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Of Shrimp and Men: Innovation, Competition and Product Diversity*

Amanda De Pirro[†] Renaud Foucart[‡]

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Abstract

Building on a model of competition with endogenous product differentiation and using data from the shrimp aquaculture industry, we show how a cost-reducing innovation can hurt the profit of the innovator by decreasing product diversity and strengthening competition. In the late 1990s, a US governmental program designed a new pathogen-free breed reducing the production cost of white legs shrimp. This innovation gave a temporary boost to the profit of American producers, largely specialized in that variety. However, over time other countries abandoned their native production to adopt the new breed. In this phase of technological catch-up US producers thus not only lost their cost advantage, but also the market power derived from the pre-innovation product differentiation.

Keywords: innovation, cost paradox, product differentiation, shrimp

JEL-Code: D43, F61, L1, L81, O3, Q22

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1 Introduction

Western manufacturing companies typically see R&D investment as a way to gain protection against international competition (Hombert and Matray, 2018). Delivering a radical innovation provides a temporary competitive advantage to the innovator, until the laggard eventually catches up (Aghion *et al.*, 2005; Griffith and Van Reenen, 2021). Competition then goes back to its initial level, until the next breakthrough.

In this paper, we show that competition in the catch-up phase can actually become much stronger than it was pre-innovation. Using a simple model of differentiated Cournot competition with endogenous choice of product variety, we find that innovation in one variety may lead to a decrease in product diversity in the catch-up phase, eventually decreasing the profit of the innovator and of all other producers. This result happens when the cost reduction delivered by the innovation is high enough for all producers to switch to the low-cost variety, but not sufficiently high to compensate the negative effect of the increase in competition.

We illustrate this theory using the case of aquaculture shrimp production in the US and in Asia. Shrimp is the most important internationally traded fishery commodity in terms of value, worth more than \$20 billion a year in 2020.¹ In the early nineties, the US was specialized in producing white legs “Vannamei” shrimp, while Asian countries such as China, Thailand, Vietnam or India, were producing Tiger “Monodon” ones. In the late nineties, a US innovation massively decreased the production costs of “Vannamei,” giving the US a competitive edge on the (differentiated) market for shrimp.

In the 2000s however, Asian countries started to switch to this much cheaper innovation, and largely stopped producing Tiger shrimp. As a consequence, not only did they caught up on the US innovation, but product diversity decreased. Instead of differentiated products in which both industries managed to thrive, most countries are now producing Vannamei shrimp and competition is much stronger. By delivering an innovation in the production of one variety of shrimp, the US gained a temporary competitive advantage, at the cost of increased competition once Asian producers caught up.

From a theoretical perspective, our paper is closely related to the “Cournot cost paradox” (Seade, 1985). In our model, innovation decreases the production cost of a variety, and this lower cost is available to all firms in the catch-up phase. Similarly, in

¹FAO Globefish trade statistics, April 2020.

the Cournot cost paradox, a common decrease in firms unit costs may lead to a lower equilibrium profit, so that R&D races are a form of prisoner’s dilemma ([Amir *et al.*, 2017](#)). The condition for such a paradox to emerge (sufficiently convex inverse demand) is however not satisfied in our model. Our results show how a different cost paradox may arise through the channel of product differentiation.

The link between product differentiation and innovation is also reminiscent of [Vives \(2008\)](#), who finds that higher product substitutability increases the incentives to innovate. The difference with our approach is that he considers substitutability as exogenous, while our effect is due to innovation changing the incentives to offer differentiated products. In a related paper, [Narajabad and Watson \(2011\)](#) show that more heterogeneous tastes decrease the incentives for innovation, as less intensive competition - modeled as higher differentiation on a Hotelling line - reduces the benefits from innovation. The key difference with our approach is that we condition the ability of a firm to adopt an innovation in the catch-up phase to the adoption of a similar variety. In the case of shrimp, to catch up on the Vannamei innovation, one also has to produce Vannamei.

Our paper relates more generally to the literature on innovation, spillovers and absorptive capacity. Historically, the need for public support to innovation has been justified by the fact that it shares some of the characteristics of a public good: the product of an innovation can be appropriated only to a limited extent ([Arrow, 1962](#), p.619). The fact that a firm can innovate by being exposed to the innovation of others therefore constitutes one of the most direct benefits from having an open economy ([Coe and Helpman, 1995](#)).

Such spillovers are however not automatic: they are the result of an investment in absorptive capacity by those who benefit from it, be it through an independent investment in R&D or through the adoption of technological standards ([Cohen and Levinthal, 1989](#); [Keller, 2004](#); [Foucart and Li, 2021](#)). The study of technological spillovers has also led to a stream of research on whether R&D investments are complements or substitutes and the implication of these results on growth models ([Cassiman and Veugelers, 2002](#); [Aghion and Jaravel, 2015](#)). More specific research on technology adoption in the field of aquaculture can be found for instance in [Kumar *et al.* \(2018\)](#).

Finally, albeit the research fields are seemingly unrelated, the logic of our main theoretical argument is mathematically very close to the “Braess Paradox” ([Braess, 1968](#); [Braess *et al.*, 2005](#)) on the congestion of road networks. In some cases, adding an express

road to a network subject to congestion leads commuters to use less diversified paths, so that everyone goes slower. In our setting, by decreasing the production cost of one variety of shrimp, everyone makes lower profit because everyone switch to producing that variety.

The paper is structured as follows. In Section 2, we provide some background on the market for shrimp and the nature of the innovation and catch-up phases that occurred between the end of the 1990s and today. We then provide in Section 3 a simple model of differentiated Cournot competition to illustrate why an innovation can lead to lower profits in the catch-up phase. Section 4 shows that data on the evolution of the shrimp market is consistent with our theoretical predictions. We conclude in Section 5.

2 Innovation and catch-up in the market for shrimp

2.1 Different varieties, same problem

Large-scale commercial farming began developing in the 1970s in the Eastern and Western Hemispheres based on farming local shrimp species. In Asia, the dominant species of choice was the Giant Tiger shrimp *P. Monodon*, native to tropical, coastal regions of the Indo-Pacific basin. In the West, the principal farmed species was *L. Vannamei*, the Pacific White shrimp which is native to the tropical Pacific coast of Latin America. In the US *L. Vannamei* was first imported as postlarvae from Panama in 1985 into South Carolina, USA. It has steadily risen in popularity to become the main species of shrimp farmed in North America (Sandifer, 1988). Still, their market share was much smaller than the one of Asian producers. A large majority of the shrimp consumed in the US were imported. In the early 1990s, Asian shrimp farmers contributed more than 90% of total world production while farmers in the West contributed less than 10% of the total (Turkmen and Toksen, 2010).

Both Asia and the West, however, had failed to set up a large-scale intensive shrimp aquaculture. Independently from the species cultured, all attempts were affected by the same common problem: the periodical outbreak of diseases. Shrimps are highly susceptible to pathogens and the rudimentary solutions available at that time were ineffective in preventing the spread of viruses across farms, that were more disrupting the more intensive the production was. With the high incidence of diseases, and the subsequent

losses, shrimp aquaculture suffered of high volatility and uncertainty in the final volumes and profits, causing a drop in investments.

In the US, despite the industry expansion undertaken during the 1980s, the rate of growth decreased progressively. The choice of focusing the production on *L. Vannamei* (which was not a native species in the US) with respect to other imported species was due to its relatively better resistance to some pathogens, especially the virus IHNV, responsible of the Runtd deformity syndrome (RDS), which had been associated with catastrophic losses of cultured blue shrimp in Latin America in early 1980s. Yet, the *L. Vannamei* was not immune to the virus and in late eighties a new wave caused a mass mortality in US farms. According to [Moss *et al.* \(2003\)](#), as a result of this outbreak the market price of IHNV-infected shrimp dropped by 10-50% relative to IHNV-free shrimp in the same period.

2.2 The US innovation

In order to promote the development of a domestic shrimp farming industry in the United States, in 1984 the U.S. Department of Agriculture launched a research program, the United States Marine Shrimp Farming Program (USMSFP), publicly funded and made up of several institutions.² Established with the general aim of increasing local production of marine shrimp while decreasing the reliance on importation, the program rapidly evolved into an effort to discover a method to prevent the emergence of pathogens. In the late eighties, researchers were able to develop Specific Pathogen Free (SPF) stocks of *L. Vannamei* that were free of IHNV by re-adapting the breeding and selection concepts from the livestock and poultry industries. In 1991, the very first commercial production trials comparing SPF and non-SPF stocks were undertaken in cooperation with the U.S. industry. Production results in SPF ponds were significantly better than in non-SPF ponds, suggesting a more than 50% increase in profitability ([Wyban, 2009](#)). Table 5 in the Appendix provides a comparison on production parameters in between SPF and non-SPF stocks.

²These include the University of Southern Mississippi, the Oceanic Institute, the Tufts University, the South Carolina Department of Natural resources, the Texas AgriLife Research, the University of Arizona and the Nicholls State University. Support was also given by the Office des International Epizootics (OIE) of Paris, France.

Based on the excellent results of pond trials in 1991, more than 5,000 SPF broodstock were produced in Kona, Hawaii in 1992 and supplied to U.S. hatcheries. From these, more than 200 million SPF postlarvae were produced from the SPF broodstock and stocked into commercial ponds in the three shrimp culture regions of the U.S. In 1992, virtually all shrimp ponds in the U.S. were stocked with SPF postlarvae. As a result of this innovation, total production of the U.S. industry doubled, contributing to a sensible increase in profitability (Wyban, 2009).

