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CENTRO STUDI LUCA D'AGLIANO
DEVELOPMENT STUDIES WORKING PAPERS

N. 222

January 2007

# Wake Up and Smell the Ginseng: International Trade and the Rise of Incremental Innovation in Low-Wage Countries

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# Wake Up and Smell the Ginseng: International Trade and the Rise of Incremental Innovation in Low-Wage Countries


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This version, 31 July 2006


Abstract: Increasingly, a small number of low-wage countries such as China, India and Mexico are involved in incremental innovation. That is, they are responsible for resolving production-line bugs and suggesting product improvements. We provide evidence of this new phenomenon and develop a model in which there is a transition from old-style product-cycle trade to trade involving incremental innovation in low-wage countries. The model explains why levels of involvement in incremental innovation vary across low-wage countries and across firms within each low-wage country. We draw out implications for sectoral earnings, living standards, the capital account and, foremost, international trade in goods.



Key words: international trade, low-wage country innovation
JEL classification: F1

*We are thankful to Joel Blit for excellent research assistance. Also to Pol Antràs and Elhanan Helpman for helpful comments on an earlier draft. Both authors gratefully acknowledge funding from the Social Sciences and Humanities Research Council of Canada (SSHRC) and the tremendous support of the Canadian Institute for Advanced Research (CIAR).



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## 1. Introduction

When the auto parts giant Delphi Technologies first set up shop in Chihuahua, no one predicted that the Mexican shop-floor engineers at this low-wage affair would soon be introducing minor product changes that would slash product failure rates. While the cumulative effects of these product changes are large, no single innovation is pathbreaking. Even the most sophisticated innovations — those that actually generate patents — are just better mouse traps that incrementally improve on existing auto parts technology. For example, most Delphi-Chihuahua patents improve on the control systems of minor moving parts. These patents are examples of incremental innovation, Rosenberg's (1982*a*) unsung hero of modern economic growth. This paper is about the rise of incremental innovation in a select group of low-wage countries, how it is allowing these countries to export increasingly sophisticated new goods, and why it is leading to a major shift in world trade patterns.

Incremental innovation in low-wage countries is not part of the lexicon of international trade theory. Instead, we are glued to Vernon's (1966) product-cycle theory in which products and processes are developed and standardized in rich countries before being moved offshore to low-wage countries. (See also Krugman, 1979, and the more sophisticated approaches of Grossman and Helpman, 1991*b*,*c* and Antràs, 2005.) Increasingly, though, the first location of production for moderately sophisticated goods is taking place in a handful of low-wage countries such as China. As a result, the many bugs that plague new goods and their production processes must be partly and sometimes wholly resolved by local managers and engineers. That is, for the first time ever a handful of low-wage countries are engaged in incremental innovation. If incremental innovation is indeed the unsung hero of modern economic growth, then the long-term implications of this development are enormous.

From the perspective of a rich-country firm, there are costs and benefits of involving low-wage countries in incremental innovation. One key benefit is that it frees up valuable innovation resources at home so that they can be focused on 'big ideas' innovation. In addition, low-wage country involvement in incremental innovation allows the firm to locate production in a low-wage country even before products and processes are fully developed and standardized: local engineers are used to help complete the process of standardization. By locating a good's first production line in a low-wage country, the process of lowering labour costs is telescoped forward. Another benefit is that in a world of complex foreign supply chains, a firm that involves local suppliers in incremental innovation can insist that each supplier deliver continual product and process upgrades. Being directly engaged in the production process, suppliers can come up with improvements on the shop floor that would have been more costly for the firm to identify from head office. These additional improvements allow firms such as Delphi to stay a hair's breadth ahead of the competition.

Against these benefits are some significant drawbacks of involving local suppliers in incremental innovation. First and foremost, parts suppliers from low-wage countries typically produce components for complex, interdependent systems in which an incremental improvement in one component is not effective unless other components are also modified. This interdependence means that parts suppliers do not internalize all of a firm's innovation costs. In the simplest case, when a firm asks a parts supplier to improve a component, the solution will usually entail *residual incompatibilities* with other components of the system, thus forcing the firm to incur the additional expense of bringing other components into line. Basically, the firm can always trust its low-wage country parts supplier to screw up a little and possibly a lot.

The modelling core of this paper is about the firm's choice of organizational form — whether or not to involve the supplier in incremental innovation — and how this choice can be used to manage the residual incompatibilities that come to the fore when incremental innovation occurs in low-wage countries. We also model a second and more familiar cost of involving a local supplier in incremental innovation. Once involved, the supplier acquires information and expertise that can be used outside the relationship. This makes it necessary for the firm to offer expensive incentives aimed at encouraging the supplier to stay within the relationship.

We embed this choice of organizational form into a general equilibrium model. This yields predictions about the extent to which a low-wage country will (1) attract rich-country firms and (2) engage in incremental innovation. We then build on these results to generate a rich set of predictions about international trade in goods, the capital account, earnings and living standards.

