be shared across a greater number of discrete firms. The quality target derived above shows how additional entry also provides a greater incentive to innovate, to compete with rivals. Yet it is not clear in the equations above if the incentive provided by additional entry compensates for the effect of a lower innovation investment required for entry in a Cournot market. This subsection seeks to establish and clearly understand the comparison of innovation in sectors characterized by Cournot and Bertrand oligopoly.

Proposition: *Let all parameters be equal in two sectors characterized by Cournot and Bertrand oligopoly. Firms participating in a market characterized by Bertrand oligopoly always set a higher quality target than firms in the market characterized by Cournot.*

Proof: Examine the difference between the two quality targets for Bertrand and Cournot sectors given in Equations 18 and 15 respectively, with n_B and n_C describing the number of firms in Bertrand and Cournot sectors:

$$A_{Diff} = A_{Bertrand} - A_{Cournot} = \overline{A}_{i,j,t-1}\frac{(\sigma_i - 1)}{\eta}\left(\frac{(n_B - 1)}{n_B} - \frac{(n_C - 1)}{(n_C + (\sigma_i - 1))}\right). \qquad (22)$$

Setting this difference equal to zero and rearranging finds that in order for the difference to be zero, $\sigma_i = 1$ or $\sigma_i = \frac{n_C - 1}{n_B - 1}$. As the first of these options breaches the assumption that varieties in the same sector are substitutes ($\sigma_i > 1$), the difference in quality targets is only zero if the elasticity is equal to the ratio of $n_C - 1$ to $n_B - 1$. Now let $\sigma_i = \frac{n_C - 1}{n_B - 1} + \varepsilon$. By substituting into $A_{Diff} > 0$ and solving for ε, the characteristics of ε describe the difference between quality targets for sectors defined by Bertrand and Cournot such that a strict requirement that ε is positive describes that a sector with Bertrand oligopoly always sets a higher quality target than a sector with Cournot oligopoly. Substituting and rearranging finds the two solutions for ε are both positive:

$$\overline{A}_{i,j,t}\frac{\left(\frac{n_C-1}{n_B-1}+\varepsilon-1\right)}{\eta} > 0 \ or \ \frac{(n_B-1)}{n_B} - \frac{(n_C-1)}{\left(n_C+\left(\frac{n_C-1}{n_B-1}+\varepsilon-1\right)\right)} > 0$$
$$\varepsilon > \frac{n_B-n_C}{n_B-1} > 0 \ or \ \varepsilon > 0 \qquad (23)$$

Alternatively substituting $\sigma_i = \frac{n_C-1}{n_B-1} + \varepsilon$ into $A_{Diff} < 0$ requires that ε be negative. As ε is strictly positive by its definition ($\sigma_i = \frac{n_C-1}{n_B-1} + \varepsilon > 1$), firms in a Bertrand sector must always set a higher quality target than Cournot, proving the proposition.

The intuitive explanation for this result is that firms in a Cournot market require a lower investment in quality improvement per firm compared to a Bertrand market to retain a greater price margin above marginal cost. In doing so, Cournot markets allow additional entry under the discrete entry barrier. While this competitive pressure also incentivizes additional innovation investment, this does not entirely compensate for the effect of Cournot. In standard microeconomic theory, firms in sectors characterized by Cournot oligopoly respond to the threat of entry by accommodating the entrant to sustain higher mark-ups above marginal cost. In contrast, firms in sectors characterized by Bertrand competition respond aggressively to the threat of entry by reducing prices to deter entry. These standard responses also occur in the model in this article, but with innovation as an additional dimension of competition. As with the standard microeconomic model, Cournot oligopoly accommodates additional competition with only a small increase in innovation investment due to greater competition, but firms in sectors characterized by Bertrand oligopoly respond aggressively with a larger increase in innovation investment to deter entry. By accommodating additional entrants, Cournot enables a greater number of firms into the market since it has a less ambitious innovation investment requirement for entry compared to Bertrand.

This is an interesting result because it implies that the number of firms is a very weak indicator of the intensity of competition. Markets characterized by Bertrand could have very few participants, but compete intensively on both price and innovation. On the other hand markets characterized by Cournot could have many participants, but weak competition as each firm accommodates competitive pressure and fails to respond sufficiently to new entry with price competition or innovative technology improvements. While the competitive intensity of innovation effort might be more difficult to measure than price, output or market concentration, a combined indicator based on all of these might provide regulators with a stronger indication of competition.