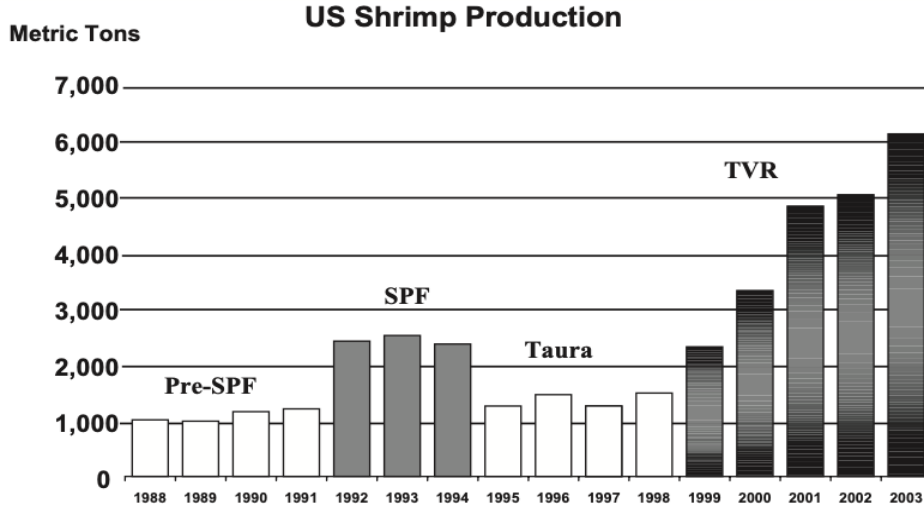
The period in between 1990 and 1995 could be referred to as the first innovating wave, or the start-up era. However, the supremacy of the bio-security methods developed in the US only became clear with the insurgence of a new disease, the Taura Syndrome (TS). The virus first appeared in Ecuador in 1991 (Brock *et al.*, 1995) and then it slowly marched up through Central America and Mexico. The original SPF stock were highly vulnerable to that new disease, so that when in the spring of 1995 TS reached the Texas shrimp farming area it wiped out the production, with a mortality rate of up to 95% at some of the largest farms. In 1996 and 1997, TS destroyed shrimp crops in South Carolina and Texas. Average annual production during that period plummeted to 1358 Metric Tons, a 44% decline from the three previous years.

The US reaction was fast. Several groups initiated breeding programs to try to develop a Taura-resistant shrimp using the same technology that successfully developed the previous SPF breed. Dramatic success breeding for TS resistance was achieved in only a few generations of selection (Wyban, 2009). By 1999, the first stocks of Taura syndrome resistant shrimp (called TVR for Taura Virus Resistant) were supplied to the U.S. industry. In the commercial ponds, TVR stocks showed better survival and production increased 40% over the previous year. For the next four years, use of TVR (and SPF) stocks by the U.S. industry resulted in continuous improvement of 34% higher production per year (see Figure 1).

2.3 The innovation catch-up

Attempts to exploit artificial selection techniques to escape the outbreak of diseases in aquaculture have not been a prerogative of the US industry only. In parallel to the USMSFP, several breeding and selection programs were carried out with *L. Vannamei* in Latin America. These programs were based on the concept that the populations should

Figure 1: US Shrimp production (source: Wyban, 2009)



be well adapted to local conditions and should be resistant or tolerant to the major disease problems endemic in the region. Thus, a major dichotomy in breeding strategies emerged, with selection, maintenance and multiplication of populations in essentially disease-free conditions under the SPF protocols while other programs used populations selected in the presence of multiple diseases. However, despite some initial success at the local level (Cock *et al.*, 2009), the Latin American attempts resulted in a failure, making clear the dominance of the US innovation.

A major impetus for eventual worldwide adoption of the SPF shrimp concept was the emergence in the mid-1990's of white spot disease (WSD) in Asia (Flegel and Alday-Sanz, 1998), which devastated the culture of the the main native species of Tiger shrimp, *P. Monodon*. Unable to contain the spread of the disease, Asian countries began looking for an alternative product. The increasing availability of SPF broodstocks of *L. Vannamei* exported by the US induced countries to progressively and irreversibly switch their production. Table 1 reports both the year of the first introduction of *L. Vannamei* and the year import of SPF/TVR broodstock officially started. With the exception of Philippines and India, whose importation of SPF broodstock was initially blocked because of bio-security concerns, Asian countries on average adopted the US innovation (initially on a trial basis) within one year after it became available to the US industry.

For Asian countries, the economic incentives to switch from *P. Monodon* to the new SPF *L. Vannamei* were outstanding, pushing producers to switch their production at a very rapid pace. The biggest success was represented by Thailand, formerly the leader

Table 1: Importation of L. Vannamei in Asian countries (source: Briggs *et al.*, 2004; Wyban, 2019; DE SILVA *et al.*, 2021)

Country	First introduction	Original source	SPF importation	Importing SPF source	Reason for importing SPF
China	1988	Tx	1999	Hi	Performance
India	2001	Ti	2009	Hi	Problems with Monodon
Indonesia	2001	Hi	2001	Hi	Problems with Monodon
Malaysia	2001	Ti	2001	Ti, Th	Problems with Monodon
Philippines	1997	Ti	2004	P, Ti	Problems with Monodon
Taiwan	1995	Hi	1998	Hi	Problems with Monodon
Thailand	1998	Ti	2001	H, Mx	Problems with Monodon
Vietnam	2000	Ch	2000	Hi	Problems with Monodon/cold tolerance

in P. Monodon production and the biggest exporter to the US, which rapidly became the main producer of L. Vannamei shrimp. To give a sense of the dramatic increase in profitability, estimates based on local surveys suggest that in Thailand farms adopting SPF L. Vannamei achieved an average increase by more than 250% compared to the traditional P. Monodon production.³

Two issues deserve attention when observing the innovation catch-up process by foreign countries. First, Asian countries did not import the innovation - the new selective production method developed by US - but rather the *product* of that innovation, the SPF/TVR broodstock. The broodstock are supplied to commercial hatcheries where postlarvae are produced for farmers to stock in ponds. In essence, through the importation of pathogen free broodstock, Asian countries were allowed to skip the earliest stage of production, which required a consistent investment to build up the facilities. In practical terms, all they had to do was to re-adopt their ponds to guarantee the growth of such breeding. It certainly required an investment by farmers to grant the post-larvae isolation, but the costs were plausibly lower (also in terms of safety) than producing the broodstock by themselves.

This leads to the second issue. Why were the US government and producers not able to protect their innovation? The reason is that, while the original research leading to the innovation was publicly funded, the actual SPF brood-stock were privately owned and free to trade. This is a standard example of Arrow (1962)’s statement on innovation being

³We provide additional details on production costs in Table 6 in the Appendix

non-appropriable: the market opportunity represented by Asian countries was simply too attractive to the US broodstock industry for spillovers not to happen.

According to a FAO report,⁴ in 2003 with five to six commercial SPF broodstock suppliers in Hawaii and one in Florida, the USA's SPF L. Vannamei broodstock industry was worth some US\$ 5 million a year, the vast majority of which was exported to Asia. In 2018, US shrimp exports (largely SPF broodstock) generated US\$ 24 million in revenue (United States Census Bureau 2019). While this amount is several orders of magnitude smaller than the billions of US\$ represented by the production of shrimp, exporting their breed was in the private interest of broodstock suppliers.

Moreover, along the years the broodstock industry has remained in the hands of very few players. Although Asian countries have recently attempted to launch their own production of domestic SPF broodstock, they are still largely relying on US exports. At present (2019-2020), production of SPF L. Vannamei broodstock in the US is concentrated in Florida, Texas and Hawaii, together producing two thirds of global SPF L. Vannamei broodstock. To give a sense of the industry concentration, Table 7 (in appendix) reports the top 15 companies in the production and trade of SPF L. Vannamei broodstock in 2019, which are responsible for at least 95% of L. Vannamei broodstock produced globally.⁵

The US shrimp industry experience constitutes an illustration of the principle that R&D outcomes are always meant to be (in the long run) non-rivalrous and non-excludable. In the case of the shrimp industry, conflicting interests with the broodstock industry have fostered the innovation's diffusion, resulting in a very short catch up period. What makes this case particularly useful to look at is the fact that the innovation happened on a single variety, so that the catch up led to a decrease in product diversity. In the next section, we show theoretically how such a phenomenon can lead to the rents being lower in the catch-up phase than pre-innovation.

3 The curse of innovation: a theory

In this section, we provide a simple model of a market in which two representative firms compete on quantity and choose their product variety. Our objective is purely descriptive: to compare the equilibrium outcome with and without innovation, and to provide

⁴<http://www.fao.org/3/ad505e/ad505e05.htm>

⁵Source: 2020 Shrimp Insights <https://www.shrimpinsights.com/>

conditions such that an innovation yields lower product diversity and lower profit for both firms in the catch-up phase than in the pre-innovation one.