### *Empirical Evidence*

Systematic evidence on incremental innovation, especially in low-wage countries, is non-existent (see Rosenberg, 1982*b*, von Hippel, 1988, and Sutton, 2001, for case-study evidence)[1]. Fortunately, there are two observable activities that are tied into incremental innovation. First, incremental innovation is most intense during the early stages of the production of new goods, when product bugs are fixed and production processes optimized. This is why learning curves are steepest by far in the earliest stages of production (e.g., Lucas, 1993, and Nahmias, 2005). Thus, one way to track incremental innovation is to track where new goods are produced. Second, while incremental innovation is about minor cumulative improvements to products and processes, occasionally it leads to patents. Thus, a second way to track incremental innovation is to track patents developed by residents in low-wage countries for rich-country corporations.

Some evidence on the first location of production of new goods can be culled from the business strategies of the world's five largest contract manufacturers (whose worldwide employment tops half a million workers). Sanmina-SCI reports that 54 of its 159 plants are exclusively engaged in producing new goods and developing new products. The top locations for these plants are (number of plants in parentheses): US (15); Canada (5); China, Hungary and Sweden (4); Finland, Germany and Israel (3); and the UK and Mexico (2). What stands out from this list is the appearance of three lower-wage countries: China, Hungary and Mexico.

[1] Anecdotal evidence on more substantial innovations frequently appears in the press. For example, 3com's 8800 high-end network switch and Nokia's 6108 handset were developed in China. Further, in 2002 China drew 3.1% of R&D expenditures abroad by US multinationals, a huge increase relative to its 1994 share of 0.1%, and equivalent to almost one-half of Japan's 2002 share (UNCTAD, 2005). However, the incremental innovations on which our paper focuses are rarely the stuff of news reports.

| | % of New Goods Imported by the United States from Each Country | | | | | | |
|---|---|---|---|---|---|---|---|
| | By Number | | | | By Value | | |
| | 1990–92 | 2000–02 | Change | $t$ | 1990–92 | 2000–02 | Change |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| **Rich** | | | | | | | |
| Japan | 68% | 55% | -13% | ($-15.51$) | 34% | 9% | -24% |
| Canada | 46% | 46% | 0% | ( 0.31) | 25% | 7% | -18% |
| Germany | 62% | 62% | -1% | ( 0.86) | 10% | 7% | -4% |
| **Poor** | | | | | | | |
| China | 17% | 48% | 30% | ( 35.80) | 0% | 5% | 5% |
| Malaysia | 9% | 16% | 8% | ( 9.25) | 2% | 7% | 5% |
| Thailand | 5% | 11% | 6% | ( 6.91) | 1% | 1% | 0% |
| India | 6% | 10% | 5% | ( 5.42) | 0% | 0% | 0% |
| Mexico | 19% | 23% | 4% | ( 4.57) | 6% | 4% | -2% |
| Philippines | 6% | 9% | 4% | ( 4.51) | 1% | 4% | 3% |
| Indonesia | 1% | 3% | 2% | ( 2.27) | 0% | 0% | 0% |

*Source*: Authors' calculations based on data from US Bureau of the Census.

*Notes*: This table reports statistics on goods that were first imported by the United States either in the period 1990–92 or the period 2000–02. Only new goods in medium-high-technology and high-technology sectors are included (US National Science Board, 2006): chemicals (including pharmaceuticals), machinery (including electronics), transportation equipment, and instruments. Column 1 states that of the innovative new goods first imported by the United States in 1990-92, Japan was an exporter 68% of the time. Column 1 sums to more than 100% because most new goods are imported into the United States from several countries. Column 5 states that of the innovative new goods first imported by the United States in 1990-92, 34% by value was imported from Japan. Column 5 would sum to 100% if all United States trading partners were listed.

**Table 1**. Origin of US Imports of Innovative New Goods

For more systematic evidence showing that this Sanmina-SCI example generalizes we turn to trade data. Following Feenstra and Rose (2000), we can identify where new goods are first produced using US import statistics. The United States classifies imports using 10-digit Harmonized System (HS) codes, which currently cover over 17,000 products and are regularly updated to incorporate new goods. A 10-digit Harmonized System (HS) good is 'new in year $t$' if it was first imported into the US in year $t$. For example, the United States first imported HS8471923600 ("Assembled laser printer units incorporating at least the media transport, control and print mechanisms, capable of producing more than 20 pages per minute") in 1994, primarily from Japan. The US first imported HS8477104000 ("Injection-molding machines for manufacturing video laser discs") in 1995, with two-thirds of imports by value coming from Germany, China and the Netherlands.