The model highlights how the mode of competition is a particularly important market characteristic for innovation. Low contestability in a Cournot sector results in a substantially lower level of innovation. When comparing Cournot and Bertrand innovation on a production factor basis (labor), Cournot sectors have lower innovation rates, even though Cournot competition allows significantly more firms to participate. These findings are supported by Navas and Licandro (2011) who examine trade liberalization and innovation, concluding that international rivalry is positive for innovation and that Bertrand oligopoly provides a stronger incentive for innovation than Cournot. Interestingly, the comparison between competition modes here is more nuanced by considering contestability rather than competition. As a result, Cournot oligopoly allows many more firms to enter than industries characterized by Bertrand oligopoly for the same resource constraint because Cournot entrepreneurs withhold a larger share of profit. Yet the incentive provided by additional entry does not compensate entirely for the effect of strategic responses in markets governed by Cournot oligopoly.

4.2 Policy Implications

Growth models, either directly or implicitly, suggest conclusions about innovation and growth policies. Over an entire economy, it may be possible for a few or many (or somewhere in between) sectors to have low levels of contestability, but the overall effect on economy-wide growth depends upon the portion of the economy made up of sectors with low contestability. The existence of some low contestability sectors does not always have a substantial effect on the economy-wide growth rate. Each sector makes up a small portion of expenditure and unless the economy is dominated by sectors with barriers to entry, the effect on growth is not necessarily substantial. By including additional microfoundations such as contestability, the model incorporates a market failure for entry and innovation at a sector level and makes a strong link between effective microeconomic policy and economic growth. The intuitive implications from growth models typically suggests macroeconomic policies such as R&D support. In addition, this model shows why growth policy should also incorporate microeconomic reform in individual sectors.

The intuitive policy response to most endogenous growth models is to examine the factors affecting the innovation cost function that determines entry and adjust these factors to stimulate innovation. In this case contestability can be expanded by increasing the particular factor of production which is constraining discrete entry. For example, taxi licenses limit competition for taxi services to only those holding such a license. As taxi licenses are the particular factor of production that blocks a marginal entrant, expanding the number of taxi licenses could be expected to increase contestability in the market and encourage innovation by market participants. Alternatively, adjusting how taxi licenses are allocated and minimizing the administrative component could allow such licenses to be contested more easily and avoid taxi businesses from holding substantial blocks of licenses and further limiting contestability. Similarly, increasing investment in R&D infrastructure or otherwise to reduce individual firm requirements for that particular factor of production that constrains entry would also expand contestability and encourage innovation.

However, these intuitive policy solutions fail to address the particular problem of a discrete entry barrier. The structural entry barrier still exists, but its effects are diminished by these "weak form" policies. There are other "strong form" policies which break the discrete nature of entry, allowing smaller firms to enter, foreign entry or other ways to expand contestability by removing the discrete entry barrier altogether. For example, the removal of license requirements, trade barriers or other minimum scale requirements enables new and smaller firms to enter and contest the market with incumbents. This subsection demonstrates the role of alternative policy responses within the model.

4.2.1 Innovation subsidies, taxes and targeted policies

The endogenous growth literature already provides an extensive analysis of innovation subsidies to support growth (see Bond-Smith (2019) for a survey of the endogenous growth literature). I briefly show here how innovation subsidies can support additional entry. Proportional subsidies for innovation have the impact of proportionally reducing the parameter γ. If $0 < s < 1$ represents the proportional subsidy, the largest integer $n_i \geq 2$ that satisfies

$$L_i \geq n_i \left(\frac{(n_i - 1)(\sigma_i - 1)}{(n_i + \sigma_i - 1)\alpha} + 1 \right) (1 - s) F_i \tag{24}$$

implicitly defines the steady state number of firms in a sector characterized by Cournot competition. Since $s < 1$, the n_i which satisfies the above condition is greater than without the subsidy. Similarly, the largest integer $n_i \geq 2$ that satisfies

$$L_i \geq \frac{(n_i - 1)(\sigma_i - 1) + \alpha n_i}{\alpha} s F_i \tag{25}$$

implicitly defines the steady state number of firms in a sector characterized by Bertrand. In both cases if the subsidy is sufficient to shift n_i by at least one integer then the innovation targets of entrants will also increase. The higher growth rate within each sector can then be calculated using the solution for n_i. Such subsidies could also target specific industries where barriers to entry are an issue. If the government's budget for such subsidies is fixed then subsidies that target industries with barriers to entry would even be more effective than subsidies that do not discriminate between sectors. In sectors with only a few firms and barriers to entry the increase in innovation from stimulating entry will be greater than industries where there are already many firms. Furthermore, by targeting only a few sectors the particular rate of s could be set higher for the targeted affected sectors.