In our framework, innovation did not originate directly from firms decisions. There is no R&D investments by producers. Their choice is simply to use or not an innovation in their production processes once that innovation becomes available. Hence, simply comparing outcomes with and without innovation seems to be a natural starting point for our analysis. The development of a radical innovation with explicit market applications - even when not stemming from the private sector - is however clearly not random. We discuss in Section 3.4 four reasons why the government had an incentive to do so: the role of consumer surplus, time discounting, political lobbying, and a possible coordination problem.

To keep our setup as simple as possible, we focus on the case of symmetric demand and cost functions. As our main result is a proof of existence of a certain type of equilibrium, we would indeed gain nothing by looking at the more realistic case in which the cost in Asian countries is lower than in the US for a similar level of technology.

3.1 Setup

Two representative firms, Home (h) and Foreign (f), produce shrimp. There are two varieties of shrimp on the market, the white legs shrimp L. Vannamei (v) and the Tiger shrimp P. Monodon (m). Each of the firms can produce only one variety. As producers decide their quantities but are price takers on world markets, and as the two varieties of shrimp are not identical, we model the market as a differentiated Cournot competition (Singh and Vives, 1984). For simplicity, assume both demand functions are symmetric.

Inverse demand for firm $i \in \{h, f\}$ is given by

$$p_i^k = A - q_i^k - g(k, l)q_j^l, \quad (1)$$

- with $k, l \in \{v, m\}$ the chosen variety of each firm, and q_i^k and q_j^l the respective quantities, $j \neq i$
- For $k \neq l$, $g = \gamma \in (0, 1)$, the two firms produce different varieties and γ characterizes the level of substitution between both varieties
- For $k = l$, $g = 1$, the two firms produce the same variety and the game is a standard Cournot with homogeneous goods and linear demand.

Our focus is on the impact of innovation on competition and product diversity. Following [Aghion *et al.* \(2005\)](#), we assume that when a firm benefits from an innovation, it gets a competitive advantage for one period. We model this advantage by a technology allowing to reduce its production cost. Then, the laggard eventually catches up on the innovation and benefit from the same technology.

The game consists in three phases.

1. In the **Pre-innovation** phase, both firms produce at constant marginal cost $c_i^k = c > 0$ for all $k \in \{v, m\}$
2. In the **Innovation** phase, firm h can produce variety v at marginal cost $c_h^v = 0$, while the production cost for the other variety and the other firm remain $c_f^v = c_h^m = c_f^m = c$.
3. In the **Catch-up** phase, both firms can produce variety v at marginal cost $c_i^v = 0$ for all $i \in \{h, f\}$, while the production cost for the other variety m remains $c_h^m = c_f^m = c$.

Our assumption that only h is in position to benefit from an innovation is without loss of generality. As the game is symmetric, the case where f benefits from an innovation is identical. Both firms benefiting from an innovation at the same time would be equivalent to either going immediately to the catch-up phase (if the innovation is on the same variety), or solving the pre-innovation game with a lower value of the cost parameter c . While the possibility of two firms being in position to benefit from an innovation does not affect our descriptive results, we show in [Section 3.4.4](#) that it may however affect the incentives to produce such an innovation.

Our parameter c is therefore a measure of how important the innovation is. A high c means that the innovation offers a significant reduction in the production costs, while a low value of c means the innovation is not substantial.

3.2 Competitive outcomes

We now look at the competitive outcomes in the three phases of the game.

3.2.1 Pre-innovation phase

We start by considering the case without innovation. As the demand and costs are symmetric, we only need to solve for two cases: both firms producing the same variety, and both producing a different variety. We denote by π^i the equilibrium profit of firm i , for a given choice and a given marginal cost of both firms in the chosen market (both in the form *home*, *foreign*). We provide the detailed computations and collect the proofs of the different Lemmas and Propositions in Appendix A. In the case without differentiation, we find the standard Cournot result,

$$\pi^h(v, v; c, c) = \pi^h(m, m; c, c) = \pi^f(v, v; c, c) = \pi^f(m, m; c, c) = \frac{(A - c)^2}{9}. \quad (2)$$

In the case with differentiation, we find

$$\pi^h(v, m; c, c) = \pi^h(m, v; c, c) = \pi^f(v, m; c, c) = \pi^f(m, v; c, c) = \frac{(A - c)^2}{(2 + \gamma)^2}. \quad (3)$$

We report in Table 2 the equilibrium profit of both firms conditional on the choice of variety. As $\gamma \in (0, 1)$, the following result immediately follows:

Lemma 1 *The Pre-innovation phase has two Nash equilibria in pure strategy, in which both firms choose different varieties.*

The formal proof is in Appendix A. In either of the Nash equilibria in pure strategy, there is product diversity and both firms make a profit $\frac{(A-c)^2}{(2+\gamma)^2}$. There is also a mixed strategy Nash equilibrium, but it is not stable in the sense that any small perturbation in the beliefs make the best responses converge towards one of the two pure strategy Nash Equilibria. The same holds for all the mixed strategy equilibria identified in the next sections.

Table 2: Equilibrium payoffs in the pre-innovation phase

		Foreign	
		v	m
Home	v	$\frac{(A-c)^2}{9}, \frac{(A-c)^2}{9}$	$\frac{(A-c)^2}{(2+\gamma)^2}, \frac{(A-c)^2}{(2+\gamma)^2}$
	m	$\frac{(A-c)^2}{(2+\gamma)^2}, \frac{(A-c)^2}{(2+\gamma)^2}$	$\frac{(A-c)^2}{9}, \frac{(A-c)^2}{9}$

3.2.2 Innovation phase

We now look at the case with innovation. We assume h benefits from a cost-reducing innovation in variety v , so that its marginal cost for that variety is equal to 0, while it remains $c > 0$ for variety m . Firm f however keeps the same marginal cost as before, $c > 0$. We report in Table 3 the Cournot equilibrium profits for each choice of variety, given the cost structure.

Table 3: Equilibrium payoffs in the innovation phase

		Foreign	
		v	m
Home	v	$\frac{(A+c)^2}{9}, \frac{(A-2c)^2}{9}$	$\frac{(A(2-\gamma)+\gamma c)^2}{(4-\gamma^2)^2}, \frac{(A(2-\gamma)-2c)^2}{(4-\gamma^2)^2}$
	m	$\frac{(A-c)^2}{(2+\gamma)^2}, \frac{(A-c)^2}{(2+\gamma)^2}$	$\frac{(A-c)^2}{9}, \frac{(A-c)^2}{9}$

Depending on the value of c , the games displays either two equilibria in pure strategy, or a unique one.

Lemma 2 *The innovation phase has either one or two Nash equilibria in pure strategy. For $c \leq \frac{A(1-\gamma)}{\gamma+5} = \tilde{c}$, the two equilibria are similar to the pre-innovation phase, both firms choose different varieties. For $c > \tilde{c}$, in the unique equilibrium the firm benefiting from the innovation h produces the variety v in which it has a cost advantage, the other firm f produces the other variety m .*

The formal proof is in Appendix A. If the cost-advantage from the innovation is small, no firm has a dominant strategy, and it is a best response for both firm to choose a different variety than the other. As the cost-reducing innovation is available to firm h only, and only for variety v , the game is however not symmetric. Firm h has a higher profit when it produces v and f produces m than in the other equilibrium. Whether firms coordinate on this equilibrium is however a matter of beliefs.

When c is sufficiently high, it becomes a dominant strategy for firm h to produce the variety v on which it has a cost advantage. In that case, the best response of firm f is to produce the other variety so that the equilibrium is unique.

3.2.3 Catch-up phase

Finally, we look at the case in which both firms have access to the new technology and can produce at low cost the variety v (but not m). In the case without differentiation, the standard Cournot result holds, with $c = 0$ when both firms produce variety v . In the case with differentiation, the firm producing the low cost variety v is always advantaged.

We report in Table 4 the Cournot equilibrium profits for each choice of variety, given the cost structure.

Table 4: Equilibrium payoffs in the catch-up phase

		Foreign	
		v	m
Home	v	$\frac{A^2}{9}, \frac{A^2}{9}$	$\frac{(A(2-\gamma)+\gamma c)^2}{(4-\gamma^2)^2}, \frac{(A(2-\gamma)-2c)^2}{(4-\gamma^2)^2}$
	m	$\frac{(A(2-\gamma)-2c)^2}{(4-\gamma^2)^2}, \frac{(A(2-\gamma)+\gamma c)^2}{(4-\gamma^2)^2}$	$\frac{(A-c)^2}{9}, \frac{(A-c)^2}{9}$

Depending on the value of c , the game displays either two equilibria in pure strategy, or a unique one.

Lemma 3 *The catch-up phase has either one or two Nash equilibria in pure strategy. For $c \leq \frac{1}{6}A(2-\gamma)(1-\gamma) = \bar{c}$, the two equilibria are similar to the pre-innovation phase, both firms choose different varieties. For $c > \bar{c}$, in the unique equilibrium both firms produce variety v .*

The formal proof is in Appendix A. In this catch-up phase, the game is symmetric among players, but not among varieties. When the benefit from the innovation c is sufficiently low, it remains beneficial for both firms to produce different varieties. While it is a best-response for each firm to produce a different variety than the other, the payoffs are not identical, as the profit of the firm producing variety v is higher. For higher values of the benefit from the innovation c , producing v becomes a dominant strategy for both firms. In that case, both firms produce the cheaper variety in equilibrium. The catch-up phase, due to the asymmetric production costs between the two varieties, is the only configuration in which the market may not display product diversity in equilibrium.