Table 1 shows that production of new goods is beginning to happen in low-wage countries. The table reports statistics for innovative new goods, i.e. new goods in medium-high-technology and high-technology sectors (US National Science Board, 2006): chemicals (including pharmaceuticals), machinery (including electronics), transportation equipment, and instruments. In the 1990-92 period, the US imported 694 innovative new goods. Of these, 472 or 68% were exported by Japan to the US (see column 1). A decade later, of the innovative new goods that first appeared in the 2000-02 period, only 55% of these were exported by Japan to the US (see column 2). The decline of 13% is statistically significant ($t = -15.51$). In contrast, only 17% of innovative new goods arrived from China in 1990–92, whereas 48% arrived from China in 2000-02. This is an increase of 30% ($t = 35.80$). The other big gainers among poor and middle-income countries were Malaysia, Thailand, India, Mexico and the Philippines. All other middle-income and poor countries (such as Indonesia) never exported substantial numbers of innovative new goods. That is, the phenomenon is confined to only a handful of countries.[2]

Columns 5–7 of table 1 provide an alternative view of the same phenomenon. They report the share of US imports of innovative new goods that originated in the indicated country by value instead of by number. For example, Japan accounted for 34% of US imports of innovative new goods in 1990–92, but only 9% in 2000–02. In contrast, China's share rose from 0% to 5% in just a decade. Thus, the conclusion that low-wage countries are beginning to be the first location of production comes from both frequency data and trade volume data. Table 1 leaves little doubt that some low-wage countries are now the location of early stages of production and hence of incremental innovation.

A second source of evidence on incremental innovation is suggested by our introductory example of Delphi patents generated by Mexican engineers at Delphi's Guadalajara facility. This source is the US patent database (`http://www.uspto.gov/`). For each patent, the database lists whether the patent is owned by a US entity (such as Michigan-based Delphi) and whether any of the inventors reside in a low-wage country. We have computed the total number of US patents with a US assignee and the share of these patents that list an inventor *residing* in China or other low-wage countries. In the 1995–97 period, of all patents assigned to US corporations, only a minuscule 0.05% listed an inventor residing in China. By 2003–05, China's share had risen to 0.33%. While 0.33% may seem small for a country as large as China, the share compares favourably to Japan's share of 1.1% in both 1995-97 and 2003–05. Further, the rapid increase in China's share since 1995–97 is suggestive of a significant increase in incremental innovation. As with US imports of innovative new goods, there are only a handful of low-wage countries appearing frequently in the US patent database. These include India and Mexico.[3]

In summary, US import and patent data both provide consistent and systematic evidence that a small number of low-wage countries are engaged for the first time in the incremental innovation associated with resolving production-line bugs and suggesting product improvements. We will show that this has important implications for the future of world trade.

[2] Data on US imports at the 10-digit HS level are subject to mis-classification by customs officials and jobbers, which result in minuscule amounts of exports of most goods by many countries. To eliminate such errors, a country is only counted as having exported a new good to the US if it accounted for at least 1% of US imports of that particular new good. Had we not done this, the statistics in table 1 would have been even more supportive of our claims.

[3] The numbers for India are virtually identical to those for China. This is surprising given India's low values in table 1. The explanation is that Indian patents in pharmaceuticals oriented to tropical diseases and in business processes do not give rise to exports of goods to the US. Mexico also experienced an increase in its patent share, which rose from 0.04% in 1995–97 to 0.09% in 2003–05. However, while China and India's shares continue to grow rapidly, Mexico's has been stagnant for the last four years.

***Related literature***

This paper has many touchstones with the existing international trade literature. Vernon's (1966) product-cycle model and its dynamic Ricardian variants (e.g., Krugman, 1979, Grossman and Helpman, 1991*b*,*c*, and Antràs, 2005) either assume or predict that innovation occurs exclusively in rich countries. They rule out innovation in low-wage countries. In the absence of local innovation, technologies diffuse to low-wage countries via such channels as imported machinery, FDI, scientific journals, technology licensing and theft (Grossman and Helpman, 1991*a*, Markusen, 2002). A few papers (e.g., Grossman and Helpman, 1991*b*,*c*) allow agents in low-wage countries to actively invest in acquiring knowledge. However, this knowledge acquisition is just reverse engineering of products originally developed and produced in rich countries.

Our paper also fits into the literature on incomplete contracts and trade. However, in order to focus on our novel contribution we sidestep the two most important questions addressed by the literature. The first is about the choice between vertical integration and outsourcing in general equilibrium (e.g., McLaren, 2000, Grossman and Helpman, 2002, 2003, Antràs, 2003). The second is about the choice between sourcing inputs from the North or from the South (e.g., Grossman and Helpman, 2005). Several papers combine both questions in order to deal with the choice between integrated home production, domestic outsourcing, FDI, and offshore outsourcing, or some subset of these (e.g., Antràs and Helpman, 2004, Grossman and Helpman, 2004, and also Antràs, 2005, who integrates this choice in a product-cycle model). Spencer (2005), Trefler (2006) and Helpman (2006) review this literature. We do not tackle these questions, choosing instead to focus on the conditions that promote incremental innovation in low-wage countries. Our starting point is that a Northern firm has already decided to locate production in the South. We model the firm's choices about (*i*) which of several low-wage countries to enter and (*ii*) whether to involve a local agent in incremental innovation.[4] Notice that we are silent on whether we are dealing with FDI or offshore outsourcing. What matters to us is only whether incremental innovation is being done.