Dividends are income in excess of wages that provides a source of taxation to fund subsidies. Taxes on dividends have the impact of proportionally reducing the payoff to entrepreneurs from innovating but not reducing their innovation effort, even if the tax is 100 per cent. To see this, consider the income of entrepreneurs with a tax on their dividend income only. If $0 \leq T \leq 1$ represents the proportional tax take on the entrepreneur's dividend then the positive dividend requirement becomes

$$(1 - T) \frac{d_{i,t}}{(1 + r_t)} F_{i,j,t-1} \geq 0. \tag{26}$$

Rearranging, *the tax has no impact on operational decisions* because it is *proportional* to firm profits *after* paying standard wages. *This result applies until the tax takes the entire dividend ($T = 1$) such that entrepreneurs are indifferent between entrepreneurship and manufacturing.* Within the the relevant range $0 \leq T \leq 1$ the only impact of the tax is on the entrepreneur's payoff beyond the standard wage rate, but not their decisions. The result is because the profit above standard wages is only due to the market power of initial entrants since the marginal entrant is blocked by discrete entry.[9] Such a proportional tax naturally targets sectors with greater barriers to entry where profits are greater.

A policy that combines proportional tax of any rate up to 100 per cent on the dividends of firms in industries with limited contestability (or firm profits after wages) and subsidies for innovation effort to induce entry is therefore growth enhancing if there are barriers to entry and market participants hold market power.

4.2.2 Other policy implications

The discrete entry assumption also has implications for merger analysis by offering nuance to policy makers' understanding of the relationship between market structure and innovation. In particular Davis

(2003) points out how the relationship between market structure and innovation performance is "far more problematic than in the case of price competition". So modelling developments such as discrete entry that offer this nuance allows anti-trust enforcement to also consider the nature of market structure, rather than simply the number of incumbent firms.

This type of response is not new to some industries where market failures that affect market structure are already clear. Regulation has enabled industries such as telecommunications or electricity to overcome the economies of scale required for entry. These industries are well known as natural monopolies because duplication of the network is expensive, preventing entry of a rival network. In terms of the model developed in this article, access to the network can be thought of as the critical factor of production required for entry into the competitive market for telecommunications services. Telecommunications regulation typically fosters a "ladder of investment" approach (Cave, 2004, 2006) that enables contestability by regulating access to unbundled services such that entrants can be established with a minimal level of investment and gradually expand with higher order levels of investment over time. Lowering the minimum viable scale or the threshold to achieve sufficiency, enables a contest for entry to emerge. Similarly, the regulated separation of retail and wholesale electricity from network services enables contestability for the retail and wholesale elements of the electricity supply chain without the scale required for firms to invest in a network. While industry regulation typically targets the natural monopoly nature of these industries, with respect to the model in this article, these types of regulations also remove the discrete entry barrier, thereby encouraging innovation as well as fostering competition on price. It is possible that other markets, not typically recognised for market power or concentration, also suffer from insufficient contestability. Policy approaches that enable new forms of market entry (such as unbundling) are therefore likely to improve contestability and stimulate innovation in a variety of industries.

Markets can also find ways to develop new tools on their own for alternate forms of entry that overcome the discrete entry barrier. For example, eBay and Amazon have enabled even very small firms to establish a national or even global online sales presence in any niche retail market. Amazon and Google both enable small businesses to utilize cloud computing without the investment required for their own data centres. Other firms such as AirBnB or Uber enable small "firms" to bypass entry barriers for accommodation or taxi services altogether by developing products in a way that does not require the particular factor of production that causes the constraint on entry.