3.3 The innovation curse

Let us now look at what firm h gains and loses in terms of equilibrium profit when benefiting from a cost-reducing innovation on variety v . There are several possible curses of innovation.

The first one is the existence of multiple equilibria in the phase following the innovation. For $c < \tilde{c}$, the innovation can be worthless in the innovation phase because no one is using it if firm h ends up specializing in the variety m in which she does not benefit from an innovation. One could however argue that the presence of an innovation would help making the equilibrium in which it is used focal (Schelling, 1980), and that firm h will benefit from the short run competitive edge offered by the cost reduction in variety v .

The second curse is a variant of the first. In the case in which two pure strategy equilibria with product diversity exist in the catch-up phase, firm h may end up specializing in the high cost variety, and receive a lower profit than before the innovation. While this is a theoretical possibility, it may be reasonable to discard it using the same focality argument as for the first point.

The third possibility is perhaps the most realistic, and the focus of this paper. The following Proposition summarizes the different cases, with the third one corresponding to the innovation curse.

- Proposition 1** 1. *For $c < \tilde{c}$, innovation benefits firm h in the innovation and in the catch-up phase, as long as the innovation serves as a focal point.*
2. *For $c \in (\tilde{c}, \bar{c})$ innovation benefits firm h in the innovation phase, as in the unique equilibrium she produces v and there is diversity. It also does in the catch-up phase, as long as the innovation serves as a focal point.*
3. *For $c \in (\bar{c}, c^*)$, innovation benefits firm h in the innovation phase, as in the unique equilibrium she produces v and there is diversity. In the catch-up phase there is no diversity, and both firms make lower profit than initially.*
4. *for $c > c^*$, innovation benefits firm h in the innovation phase, as in the unique equilibrium she produces v and there is diversity. In the catch-up phase there is no*

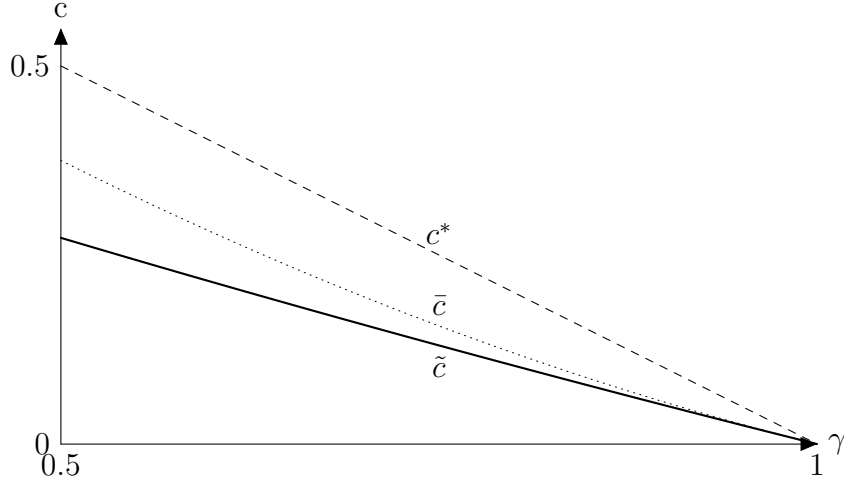


Figure 2: Critical values of c , for $A = 3$.

diversity, but both firms nonetheless make higher profit than initially thanks to a sufficiently high reduction in their costs.

The formal proof is in Appendix A. We provide an illustration with arbitrary parameter values in Figure 2 and show formally in the Appendix that $\tilde{c} < \bar{c} < c^*$.

In the first two cases, innovation is unambiguously positive for the firm benefiting from it: firm h obtains a cost advantage and product diversity remains the same. In the fourth case, innovation is also positive: despite the fact that a decrease in product diversity increases the intensity of competition, the cost advantage is so high that it compensates for the loss.

In the third case however, innovation gives a short-term advantage in the innovation phase, at the cost of a lower profit in the catch-up phase than pre-innovation. In Section 4, we show that the data on the shrimp market is consistent with this theoretical prediction. In the next subsection, we briefly review why the configuration described in case 3 does not necessarily imply that developing the innovation was an error for the government.

3.4 Discussion

Our descriptive model aims at providing the basic intuition for our result that an innovation may lead to lower profit in the catch-up phase for the firm benefiting from it. In this subsection, we briefly review the reasons why such an innovation may happen in the first place. We discuss only the case in which $c \in (\bar{c}, c^*)$, which is the focus of this paper.

3.4.1 Consumer surplus:

We have so far only looked at the problem through the lens of the producers. However, what we describe as an “innovation curse” for the producers is not necessarily detrimental to consumers in our model. Intuitively, the reason why the market power of firms is higher when products are differentiated stems from consumer preference for diversity. Whether consumers benefit from the innovation in catch-up phase depends on whether the gains from the lower prices are higher than the losses from the lower product diversity. This trade-off touches the eternal question of what the optimal level of product diversity is in the presence of product differentiation (see for instance [Dixit and Stiglitz, 1977](#); [Wolinsky, 1986](#); [Anderson and Renault, 1999](#); [Dhingra and Morrow, 2019](#)) and it can thus be perfectly reasonable to assume that a government wants to subsidize an innovation that hurts their producers if it values consumer surplus sufficiently.

3.4.2 Time discounting:

The most obvious rationale for a firm to benefit from an innovation despite losing profit in the catch-up phase is time preferences. As long as firm h discounts sufficiently the future she will be better off in the presence of an innovation. Let us first look at a standard textbook setting in which the innovation is delivered directly by the firm (and thus not by the government). To deliver an innovation with probability θ , firm h has to spend in R&D an amount equal to $c(\theta)$, with c continuous, increasing and concave and $c(0) = 0$. Denote the equilibrium profit of firm h in the innovation phase by $\pi_1(s)$, the profit in the catch-up phase by $\pi_2(s)$, the state of the world with or without an innovation by $s \in \{I, NI\}$, and the discount factor $\delta \leq 1$. The optimal investment in R&D of firm h maximizes

$$\arg \max_{\theta} (\theta \pi_1(I) + (1 - \theta) \pi_1(NI)) + \delta (\theta \pi_2(I) + (1 - \theta) \pi_2(NI)) - c(\theta). \quad (4)$$

As we have seen that $\pi_1(I) > \pi_1(NI)$, there is always a value of δ sufficiently low for the optimal θ to be strictly positive, even when $\pi_2(I) < \pi_2(NI)$.

Adding to the model the possibility of government subsidies would simply increase the amount of investment, as long as the gains in the innovation phase are larger than the discounted loss in the catch up phase, $\pi_1(I) - \pi_1(NI) > \delta (\pi_2(NI) - \pi_2(I))$.

3.4.3 Political lobbying:

This third possibility is particularly relevant in the market for shrimp, in which the innovation was the direct result of government support. An industry may lobby the government for short term gains in order to safeguard jobs, knowing very well that if the result in the catch-up phase is negative it may be in the position to lobby again. In the case of shrimp, this means political support for anti dumping policies in the catch-up phase. We describe in Section 4 how this is exactly what happened in the case of shrimp. An alternative argument, similar to the time discounting one, is that an incumbent politician may invest in short term fixes for re-election purposes without putting a lot of weight on the long run consequences.

3.4.4 Coordination problem:

In the model, we have assumed that firm h is the only one able to provide an innovation. Relaxing this assumption, it is easy to see that firms may be stuck in an equilibrium reminiscent of the prisoners' dilemma documented in [Amir *et al.* \(2017\)](#). In our setting, developing an innovation gives a short-term advantage to the firm benefiting from a lower cost, and both firms make identical profit in the catch-up phase, lower than pre-innovation.

Assume for simplicity that innovation is deterministic and costless, but can only be achieved in one variety (else, we go back to the straightforward case where profit can only increase). If firms value sufficiently the future, it is in their common interest not to invest when $c \in (\bar{c}, c^*)$. And, indeed, an equilibrium exists in which both firms expect the other not to develop an innovation, and it is a best response not to do so. However, a second equilibrium also exists: if both firms expect the other to innovate, it is a best response to also innovate, as the profit when both firms innovate is equal to the equilibrium of the catch-up phase, $\frac{(A-c)^2}{9}$, higher than being the laggard in the innovation phase $\frac{(A(2-\gamma)+\gamma c)^2}{(4-\gamma^2)^2}$.⁶

4 The curse of innovation in the market for shrimp

In this section, we look in more details at data on shrimp production, and show that the observed trends are consistent with the prediction of a change in the level of product

⁶The condition is $c < \frac{A(2-\gamma)(1-\gamma)}{\gamma^2-3\gamma-4}$, always satisfied as $\gamma \in (0, 1)$.

differentiation (cases 3 and 4 of Proposition 1). We then look at the profit level and the introduction of anti-dumping duties in the catch-up phase, that seem to indicate that the innovation in *L. Vannamei* is closer to the curse of innovation described in case 3.

We retrieved data on shrimp production from the Food and Agriculture Organization (FAO) database. The organization collects data on the annual production (in volumes and value) of fishery commodities, as well as imports and exports (including re-exports) of fishery commodities by country. Specifically, the data on domestic production in terms of volumes are available from 1980. Production values are available from 1984.