Our second cost of doing incremental innovation in low-wage countries deals with the possibility that a local parts supplier could take the knowledge gained from incremental innovation and use it outside of the relationship. This means that our paper is also related to work on contract enforcement and trade. See the seminal work of Ethier and Markusen (1996) as well as Markusen (2002) and Nunn (2007). Weak contract enforcement is one of several possible reasons why a local parts supplier can use proprietary knowledge outside of the relationship. Ethier and Markusen (1996) are interested in the choice between exporting and producing abroad for goods whose production has already been standardized. Producing abroad allows the firm to benefit from lower wages, but at a cost: it also allows the local agent to *passively* absorb the firm's technology and steal it. This is an important insight. In contrast, we are interested in *active* participation of local agents in the incremental innovation of new goods.

[4]In an earlier draft of this paper (Puga and Trefler, 2005) there was a third choice, namely, whether to delegate control of incremental innovation decisions to the local agent. This aspect of the paper built on our earlier closed-economy work on organizational choice with incremental innovation (Puga and Trefler, 2002) which in turn built on Aghion and Tirole (1997). This choice and the common elements with Puga and Trefler (2002) have been eliminated in the current version of the paper in order to simplify the analysis.

The paper is organized as follows. Section 2 sets up the model. Section 3 analyzes the decision by a single rich-country firm about whether to involve her low-wage country partner in incremental innovation. Sections 4 and 5 embed this choice in a general equilibrium international trade framework with multiple rich-country firms and alternative low-wage country locations. This yields predictions about the extent to which different low wage countries will engage in incremental innovation and attract rich-country firms, as well as predictions about international trade in goods, the capital account, earnings and living standards. Section 6 concludes.

## 2. Set-up

We have in mind a situation in which a US firm with an existing product has decided to produce it in China. Changes in market conditions and available technologies force the US firm to incrementally improve the product or its production process so that it remains viable. We refer to the American firm as the principal, denoted by 'she' or a subscript $p$. The firm has a Chinese partner, who we refer to as the agent, denoted by 'he' or a subscript $a$. We are not concerned here with how the US principal came to have the asset that allows her to produce (although we will discuss free entry in section 5) or why she has decided to produce in abroad (although in sections 4–5 we will analyze the choice between alternative foreign countries). Nor are we concerned here with the mode of entry into China. For our purposes the Chinese partner is the senior manager/engineer either of an independent Chinese supplier (offshore outsourcing) or of a US-owned subsidiary (FDI). Our analysis instead focuses on the extent to which American firms involve the managers and engineers of Chinese plants in the innovation process. This will provide the building blocks for our general equilibrium analysis of incremental innovation and international trade.

### *Incremental innovation*

The American principal can develop the incremental innovation in the United States and ask the Chinese agent merely to implement it. We call this 'Principal Innovation' and denote it by superscript $PI$. Alternatively, the American principal can assign the role of developing the incremental innovation to her agent in China. We call this 'Agent Innovation' and denote it by superscript $AI$. Developing the incremental innovation requires 'creative' effort either from the principal under principal innovation or from the agent under agent innovation. Let $e_i$ be the innovation effort of $i$ ($i = p,a$) where $e_i \in [0,1]$. Innovation effort level $e_i$ leads to a successful incremental innovation with probability $e_i$ and to no innovation with probability $1 - e_i$.

Incremental innovations designed by the Chinese agent are different from those designed by the American principal. In particular, interactions between interdependent components of a complex system imply that an incremental innovation designed by the Chinese agent creates some residual incompatibilities for the American principal. The principal must then exert some 'debugging' effort to sort out these residual incompatibilities. The importance of residual incompatibilities is parameterized by $r \in [0,1]$. For simplicity, we assume that debugging effort by the principal is the only characteristic distinguishing one incremental innovation from another. Every successfully developed and debugged incremental innovation allows production of one unit of output with no additional inputs required other than those provided by the principal and the agent and yields the same total profit $\pi$.

Both the creative effort $e_i$ required to develop an incremental innovation and the debugging effort required to sort out residual incompatibilities $r$ are costly because they eat into an individual's unit endowment of leisure. Leisure for the principal and the agent are:

$$
\begin{aligned}
l_p &= \begin{cases} 1 - e_p & \text{under principal innovation,} \\ 1 - r & \text{under agent innovation,} \end{cases} \\
l_a &= \begin{cases} 1 & \text{under principal innovation,} \\ 1 - e_a & \text{under agent innovation.} \end{cases}
\end{aligned} \tag{1}
$$

Preferences are Cobb-Douglas with equal exponents on consumption and leisure and homothetic over all goods. Thus, indirect utility for economic actor $i$ ($i = p,a$) is

$$U_i = \frac{y_i}{P} l_i \ . \tag{2}$$

where $y_i$ is $i$'s income $l_i$ is $i$'s leisure and $P$ is the relevant price index.

***Sequence of events***

We turn now to the sequence of events. The American principal and Chinese agent randomly match and sign a contract governing their relationship. Contracts are incomplete in the sense that they cannot be contingent on innovation effort, on the quality of innovations, or on profits. The agent has no liquid assets so the principal cannot ask for lump-sum transfers from the agent. In addition, at the time of signing the contract, the principal and the agent have only a rough idea of how good the Chinese agent will be at incrementally improving the principal's product. It is only in the course of working together that they get a clearer sense of the residual incompatibilities or debugging effort that the principal will bear if the agent develops the incremental innovation. We formalize this learning process in a stylized way. When the principal and agent match they have only a broad sense of the residual incompatibilities that an agent-developed innovation will create for the principal. This is described by a prior cumulative distribution function $F(r)$ over the residual incompatibilities parameter $r$. After working together they learn $r$ exactly.