In this way, markets with a discrete entry barrier are also likely to be an attractive target for these types of innovations that overcome entry barriers. Even so, these barriers constrain entry and encourage investment in certain innovations that would be unnecessary if the original market design enabled contestability. These innovations are possible because the innovator extracts some of the monopoly rents that would otherwise accrue to incumbents. While markets can sometimes overcome entry barriers, this type of innovation investment would be unnecessary if markets were already sufficiently contestable. Similarly, all of these examples may introduce network effects that risks a reduction in future contestability. Such innovations create barriers to entry elsewhere by shifting market power to the market for a "gate-keeper". In the case of AirBnB and Uber, these new markets have strong network effects due to two-sided markets, such that the participant with the largest network now holds market power and can extract excessive profits. Regulators and policy makers should consider whether the barrier or factor of production itself is unnecessary and whether investment in these types of innovations should be required or not in order to overcome any contestability issues. At the same time, regulators should monitor whether new innovations introduce contestability issues and respond accordingly.

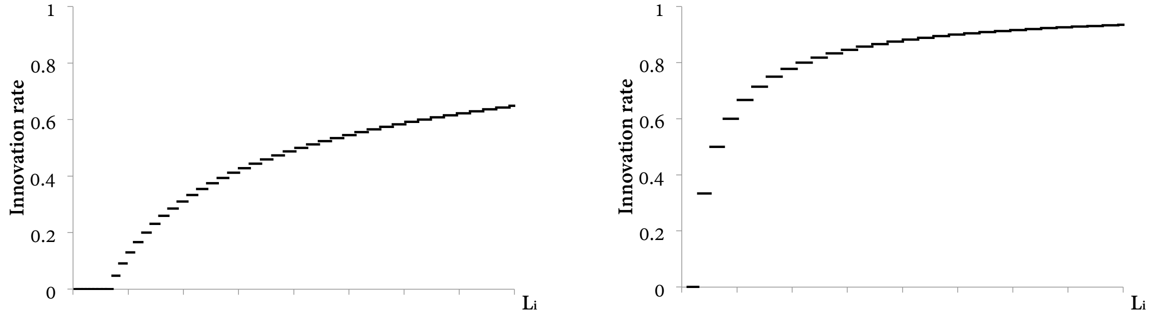
4.3 Numerical examples

While the main analytical results of the paper are already examined above, this subsection uses numerical examples to aid intuition. The supply of specialized labor is varied as the key metric determining contestability in each sector to understand the relationship between contestability and innovation. This conveniently isolates the impact of limited contestability by adjusting only the labor supply on a sector basis which determines the number of participating firms under the discrete entry barrier and also allows for a fair comparison between Bertrand and Cournot competition. Furthermore, the use of a growth model without scale effects or inverse scale assumptions (Bond-Smith et al., 2018; Bond-Smith, 2019; Bond-Smith and McCann, 2020) means any differences between sectors' investment in innovation is exclusively a result of contestability under the discrete entry barrier. The analysis compares innovation outcomes in relation to mode of competition and extent of contestability, drawing implications for different economies, industries, regions and countries, and does not represent calibrated estimates of specific economic outcomes.[10]

Model parameters are based on typical calibrations using CES preferences. Krugman (1991) uses an elasticity of $\sigma = 4$ and Baldwin and Forslid (2000) uses $\sigma = 5$. Since the model here is disaggregated into many sectors, varieties in the same sector can be expected to be closer substitutes than these calibrations imply. This justifies a much higher elasticity of substitution, however, an extremely high σ means consumers are more responsive to changes in quality such that the elasticity overwhelms other factors to determine the quality target. On the other hand, reducing σ reduces the difference between Cournot and Bertrand, although the conclusions remain unchanged. Therefore, a fixed elasticity of $\sigma = 10$ is chosen for all simulations. While the parameter is higher than Krugman (1991) or Baldwin and Forslid (2000), it must be higher due to greater disaggregation but it is not so high as to overwhelm calculations and is sufficiently high to demonstrate clear differences between models of oligopoly. A sensitivity analysis of σ does not affect the the conclusions drawn.[11]

The rate of time preference follows Baldwin and Forslid (2000) with $\alpha = \frac{1}{2}$, which implies an annual discount rate of approximately 7% when periods represent 10 years. It results in a technology improvement rate of 1 in the continuous model which enables a simple comparison. Alternative calibrations for α only change the rate of innovation in the steady state. η is calibrated such that the expected free entry rate of technology improvement equals the rate of time preference, i.e. $\eta = \frac{(\sigma-1)}{2} = 12$. γ only has the effect of adjusting the scale in L and its calibration does not affect results, but the same γ is used for comparing Bertrand and Cournot sectors. Initial values for A_i are set to one such that growth in technology can be easily compared to initial technology levels.