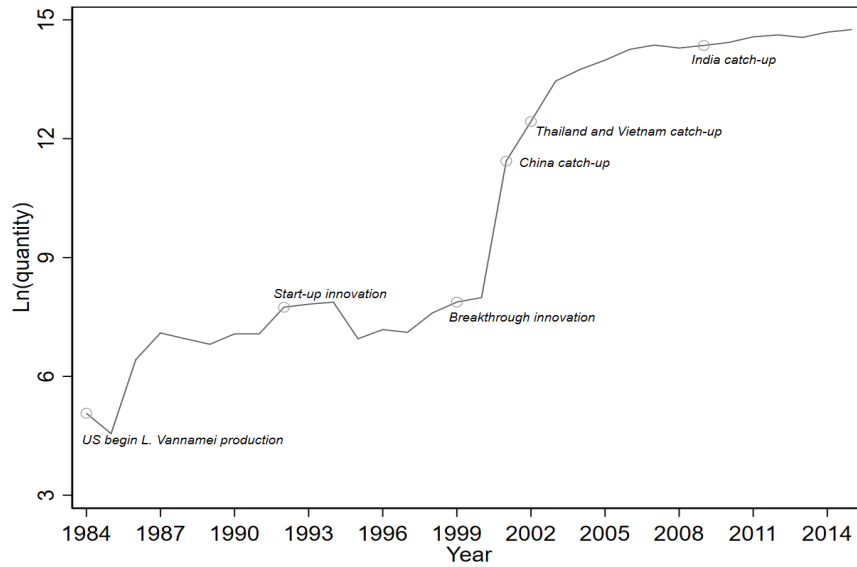
Data can be disaggregated up to the species level. This means that for each country we could retrieve data for any species cultivated. Based on the scope of this study, we focused the attention on the aquaculture/fisheries sector, thereby not considering wild-caught shrimp.

Two things must be noticed with respect to FAO data. First, they do not specify the production's destination (i.e. whether it is for domestic or foreign consumption). It is not possible to retrieve this information by looking at the exports in so far the export dataset relies on a different classification, not distinguishing by species. Second, while quantity data are largely available, most of the corresponding data in terms of production values (in US dollars) are missing, with the exception of the most recent years. Finally, with regards *L. Vannamei*, data for Asian countries are generally available one-two years after the formal date of production's beginning reported by the literature as in Table 1, in line with the time required for cultivation trials.

Figure 3 looks at the total production of *Vannamei* shrimps by the five major producers (US, China, India, Thailand and Vietnam), that overall account for 80% of world production. We denote with dots the different stages of innovation detailed in Section 2. In 1984, the US started to produce white legs shrimp. In 1992, the first SPF shrimp were developed (start-up era). 1999 is the breakthrough second generation of SPF shrimp giving US producers a major cost advantage. Following this cost-reducing innovation, the quantity of *Vannamei* shrimp increases massively. The years 2001, 2002 and 2009 correspond to the sequential adoption of the new breed by major Asian producers. We observe that during those latter years the produced quantity continued to increase, but at a much slower pace.

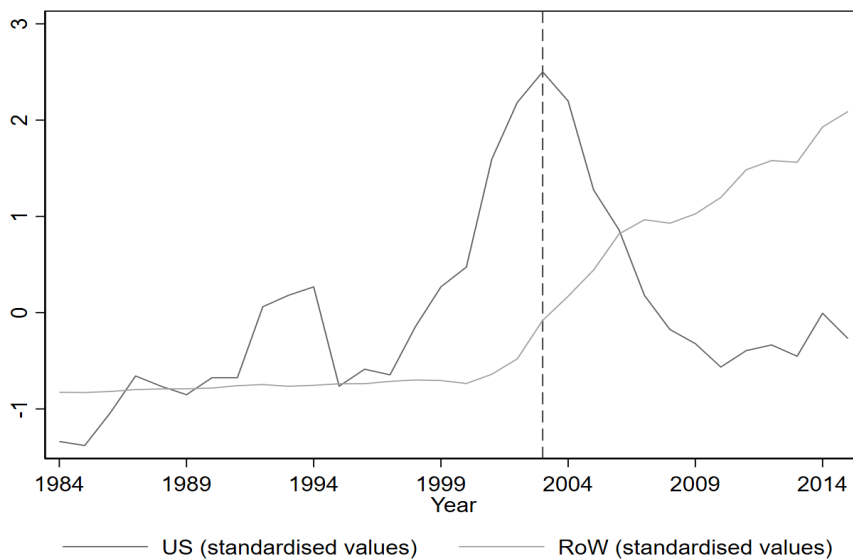
The reason for this change of pace can be seen on Figure 4, decomposing the total

Figure 3: The three phases of innovation



production of Vannamei in the US and in the rest of the world. The vertical dashed line (2003) marks the year all the Asian major competitors (with the exception of India) had terminated the production trials and began operating in the global market. The increase in the US production of Vannamei starts with the SPF innovation, and the decrease in the production starts when the production in the rest of the world increases, in particular following the adoption of Vannamei by Thailand and China.

Figure 4: US and total world L. Vannamei production (1984-2015)



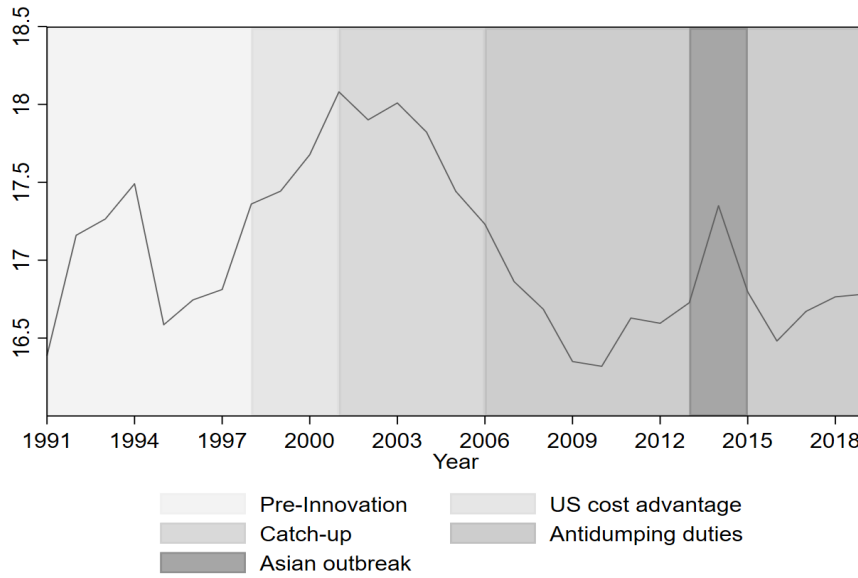
We provide additional Figures in Appendix B documenting the evolution in the choice of product variety. We report FAO estimates of the impact of the innovation on production costs in different countries in Table 8. With the exception of China, whose costs were much lower even in the pre-innovation period, all other countries experienced a consistent reduction in cost by on average 30%. In Figure 6, we plot the total production of shrimp (all species) by country in the US and in the major Asian producers. For each country, the dashed vertical line corresponds to the year of adoption of SPF L. Vannamei. Data suggest a net acceleration in the rate of production following the adoption of Vannamei in Thailand, Vietnam and India, while it didn't affect China's trend (consistently with the absence of a cost reduction in this latter case). Figure 7 reports the market share of Vannamei against the major native species in the main Asian producing countries following the adoption of the SPF breed. All of these figures are consistent with the theoretical prediction that a sufficiently important innovation, $c > \bar{c}$ leads to a decrease in product diversity in the catch-up phase.

The question of whether this innovation was sufficiently important to avoid a decrease in the US firms' profit (whether or not $c > c^*$) is however more complicated to assess. We plot on Figure 5 the aggregate estimated profit of the US industry. We computed quantity data from the FAO, the price data from the FED global shrimp prices time series (wholesale price in New York, \$ per kilo), and the average production cost from Briggs *et al.* (2004). Estimates are adjusted for inflation.

The very low profit in 1991 correspond to the outbreak of the Taura syndrom, and the years 1995-97 correspond to the outbreak of the white spot disease. Then, 1999 is the year of the major breakthrough that gave US producers a cost advantage. It is clear that this innovation coincides with the beginning of an increase in profits, and that the years when Asian countries switched to L. Vannamei corresponds to a turning point in which profits start to fall. Then, profits decrease to a level much lower than the one of 1998-99. The trend up to 2010 is consistent with the theoretical result that $c < c^*$ and that profit decreased below the pre-innovation one.

The story however does not stop there. In early 2000s, the decline in US market share and the dramatic rise in importation caused a 40% drop in employment in US shrimping factories (Beaulieu, 2005). In the attempt to save their dying industry, the Southern Shrimp Alliance (SSA), a group of eight south-eastern states consisting of forty-

Figure 5: Aggregate US industry profit (1991-2019)



two shrimp processors successfully petitioned the US government to impose anti-dumping duties on imports from Thailand, China, Vietnam, India, Ecuador, and Brazil. The first duties were imposed in 2005, with a calculated margin ranging from 2% (in the case of Ecuador exporters) up to 112% (in the case of China exporters).⁷ The antidumping duties imposition represents a prominent case for the scope and length of these measures and it gave rise to one of the most long-standing disputes before the World Trade Organization. Countries affected by antidumping duties repeatedly questioned the methodology used by US investigation authorities to calculate dumping margins (which are regularly updated and reviewed). Along the years, only Ecuador and Brazil (two countries that have always produced the L. Vannamei variety) had obtained a significant lift of these measures, so that comparing pre-innovation and catch-up profits after 2006 may be a misleading exercise.