By default, the principal and the agent engage in principal innovation, a product-cycle relationship in which all of the technology is developed by the principal in the United States and then transferred to China for use in production by the Chinese agent. The Chinese agent receives a previously-agreed wage $w$.[5] However, after they start working together and learn $r$, the principal may offer to involve the agent in innovation. Local agent involvement allows the American principal to replace her innovation effort with that of her Chinese agent.

There are, however, two disadvantages of involving the Chinese agent in innovation. First, as discussed above, an incremental innovation developed by the Chinese agent creates residual

[5] The principal is protected by limited liability, so if there is no incremental innovation and thus production fails the principal does not need to pay the agent's wage.

incompatibilities that the American principal has to resolve. In addition to residual incompatibilities, there is a second 'earnings premium' disadvantage to involving the Chinese agent in developing an incremental innovation. To be able to contribute to the incremental innovation, the agent needs confidential technical and/or marketing specifications from the American firm. Much of this information will typically be non-codifiable information passed on by US managers and engineers to their Chinese counterparts. This information will almost certainly be valuable outside the relationship. Thus, once the Chinese agent has this information, the American principal will have to pay an earnings premium in order to retain the Chinese agent.

We assume there is a surplus if, after the agent has been given access to confidential information, the principal and agent maintain their relationship. The outcome of bargaining over this surplus can be described as an ex-post sharing rule whereby the agent gets a share $\lambda$ of profits and the principal a share $1 - \lambda$. For instance, suppose the principal and agent successfully develop an incremental innovation. If they produce together, joint profits are $\pi$. If they go their separate ways, the principal obtains profits $\pi_p^O$, net of the additional costs she must incur to be able to produce without the agent. Likewise, the agent obtains profits $\pi_a^O$, net of the additional costs he must incur to be able to produce without the principal. The surplus of the relationship is $\pi - \pi_p^O - \pi_a^O$, which we assume is positive. If, for example, we use the Nash bargaining solution with equal weights to allocate the surplus, when the agent is involved in incremental innovation he gets $\frac{1}{2}\pi + \frac{1}{2}(\pi_a^O - \pi_p^O)$ while the principal keeps $\frac{1}{2}\pi - \frac{1}{2}(\pi_a^O - \pi_p^O)$. In this case, under agent innovation ex-post bargaining leaves the agent with a share of profits $\lambda = \frac{1}{2} + \frac{1}{2}(\pi_a^O - \pi_p^O)/\pi$. If the agent is not involved in innovation, he does not gain access to information that would allow him to produce without the principal and is better off staying in the relationship and collecting the wage $w$.

It follows that income for the agent and principal, conditional on production, is

$$\begin{aligned} y_a &= \begin{cases} w & \text{under principal innovation,} \\ \lambda\pi & \text{under agent innovation,} \end{cases} \\ y_p &= \pi - y_a \, . \end{aligned} \tag{3}$$

## 3. The choice over the agent's involvement in innovation

The level of agent involvement in innovation will depend on the earnings premium $\lambda\pi/w$ and on the importance of residual incompatibilities $r$. This section describes exactly how.

### *Principal innovation*

Under principal innovation, with probability $e_p$ an incremental innovation is developed by the principal which yields incomes $y_a = w$ and $y_p = \pi - w$. With probability $(1 - e_p)$ no incremental innovation is developed and $y_a = y_p = 0$. Substituting this and (1) into (2), yields the following expected utility levels for the principal and the agent:

$$\mathbf{E}U_p^{PI} = e_p \frac{\pi - w}{P}(1 - e_p) \, , \tag{4}$$

$$\mathbf{E}U_a^{PI} = e_p \frac{w}{P} \, . \tag{5}$$

The problem for the principal is to choose $e_p$ in order to maximize $\mathbf{E}U_p^{PI}$, which yields $e_p = 1/2$. Substituting this equilibrium effort level into (4) and (5) yields equilibrium expected utility levels:

$$\mathbf{E}U_p^{PI} = \frac{1}{4}\frac{\pi - w}{P} \ , \tag{6}$$

$$\mathbf{E}U_a^{PI} = \frac{1}{2}\frac{w}{P} \ . \tag{7}$$

*Agent innovation*

Under agent innovation, substituting (1) and (3) into (2), yields the following expected utility levels for the principal and the agent:

$$\mathbf{E}U_p^{AI} = e_a\frac{(1-\lambda)\pi}{P}(1-r) \ , \tag{8}$$

$$\mathbf{E}U_a^{AI} = e_a\frac{\lambda\pi}{P}(1-e_a) \ . \tag{9}$$

The problem for the agent is to choose $e_a$ in order to maximize $\mathbf{E}U_a^{AI}$, which yields $e_a = 1/2$. Substituting this equilibrium effort level into (8) and (9) yields equilibrium expected utility levels:

$$\mathbf{E}U_p^{AI} = \frac{1}{2}\frac{(1-\lambda)\pi}{P}(1-r) \ , \tag{10}$$

$$\mathbf{E}U_a^{AI} = \frac{1}{4}\frac{\lambda\pi}{P} \ . \tag{11}$$

*The principal's choice*

The principal chooses the organizational form that she prefers between principal innovation and agent innovation.