As noted in the equations above, there is a positive relationship between innovation and competition measured by the number of firms. However, this does not tell the full story. The comparison on a firm level basis can be misleading, because firms in Bertrand and Cournot sectors require different levels of the factor of production for entry. As noted in the analytical results above, the resource constraint barrier allows many more entrants under Cournot than under Bertrand competition. For example, using the calibration above, a labor supply that results in 5 firms (and an innovation rate at 0.33) in a Bertrand sector results in 12 firms (and an innovation rate of 0.05) if it were a Cournot sector. Using the calibration above, Figure 1 considers the innovation rates in relation to the labor supply, which operates as a proxy for calibrating contestability. Innovation rates rise with increases in the supply of the critical factor of production (in this case labor). Both charts have the same scale in L_i.



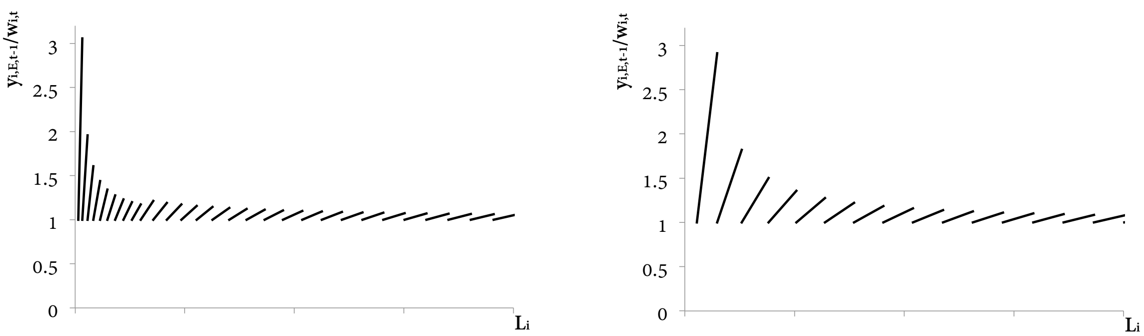
(a) Cournot competition (b) Bertrand competition

Figure 1: Labor supply vs innovation rate

Innovation rates increase stepwise as additional labor allows an additional firm to contest the market at each "step". Each step is discrete and tends towards the growth rate of the continuous model. These steps upwards are initially larger in Bertrand competition resulting in higher innovation rates for the same labor supply (keeping all other parameters the same). But these higher rates occur with substantially fewer firms in Bertrand competition, meaning the two alternatives are not as substantially different as it would seem in the analytical results for quality-improvement targets. Comparing the innovation rates under Bertrand and Cournot competition, the trend towards the continuous free entry innovation rate (1) is much closer when compared on a labor supply (or contestability) basis rather than a number of firms basis.

Continuing with this calibration, it is also possible to consider how the relationship between innovation and income inequality is affected by varying levels of contestability. The impact of the discrete entry barrier on income inequality varies according to the extent that the marginal firm is prevented from participating by the limited supply of specialized labor. When the labor supply barely allows a marginal firm to participate, entrepreneurs earn exactly the same as workers in manufacturing and the entrepreneurial dividend diminishes to zero. However, if the labor supply prevents entry of a marginal firm to any degree, those workers who are lucky enough to be employed as entrepreneurs can earn substantially more than manufacturing workers through their entrepreneurial dividend.