Second, in 2014, a new major disease, the Early Mortality Syndrome (EMS) wiped out Chinese and Thai production of shrimp by more than 50%, leading to price increases of more than 40% for a kg of Vannamei shrimp.⁸ The disease only affected South-East

⁷Source: United States Department of Commerce, International Trade Administration (ITC), Enforcement and Compliance, Antidumping and Countervailing Case Information (<http://enforcement.trade.gov/stats/iastats1.html>). Table 9 in the Appendix provides details on the calculated margins during the first round of investigations in 2005.

⁸<https://www.fao.org/in-action/globefish/market-reports/resource-detail/en/c/338034/>

Asia, and never reached US producers, leading to a new phase of profit increase for US producers, not specifically linked to any product innovation.

5 Conclusions

This paper is a first attempt at looking at the link between innovation and the endogenous level of product diversity. Our results suggest that innovation may constraint firms active in a previously diversified market to sell more homogeneous products, and that such an incentive may lead to more intense competition in the catch-up phase than pre-innovation.

While our contribution is both theoretical and empirical, a first limitation of our approach is that our findings cannot be interpreted as causal. We present a model explaining a mechanism, and find evidence that the market for shrimp behaved in a way that is consistent with the mechanism we identified. A second limitation is that our setting and data do not allow us to study the link between product diversity and the more general question of the dynamic of innovation. Our static results suggest that the “curse of innovation” case, by decreasing the profit in the catch-up phase, may actually make the subsequent innovation more attractive, not less. It would also increase the advantage from staying one step ahead of the competitors in a model similar to [Aghion *et al.* \(2005\)](#).

While the empirical focus of this paper is on the shrimp industry, the theoretical results refer to any innovation that would make a variety cheaper to produce. This may apply more generally to the agricultural sector, where an innovation often consists in developing a more resistant or cheaper to produce variety. It could also correspond more broadly to technological innovations in which the adoption of a, superior, common standard constraints product diversity.

References

- AGHION, P., BLOOM, N., BLUNDELL, R., GRIFFITH, R. and HOWITT, P. (2005). Competition and innovation: An inverted-u relationship. *The Quarterly Journal of Economics*, **120** (2), 701–728.

- and JARAVEL, X. (2015). Knowledge spillovers, innovation and growth. *The Economic Journal*, **125** (583), 533–573.
- AMIR, R., HALMENSCHLAGER, C. and KNAUFF, M. (2017). Does the cost paradox preclude technological progress under imperfect competition? *Journal of Public Economic Theory*, **19** (1), 81–96.
- ANDERSON, S. P. and RENAULT, R. (1999). Pricing, product diversity, and search costs: A bertrand-chamberlin-diamond model. *The RAND Journal of Economics*, pp. 719–735.
- ARROW, K. (1962). Economic welfare and the allocation of resources for invention. In *The rate and direction of inventive activity: Economic and social factors*, Princeton University Press, pp. 609–626.
- BEAULIEU, C. (2005). Shrimp dumping: an analysis of antidumping laws in the United States and the World Trade Organization. *SCJ Int’l L. & Bus.*, **2**, 217.
- BRAESS, D. (1968). Über ein paradoxon aus der verkehrsplanung. *Unternehmensforschung*, **12** (1), 258–268.
- , NAGURNEY, A. and WAKOLBINGER, T. (2005). On a paradox of traffic planning. *Transportation science*, **39** (4), 446–450.
- BRIGGS, M., FUNGE-SMITH, S., SUBASINGHE, R. and PHILLIPS, M. (2004). Introductions and movement of *penaeus vannamei* and *penaeus stylirostris* in asia and the pacific. *RAP publication*, **10** (2004), 92.
- BROCK, J. A., GOSE, R., LIGHTNER, D. V., HASSON, K. *et al.* (1995). An overview on Taura syndrome, an important disease of farmed *Penaeus vannamei*. *Swimming through troubled water. Proceedings of the special session on shrimp farming, San Diego, California, USA, 1-4 February, 1995.*, pp. 84–94.
- CASSIMAN, B. and VEUGELERS, R. (2002). R&D cooperation and spillovers: some empirical evidence from Belgium. *American Economic Review*, **92** (4), 1169–1184.
- COCK, J., GITTERLE, T., SALAZAR, M. and RYE, M. (2009). Breeding for disease resistance of *Penaeid* shrimps. *Aquaculture*, **286** (1-2), 1–11.

- COE, D. T. and HELPMAN, E. (1995). International r&d spillovers. *European Economic Review*, **39** (5), 859–887.
- COHEN, W. M. and LEVINTHAL, D. A. (1989). Innovation and learning: the two faces of R & D. *The Economic Journal*, **99** (397), 569–596.
- DE SILVA, M., RANJULA, M., THANUJA, M., KATUWAWALA, D. and SUMANAPALA, A. (2021). Review on impacts of *Litopenaeus vannamei* on aquaculture.
- DHINGRA, S. and MORROW, J. (2019). Monopolistic competition and optimum product diversity under firm heterogeneity. *Journal of Political Economy*, **127** (1), 196–232.
- DIXIT, A. K. and STIGLITZ, J. E. (1977). Monopolistic competition and optimum product diversity. *The American Economic Review*, **67** (3), 297–308.
- FLEGEL, T. and ALDAY-SANZ, V. (1998). The crisis in Asian shrimp aquaculture: current status and future needs. *Journal of Applied ichthyology*, **14** (3-4), 269–273.
- FOUCART, R. and LI, Q. C. (2021). The role of technology standards in product innovation: Theory and evidence from UK manufacturing firms. *Research Policy*, **50** (2), 104157.
- GRIFFITH, R. and VAN REENEN, J. (2021). Product Market Competition, Creative Destruction and Innovation.
- HOMBERT, J. and MATRAY, A. (2018). Can innovation help US manufacturing firms escape import competition from China? *The Journal of Finance*, **73** (5), 2003–2039.
- KELLER, W. (2004). International technology diffusion. *Journal of Economic Literature*, **42** (3), 752–782.
- KUMAR, G., ENGLE, C. and TUCKER, C. (2018). Factors driving aquaculture technology adoption. *Journal of the World Aquaculture Society*, **49** (3), 447–476.
- MOSS, S. M., ARCE, S. M., MOSS, D. R. and OTOSHI, C. A. (2003). Disease prevention strategies for penaeid shrimp culture. In *Proceedings of the Thirty-second US*

- Japan Symposium on Aquaculture. US-japan Cooperative Program in Natural Resources (UJNR). US Department of Commerce, NOAA, Silver Spring, MD, USA, Cite-seer, pp. 34–46.*
- NARAJABAD, B. and WATSON, R. (2011). The dynamics of innovation and horizontal differentiation. *Journal of Economic Dynamics and Control*, **35** (6), 825–842.
- SANDIFER, P. A. (1988). Aquaculture in the West, a perspective. *Journal of the World Aquaculture Society*, **19** (2), 73–84.
- SCHELLING, T. C. (1980). *The Strategy of Conflict: With a New Preface by The Author.* Harvard University Press.
- SEADE, J. (1985). *Profitable cost increases and the shifting of taxation: equilibrium responses of markets in oligopoly.* Tech. rep.
- SINGH, N. and VIVES, X. (1984). Price and quantity competition in a differentiated duopoly. *The Rand Journal of Economics*, pp. 546–554.
- TURKMEN, G. and TOKSEN, E. (2010). Biosecurity and major diseases in shrimp culture. In *2nd International Symposium on Sustainable Development*, pp. 606–615.
- VIVES, X. (2008). Innovation and competitive pressure. *The Journal of Industrial Economics*, **56** (3), 419–469.
- WOLINSKY, A. (1986). True monopolistic competition as a result of imperfect information. *The Quarterly Journal of Economics*, **101** (3), 493–511.
- WYBAN, J. (2009). World shrimp farming revolution: industry impact of domestication, breeding and widespread use of specific pathogen free *Penaeus vannamei*. *Proceedings of the special session on sustainable shrimp farming, World Aquaculture*, **2009**, 12–21.
- (2019). Selective breeding of *Penaeus vannamei*: impact on world aquaculture and lessons for future. *Journal of Coastal Research*, **86** (SI), 1–5.