**Proposition 1** (Extent of the agent's involvement in innovation) *The principal prefers agent innovation to principal innovation if and only if*

$$r < \bar{r} \equiv 1 - \frac{1}{2}\frac{1 - w/\pi}{1-\lambda} \ . \tag{12}$$

***Proof*** The principal prefers agent innovation to principal innovation if and only if $\mathbf{E}U_p^{AI} > \mathbf{E}U_p^{PI}$, where $\mathbf{E}U_p^{AI}$ is given by equation (10) and $\mathbf{E}U_p^{PI}$ by equation (6). □

Of course, the agent will only accept to be involved in incremental innovation if $\mathbf{E}U_a^{AI} \geqslant \mathbf{E}U_a^{PI}$.

**Lemma 1** (Agent's participation in innovation) *The agent accepts the principal's offer of involvement in innovation if and only if the earnings premium is high enough, $\frac{\lambda\pi}{w} \geqslant 2$.*

***Proof*** The agent accepts the principal's offer of involvement in innovation if and only if $\mathbf{E}U_a^{AI} \geqslant \mathbf{E}U_a^{PI}$, where $\mathbf{E}U_a^{AI}$ is given by equation (11) and $\mathbf{E}U_a^{PI}$ by equation (7). □

It may be useful to the reader if we recap our partial equilibrium analysis before embedding it in a general equilibrium international trade framework. The American principal and Chinese agent match and have a prior $F(r)$ about their residual incompatibilities parameter $r$. Initially they agree on a contract which pays the agent a wage $w$ for starting up a product-cycle relationship. This wage $w$ will adjust to reflect the general equilibrium outside opportunities available to the principal and the agent at the time of signing the contract. Once the relationship is started up both parties learn $r$. When $r$ is large, the principal remains in charge of the incremental innovation and chooses her level of creative effort $e_p$. If the principal is successful in developing an incremental innovation then there is production and the agent is paid $w$. When instead $r$ is small, the principal asks the agent to become involved in innovation. If the agent accepts, he chooses his level of creative effort $e_a$. If the agent is successful in developing an incremental innovation then the principal must exert debugging effort $r$ to resolve residual incompatibilities. At that point, whatever the level of creative effort exerted by the agent and the residual incompatibilities created by his incremental innovation, the principal will have to pay the agent $\lambda\pi$ instead of $w$ in order to keep him from running away with the knowledge acquired.

For the American principal the key advantage of involving the Chinese agent in incremental innovation is that it allows her to replace her own innovation effort, $e_p = 1/2$, with that of her Chinese agent. There are, however, two disadvantages of involving the Chinese agent in innovation. First, an incremental innovation developed by the Chinese agent creates residual incompatibilities that the American principal has to resolve. Second, an agent involved in innovation must be paid an earnings premium to keep him from running away with the knowledge acquired. Proposition 1 shows there is a threshold level of residual incompatibilities $\bar{r}$ above which the principal does not find it worthwhile to involve the agent in innovation. This threshold level is a decreasing function of the earnings premium. Earlier we presented this earnings premium from the point of view of the agent, $\frac{\lambda\pi}{w}$. However, from the principal's perspective this is better expressed as the ratio of the principal's income under principal innovation to the principal's income under agent innovation $\frac{\pi-w}{(1-\lambda)\pi} = \frac{1-w/\pi}{1-\lambda}$. This is the ratio that appears in the right-hand side of equation (12).

Note that we have set up the model so that innovation effort levels are independent of firm profits $\pi$. General equilibrium feedbacks will enter only via the earnings premium and its effect on the threshold level for the residual incompatibilities parameter $\bar{r}$. Our parsimonious approach is intended to highlight the key role of the earnings premium. It will also have the effect of simplifying the analysis of general equilibrium international trade flows.

## 4. International trade and incremental innovation

We now turn to the implications or our model for incremental innovation in low-wage countries as well as for international trade and income disparities. So far we have focused on the decision by a single US firm about whether to involve her Chinese partner in incremental innovation. In this section we consider multiple US firms or principals. Different principal-agent matches will have different values of $r$ and hence choose different ways of organizing innovation. All that is required for the coexistence of different organizational forms is sufficient heterogeneity in the distribution of matches i.e., in the distribution of $r$. This will play an important part in our discussion of why some countries are stuck in product-cycle trade while others have moved to incremental innovation-based trade.[6]

Let $M$ be the endogenous number of US firms. Each firm must choose a production location from among multiple low-wage countries. For concreteness, let each principal be a US auto designer or manufacturer who has decided to produce auto parts (or autos for short) in a low-wage country. Since we are not interested in the choice between producing in high-wage versus low-wage countries we assume that all auto production takes place in low-wage countries. For clarity we consider only two low-wage countries — China and Indonesia.[7] This choice of country labels reflects that both China and Indonesia are low-wage countries recipients of substantial foreign investments. However, China has become a prominent location for first production of new innovative goods and experienced rapid growth in innovations developed by locals for US multinationals (see the numbers in the Introduction, particularly table 1), whereas Indonesia has not.