In terms of the number of firms this is already clear from the analytical solutions for wages. Since the degree of contestability (calibrated by L_i) implies both the number of firms and the competitive manufacturing wage it is more helpful to compare outcomes with respect to contestability. The extent of the range of income inequality declines as the labor supply increases. Figure 2 describes the ratio of entrepreneurs' income including dividends to the wage of manufacturing workers' wages as the labor supply increases under both Cournot and Bertrand competition respectively.[12] While the barrier to entry enables those firms permitted entry to exercise market power over prices and to withhold innovative effort, the extent that this is reflected in the entrepreneurial wage or shared with all workers depends upon the extent that the barrier to entry is binding upon a marginal entrant. In this way there are two processes affecting wage inequality. Firstly, the ability to appropriate monopoly rents and limit innovation declines as contestability increases. But secondly, the extent that the payoff is shared with other employees decreases until a step change occurs with an additional discrete firm. As a result, the relationship between inequality and barriers to entry is ambiguous because it depends upon very specific industry characteristics.



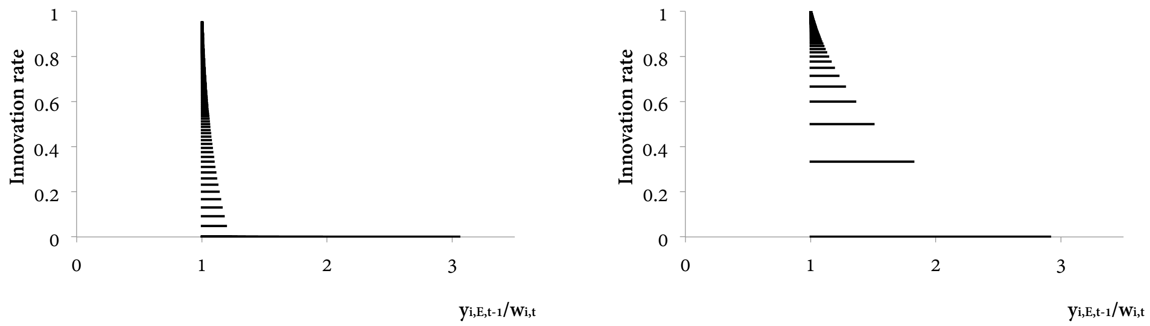
(a) Cournot competition

(b) Bertrand competition

Figure 2: Labor supply vs ratio of entrepreneurial income to the market wage

For very low contestability (or labor supply), the resulting level of inequality varies substantially, but the range diminishes as contestability increases. Notably, the range of wage inequality increases in a single step in the Cournot sector at the contestability level when growth commences. This is because the labor supply committed to innovation given by Equation 16 is constant when there is no growth at low levels of contestability, but profit increases at the contestability level where innovation results in a quality improvement. Notably the steps are larger under Bertrand competition than under Cournot because Cournot allows many more firms to enter for the same resource constraint.

Alternatively, Figure 3 compares innovation rates and wage inequality at various levels of the labor supply under Cournot and Bertrand competition respectively. While the rate of quality improvement in both Cournot and Bertrand eventually converges to one, this does not quite occur even within the very large range used in these figures. Notably, the upper limits of wage inequality are negatively correlated with the rate of quality improvement because high inequality and low innovation are both a result of low contestability. As in the above analysis, the relationship between inequality and innovation is ambiguous because it depends upon specific industry characteristics.



(a) Cournot competition

(b) Bertrand competition

Figure 3: Innovation rate vs ratio of entrepreneurial income to the market wage

5 Concluding remarks

Using a simple discrete entry barrier (i.e. only an integer number of firms is permitted) as a tool to model contestability and relax the continuous free entry assumption, this article develops a framework for examining the impact of market structure on innovation, entrepreneurship and growth, reflecting recent empirical findings of concentration, market power, rent seeking and limited economic dynamism. This offers a generalized understanding of how limiting contestability reduces innovation, can increase inequality and how sectors characterized by Cournot with limited contestability face a greater constraint on innovation than sectors characterized by Bertrand, with important implications for regional, competition and innovation policy. When markets are less contestable then entrepreneurs who gain entry can extract monopoly rents with limited competition on price/quantity or innovation. However, the ability for entrepreneurs to appropriate rents depends upon the extent that contestability is binding upon a marginal firm. The model here provides a unique insight into this ambiguous and nuanced relationship between market structure and innovation.

The model provides a particularly useful framework for examining the relationship between market structure, innovation, entrepreneurship and growth by combining the partial equilibrium characteristics of individual sectors such as imperfect markets and Cournot or Bertrand oligopoly with the broader general equilibrium features of endogenous growth theory. This encourages a revision of our understanding of endogenous growth to also consider microeconomic and industry characteristics. This re-examination of the relationship between contestability and innovation suggests that effective innovation growth policy should address the causes of market structure that have flow-on effects for entrepreneurial investment and income inequality. In this way, the model emphasises that good microeconomic policy is also good macroeconomic growth policy. Simple extensions of the model could also be used in future research to examine how other microeconomic characteristics impact entrepreneurship, innovation and growth.