Appendix

A Detailed resolution of the theoretical model

A.1 Pre-innovation phase, Proof of Lemma 1

The profit of firm $i \in \{h, f\}$, with $i \neq j$ is given by

$$\pi_i = (A - q_i - \gamma q_j - c)q_i \quad (5)$$

Differentiating with respect to q_i , the first order condition yields

$$q_i^* = \frac{1}{2}(A - c - \gamma q_j^*) \quad (6)$$

As the game is symmetric, we can replace q_j^* by q_i^* and find

$$q_i^* = q_j^* = \frac{A - c}{2 + \gamma} \quad (7)$$

Using the result in (7) and replacing in the profit function (5) yields the differentiated Cournot equilibrium profit,

$$\pi_i^* = \pi_j^* = \frac{(A - c)^2}{(2 + \gamma)^2} \quad (8)$$

Replacing $\gamma = 1$ yields the non-differentiated Cournot equilibrium profit,

$$\pi_i^* = \pi_j^* = \frac{1}{9}(A - c)^2 \quad (9)$$

Given the above profits, it follows directly that the best response of a firm to a pure strategy of the other is to choose the other variety. There is also an equilibrium in mixed strategy, such that both firms choose each variety with equal probability. For any probability σ that firm i chooses variety k , the best response of firm $j \neq i$ is to choose variety $l \neq k$ with certainty when $\sigma > 1/2$, and to choose variety k with certainty when $\sigma < 1/2$. As the firms are symmetric, it implies that any small perturbation in σ around an exact value of $1/2$ leads to an equilibrium in pure strategy.

A.2 Innovation phase: proof of Lemma 2

The respective profit functions become

$$\pi_h = (A - q_h - \gamma q_f)q_h \quad (10)$$

$$\pi_f = (A - q_f - \gamma q_h - c)q_f \quad (11)$$

Differentiating with respect to q_i , the first order conditions yield

$$q_h^* = \frac{1}{2}(A - \gamma q_f^*) \quad (12)$$

$$q_f^* = \frac{1}{2}(A - \gamma q_h^* - c) \quad (13)$$

Solving the system of equations we find

$$q_h^* = \frac{A(2 - \gamma) + \gamma c}{4 - \gamma^2} \quad (14)$$

$$q_f^* = \frac{A(2 - \gamma) + c}{4 - \gamma^2} \quad (15)$$

Using the result in (14) and (15) and replacing in the profit functions (10) and (11) yields the differentiated Cournot equilibrium profit,

$$\pi_h^* = \frac{(A(2 - \gamma) + \gamma c)^2}{(4 - \gamma^2)^2} \quad (16)$$

$$\pi_f^* = \frac{(A(2 - \gamma) - 2c)^2}{(4 - \gamma^2)^2} \quad (17)$$

Replacing $\gamma = 1$ yields the non-differentiated Cournot equilibrium profit,

$$\pi_h^* = \frac{(A + c)^2}{9} \quad (18)$$

$$\pi_f^* = \frac{(A - 2c)^2}{9} \quad (19)$$

For the same reasons as in the case without innovation, both firms producing variety m is never a Nash equilibrium. Similarly, Home producing v and Foreign producing m is always a Nash equilibrium, as $\frac{(A(2-\gamma)-2c)^2}{(4-\gamma^2)^2} > \frac{(A-2c)^2}{9}$ for all $\gamma < 1$. Simplifying, $\frac{(A(2-\gamma)-2c)}{(4-\gamma^2)} - \frac{(A-2c)}{3} = \frac{(1-\gamma)(A(2-\gamma)+2c(\gamma+1))}{3(4-\gamma^2)}$, with $(1-\gamma) > 0$, $A(2-\gamma) + 2c(\gamma+1) > 0$ and the denominator always strictly positive for $\gamma < 1$.

There are either one or two Nash equilibria in pure strategy. Both firms producing v is never a Nash equilibrium (as it would be a best response for Foreign to produce m at the same marginal cost with less competition). However, if the benefits from innovation is sufficiently low, the equilibrium in which Home produces m and Foreign produces v (and no one makes use of the innovation) may continue to exist. The condition for this second equilibrium to exist is $c \leq \frac{A(\gamma-1)}{\gamma+5} = \tilde{c}$. We show in A.4 that this last possibility is however not relevant to the case in which innovation increases future competition.

A.3 Catch-up phase: proof of Lemma 3

The values in Table 4 combine the standard Cournot result of Lemma 1, using $c = 0$ for variety v , with the asymmetric payoffs in Lemma 2 for the case when one firm produces variety v and the other c . The case where both firms producing variety m is the standard Cournot outcome with marginal cost c , and it is straightforward to see it never constitutes a Nash equilibrium.

There is either a single Nash equilibrium without diversity in which both firms produce variety v , or two equilibria in pure strategy with diversity. The equilibrium is unique without diversity if and only if a firm prefers to produce the low cost variety v without product diversity than producing the high cost one m with diversity, $\frac{A^2}{9} > \frac{(2c-A(2-\gamma))^2}{(4-\gamma^2)^2}$. Choosing v is then a dominant strategy for both players. This is equivalent to a condition on the cost reducing innovation being sufficiently large, $c > \frac{1}{6}A(2-\gamma)(1-\gamma) = \bar{c}$. Note that the condition is easier to satisfy when the substitutability between the two varieties γ is high, as the benefit from producing variety m then decreases.

A.4 Proof of Proposition 1

Denote by c^* the level of initial cost such that an innovation that leads to lower product diversity still offers a higher producer surplus than product differentiation without innovation. The gain from the innovation is the lower cost. The loss from the innovation is the increased competition. The latter dominates if and only if $\frac{(A-c)^2}{(2+\gamma)^2} > \frac{A^2}{9}$. This expression simplifies to $c < \frac{1}{3}A(1-\gamma) = c^*$. The key result is that $c^* - \bar{c} = \frac{1}{6}A(1-\gamma)\gamma > 0$: there always exists a value of $c \in (\bar{c}, c^*)$ such that both firms choose to produce v after the technological catch up, and such that in that equilibrium the profit of both firms in the catch up stage is lower than it was before the innovation. It is also possible to show that $\bar{c} > \tilde{c}$. This implies that in the case where innovation decreases diversity in the catch up stage, the innovator is actually guaranteed to temporarily benefit from its innovation as there is a unique equilibrium when home has a cost advantage in v .

As we have established that $\tilde{c} < \bar{c} < c^*$, we can characterize the different possibilities.

1. By Lemma 2 and 3, we know that for $c < \tilde{c}$, the equilibrium is such that both firms produce a different variety both in the innovation and in the catch-up phase. As long as firm h specializes in variety v (our focality argument), it follows directly

that the profit is higher with a lower cost.

2. By Lemma 2 and 3, we know that for $c \in (\tilde{c}, \bar{c})$, the equilibrium is such that both firms produce a different variety both in the innovation and in the catch-up phase. The difference with case 1 is that there is no need to make an assumption that firm coordinate towards h producing v in the innovation phase, as this is the unique equilibrium. We however need the focality argument for the catch-up phase that firm h continues to produce v .
3. By Lemma 2 and 3, we know that for $c \in (\bar{c}, c^*)$, the equilibrium is such that both firms produce a different variety both in the innovation phase (with h producing v) and both firms produce v in the catch-up phase. By definition of c^* , for $c < c^*$ the profit in the catch-up phase is lower than in the pre-innovation phase.
4. By Lemma 2 and 3, we know that for $c > c^* > \bar{c}$, the equilibrium is such that both firms produce a different variety both in the innovation phase (with h producing v) and both firms produce v in the catch-up phase. By definition of c^* , for $c \geq c^*$ the profit in the catch-up phase is higher than in the pre-innovation phase.

B Additional Tables and Figures

Table 5: Comparison of High Health vs. non-high health shrimp in a commercial intensive system in Hawaii, 1991 (source: [Wyban, 2009](#))

	Non-High Health	High Health
Stocking Density (#/m2)	97	90
Duration (days)	101	104
Survival (%)	86	90
Mean Weight (g)	8.5	11.8
CV (%)	38	9
FCR	3.34:1	2.1:1
Total Crop (kg)	1,424	1,937
Crop Value	\$12,507	\$20,326
Crop less feed costs	\$7,228	\$15,852

Table 6: Comparison of production between *P. monodon* and *P. vannamei* in Thailand
(source: [Wyban, 2009](#))

Parameter	P. Monodon	SPF Vannamei	% difference
Density (PL/m ²)	40-50	120-200	300%
Crop duration (days)	110-140	105-120	27%
Harvest size (g) (#/kg)	22-28 (40/kg)	21-25 (42/kg)	5%
Yield MT/ha/crop	8	24	300%
Crop value (\$/ha)	\$45,000	\$96,000	220%
Crop costs (\$/ha)	\$32,000	\$60,000	187%
Production profit (\$/ha)	\$13,000	\$36,000	280%

Table 7: Major breeding companies in 2019 (source: 2020 Shrimp Insights)

Breeding company	Since	Locations
Molokai Broodstock Company (MBC)	1984	Hawaii
Oceanic Institute (OI)	1989	Hawaii
Kona Bay Shrimp	1996	Hawaii, Ecuador
Shrimp Improvement Systems (SIS)	1998	Hawaii, Florida and India
SyAqua	2002	Florida, Thailand and Indonesia
Charoen Pokphand Foods (CPF)	2003	Thailand, China, Vietnam, India, Malaysia, Philippines, US, others
Top Aquaculture Technology	2003	Thailand
Global Gen Indonesia (PT Bibit Unggul)	2006	Indonesia
Viet-Uc	2011	Vietnam
Primo Broodstock	2011	Texas and Florida
Sea Products Development (SPD)	2011	Texas
Blue Genetics	2013	Mexico and India
American Penaeid Inc.(API)	2014	Florida
North America Broodstock (NAB)	2016	California
Benchmark Genetics USA (Benchmark)	2016	Florida, Colombia and Thailand