To bring the results into stark relief we allow for only one difference between China and Indonesia. When a principal goes to China, she is less likely to face large residual incompatibilities. Mathematically, let $F$ be the cumulative distribution function of the $r$ in China and let $F^*$ be the corresponding cumulative distribution function in Indonesia. Both $F$ and $F^*$ are assumed differentiable. Asterisks will denote Indonesian variables throughout. We assume that $F^*$ first-order stochastic dominates $F$. This means that $F^*$ is right-shifted relative to $F$: $F^* \leqslant F$ for all $r$, with strict inequality for some $r \in (0,1)$. As is well known, first-order stochastic dominance implies $\int_0^1 u(r)\mathrm{d}F^*(r) \leqslant \int_0^1 u(r)\mathrm{d}F(r)$ for any non-increasing function $u(r)$.

Although we believe the assumption that $F^*$ first-order stochastic dominates $F$ to be the obvious one, it is worth reviewing the evidence for what the Chinese distribution looks like relative to countries such as Indonesia, Thailand and the Philippines. First, relative to Indonesian engineers, Chinese engineers receive training that allows them to work more effectively with US engineers. Part of this is the high quality of Chinese engineering schools. The *Times Higher Education Supplement* places 2 Chinese engineering schools in the top 15 worldwide and another 6 in the top 100. In contrast, no Indonesian, Thai or Philippine school makes this list.[8] Also, there is a large number of Chinese nationals who graduated from US engineering schools and moved back to China. Among foreign-born scientist and engineering students who are enrolled in US schools but have no firm plans to stay in the United States, 25% are from China whereas only 1% are from Indonesia, Thailand and the Philippines combined.[9] The large number of Chinese with US engineering degrees makes it easier to initiate contacts (credentialism) and communicate engineering solutions.

Second, Chinese engineers likely have better specific industrial training than their Southeast Asian counterparts. They have been nurtured by the Chinese diaspora in Hong Kong, Taiwan, Singapore and the United States which has invested heavily in bringing Chinese manufacturing

[6]This coexistence of forms has the flavour of Melitz (2003) where exporters and non-exporters coexist because of cross-plant differences in productivity. Likewise, Antràs and Helpman (2004) use Melitz's productivity heterogeneity to generate the coexistence of integrated home production, domestic outsourcing, FDI and offshore outsourcing.

[7]As will become clear, it requires virtually no change in our analysis to allow for any finite number of low-wage agent countries and high-wage principal countries.

[8]Rankings are published in *Times Higher Education Supplement*, 5 November 2004, available at `http://www.thes.co.uk/worldrankings/`.

[9]Authors' calculations based on data in Johnson (1998) and `http://sestat.nsf.gov`.

plants up to snuff. Kerr (2006) shows that the large ethnic Chinese and ethnic Indian research communities based in the United States have greatly facilitated knowledge diffusion and increased output in innovative sectors back in China and India (Kerr, 2006, uses data on ethnic inventor names appearing in US patents, data on foreign citations to these patents, as well as data on migration and production patterns). There is also significant evidence that Chinese plants are adopting Western management techniques which emphasize quality control and information flow. This can be seen, for example, in the prevalence of ISO 9001 certificates, a standard reference for quality management practices in business-to-business dealings. As of December 2003, China had a stock of almost 100,000 ISO 9001 certificates compared to only 3,449 for Indonesia, Thailand and the Philippines combined. Even controlling for differences in country size, this is a huge difference in certifications.[10]

Third, China is a major FDI destination for US firms not just because of its low-wages, but also because of the size of its internal market. This means that firms in China are producing for domestic consumption, a fact that puts Chinese engineers in closer proximity to customers. For instance, Nokia designed its 6108 handset in Beijing to optimize its Chinese text messaging capabilities. It has since had several other handsets designed in Beijing for different markets. The size of China's market and the nascent sophistication of its consumers flips Vernon's (1966) argument on its head. Proximity to discerning consumers is a key driver of Vernon's argument for why innovation occurs in rich countries. Now it is an argument for why incremental innovation occurs in China.

For these three reasons it is appropriate to assume that $F^*$ first order stochastic dominates $F$. Note that all three reasons apply almost as much to India as they do to China.

Returning to the model, each principal makes her location choice knowing the distribution of $r$ she will encounter in China and in Indonesia. However, it is only after she has made her location choice and started working with a particular agent that she learns the value of $r$ associated with working with that agent i.e., she learns the cost of sorting out residual incompatibilities. Thus, in deciding whether to locate in China or in Indonesia each principal takes expectations over $r$. Similarly, in deciding whether to become an agent in the auto sector or to engage in an as-yet unmodelled alternative occupation, each agent must take expectations over $r$.