In particular, the model's findings appear most relevant for relatively small or isolated regional markets where entry may be more difficult or there is only the capacity for a few firms to enter and such entry criteria could affect a larger share of the economy. It is possible that the type of barriers described are also more common in relatively small or isolated regions, where import competition can be relatively more expensive due to economies of scale in transport, there is only capacity for a few firms at a viable scale or where cultural and nationalistic barriers may make entry by foreign firms difficult. Characteristics such as population settlement patterns and geographic isolation (Battersby, 2007) may help to explain rates of innovation in these regions (Wilkie and McDonald, 2008). Therefore, the model provides new and interesting implications for innovation and economic growth policy that are particularly relevant to small, isolated or peripheral regions and countries. The size of these markets may not be attractive to a multinational or new entrant such that many subsectors in these economies can remain isolated from the competitive forces that occur in larger agglomerated economies. In this way, the model provides further evidence for localized and industry-specific innovation and growth policy, particularly in small, isolated, non-tradables markets or markets with significant economies of scale where sufficient discrete entry is more likely to be an issue.

Models that examine the relationship between competition and innovation will benefit from understanding the causes of market structure. The ability to contest the market cannot always be assumed, especially in a regional context. Contestability characteristics are unique to each individual sector and region such that policies to stimulate growth should target innovation or firm entry in these individual sectors and regions. Innovation and growth policy does not necessarily require an economy-wide generic policy approach, but is perhaps a localized, industry- and economy-specific policy problem. Fields such as industrial organization, labor economics, economic geography, and regional and urban economics have much to contribute to the study of local or industry factors affecting entry, contestability, entrepreneurship, innovation and subsequently economic growth. In a similar way, the growth model here adds to the growing body of evidence that innovation policy should focus on localized and industry-specific factors.

Notes

[1]Source: Wall Street Journal (2015) Carnegie Mellon reels after Uber lures away researchers, http://on.wsj.com/1FnLNyW. Accessed November 2016.

[2]For a definition see Section 3.3 Horizontal Merger Guidelines issued by the U.S. Department of Justice and the Federal Trade Commission April 2, 1992 and revised April 8, 1997. Alternatively Section 9.3 of the current guidelines issued August 19, 2010, considers whether entry is sufficient.

[3]See Bond-Smith (2019) for a comprehensive review of the endogenous growth literature.

[4]Further discussion of barriers to entry and the techniques used in this paper are in an appendix.

[5]This assumption is required in order to relax the assumption of continuous free entry. If workers are mobile between sectors, workers distribute selves across sectors such that each sector is relatively large. As a result, competition with a large number of entrants, even with discrete entry, approximates the standard approach with continuous free entry.

[6]As necessary for modelling purposes, this definition of entrepreneurship, excludes traditional self-employment. To compare to the model, traditional self-employment could be thought of as employment by a firm where the firm is owned by the worker and the worker undertakes effort in both entrepreneurship and manufacturing.

[7]More detailed models could also include strategies to control the critical factor of production, such as forming a cartel or lobbying for protective regulations.

[8]Of course, it is possible that workers with very specific skills in an industry with only a few employers could face non-competitive wages (Bhaskar et al., 2002), but monopsony pressure on the labor market is beyond the scope of this article.

[9]The model assumes that effort is inelastic. If entrepreneurs/workers could adjust effort in response to wages or payoffs these results would change as entrepreneurs could be expected to reduce their effort in response to a lower payoff due to taxes. Other results in the model would also change such as a reduction in the sharing of profits with other entrepreneurs. Given the wider effect of altering this assumption a full exploration of this alternative model is beyond the scope of the article.

[10]Calibrating the model to a specific real world example is beyond the scope of this article as it requires a detailed empirical foundation for calibration.

[11]The magnitude of difference between Cournot and Bertand increases as σ increases, but the relationships remain the same so long as products are assumed substitutes ($\sigma > 1$).

[12]The scale in L_i is increased from Figure1.

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