Table 8: Average production costs estimates, by country

Country	Pre-innovation costs (US\$/kg)	Post-innovation costs (US\$/kg)	Perc. change	Source
United States	3.7	2.30	-37	Authors' own calculations based on Wyban, 2009
China	2.00	2.00	-0	FAO
Thailand	3.1	2.14	-30	FAO
Philippines	3.40	1.89	-44	FAO
Taiwan	3.50	1.95	-44	FAO
Malaysia	4.27	2.63	-38	FAO
India	3.50	3.35	-4	FAO
Sri Lanka	4.13	-	-	FAO

Figure 6: Production trends (in tons) by country, 1980-2015

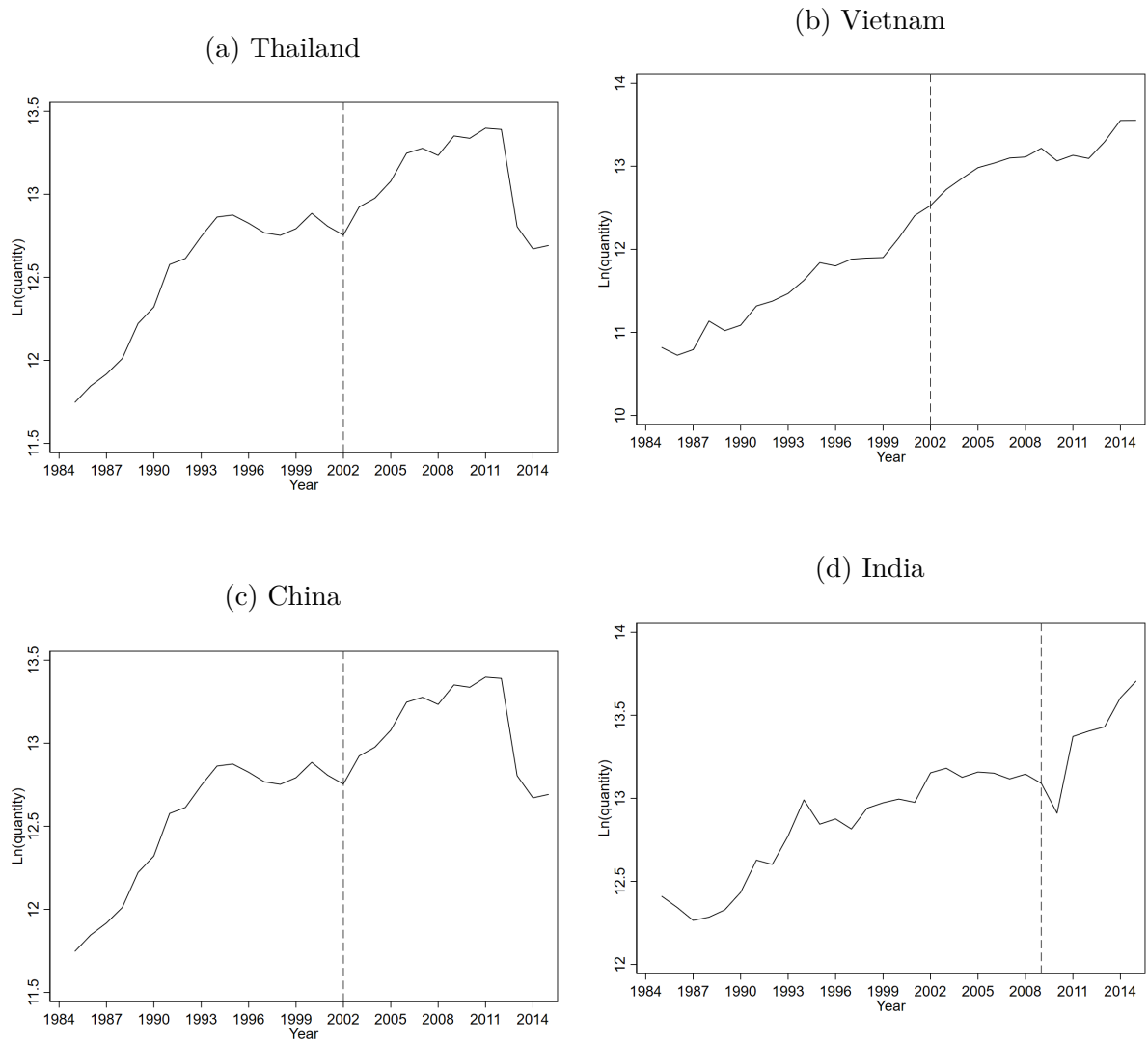


Figure 7: Switch in production: native main species vs SPF/TVR L. Vannamei.

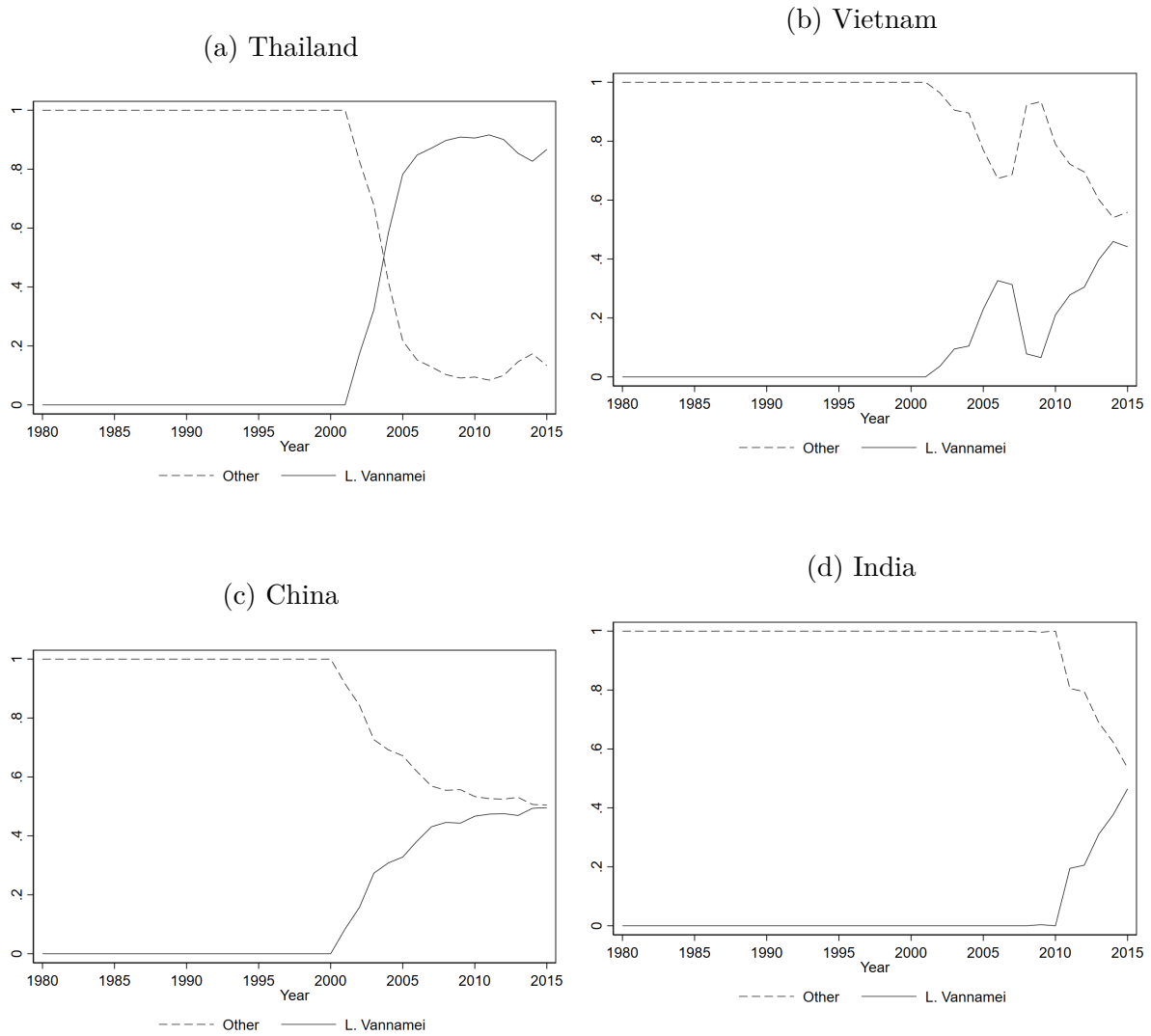


Table 9: US Imported Shrimp Antidumping Duty Investigations, 2005

Country	Product	Initiation	Final	Duty order	Min	Max
Brazil	Frozen Warmwater Shrimp	27-Jan-04	23-Dec-04	1-Feb-05	4.97%	67.80%
Ecuador	Frozen Warmwater Shrimp	27-Jan-04	23-Dec-04	1-Feb-05	2.48%	4.42%
India	Frozen Warmwater Shrimp	27-Jan-04	23-Dec-04	1-Feb-05	4.94%	15.36%
Thailand	Frozen Warmwater Shrimp	27-Jan-04	23-Dec-04	1-Feb-05	5.29%	6.82%
China	Frozen Warmwater Shrimp	27-Jan-04	8-Dec-04	1-Feb-05	27.89%	112.81%
Vietnam	Frozen Warmwater Shrimp	27-Jan-04	8-Dec-04	1-Feb-05	4.30%	25.76%