We focus our analysis on the case in which principals' choices of organizational forms are non-trivial, i.e. the case in which agent innovation and principal innovation can both arise for some values of $r$. By proposition 1, a principal chooses agent innovation over principal innovation if and only if $r < \bar{r}$. Since $r \in [0,1]$, with $\bar{r} < 0$ a principal would prefer principal innovation for all $r$, while with $\bar{r} > 1$ a principal would prefer agent innovation for all $r$. Thus, agent innovation and principal innovation are both possible preferred choices for a principal for some values of $r$ if and only if $0 < \bar{r} < 1$, where $\bar{r}$ is given by proposition 1. In addition to agent innovation being the preferred choice for principals over some range of residual incompatibilities, for agent innovation to actually happen it must be the case that agents accept principals' requests to become involved in incremental innovation. By the agent's participation in innovation condition of lemma 1, this requires $\frac{\lambda\pi}{w} \geqslant 2$. The appendix shows that $0 < \bar{r} < 1$ and $\frac{\lambda\pi}{w} \geqslant 2$ are easy to simultaneously satisfy

[10] Data are from ISO Central Secretariat (2003).

in general equilibrium. Expected utility from entering the Chinese auto sector is then given by

$$\mathbf{E}U_i = \underbrace{\int_0^{\bar{r}} \mathbf{E}U_i^{AI} \mathrm{d}F(r)}_{\text{Agent Innovation}} + \underbrace{\int_{\bar{r}}^1 \mathbf{E}U_i^{PI} \mathrm{d}F(r)}_{\text{Principal Innovation}} , \qquad i = p,a . \tag{13}$$

The Indonesian equivalent of equation (13) replaces $F$ with $F^*$.

***The agents' problem***

Consider equation (13) from the perspective of a Chinese agent. Substituting in the values of $\mathbf{E}U_a^{AI}$ and $\mathbf{E}U_a^{PI}$ given respectively by (11) and (7) yields expected *ex ante* utility for a Chinese national from being in the auto sector:

$$\mathbf{E}U_a(w,F) = \underbrace{\frac{1}{4}\frac{\lambda\pi}{P} F\left(\bar{r}(w)\right)}_{\text{Agent Innovation}} + \underbrace{\frac{1}{2}\frac{w}{P}\left[1 - F\left(\bar{r}(w)\right)\right]}_{\text{Principal Innovation}} \tag{14}$$

where, from proposition 1, $\bar{r}(w) = 1 - \frac{1}{2}\frac{1-w/\pi}{1-\lambda}$. The Indonesian equivalent of equation (14) replaces $F$ with $F^*$ and $w$ with $w^*$ to yield $\mathbf{E}U_a(w^*, F^*)$.

In addition to producing autos, both China and Indonesia produce apparel. Apparel is produced with raw labour i.e., without innovation effort $e_i$. Apparel production is subject to diminishing returns to labour — think of this as capturing a fixed factor such as land. To avoid scale effects associated with the fixed factor we assume that China and Indonesia are the same size, each having a workforce of size $L$. We denote the (endogenous) number Chinese nationals who choose to become agents in the auto sector by $m$, so that $L - m$ is employment in the Chinese apparel sector. We choose apparel as the numéraire so that its price is unity. Let $w_A(L-m)$ be the marginal product and wage of labour in the apparel sector when $L - m$ workers are employed in the apparel sector. By diminishing returns to labour $w_A' < 0$.

If China produces both apparel and autos then its nationals must obtain the same *ex-ante* expected utility whether they work in the apparel sector or are agents in the auto sector. Utility from working in the apparel sector is $w_A/P$. A Chinese agent is *ex-ante* indifferent between working in the apparel and auto sectors when

$$\mathbf{E}U_a(w,F) = \frac{w_A(L-m)}{P} . \tag{15}$$

The corresponding indifference condition for Indonesian nationals is

$$\mathbf{E}U_a(w^*,F^*) = \frac{w_A(L-m^*)}{P} . \tag{16}$$

These two equations are central to our analysis.[11]

[11] Agents who choose the auto sector and get a low draw of $r$ are *ex-post* better off than workers in the apparel sector, whereas agents who get a high draw of $r$ are *ex-post* worse off than workers in the apparel sector. As in models à la Harris and Todaro (1970), we assume that after $r$ is realized it is not possible for workers with a bad draw to relocate to the apparel sector. Alternatively, we could introduce the need to obtain a degree prior to working in the auto sector and finding out the realization of $r$. The earnings of agents would then have to be higher in order to compensate for the cost of an education. For a high enough cost of education, even an agent in a high-$r$ match will be *ex post* better off in autos than in apparel.

***The principals' problem***

Each American principal must employ either a Chinese or Indonesian agent to produce one unit of autos. In choosing between locating in China and Indonesia, each principal compares *ex ante* expected returns of entering each country. Given that all successfully developed and debugged innovations yield the same total profit, from the point of view of a principal there are only two differences between China and Indonesia: (*a*) the distributions $F$ and $F^*$ and (*b*) auto sector wages, $w$ and $w^*$. Substituting the values of $\mathbf{E}U_p^{AI}$ and $\mathbf{E}U_p^{PI}$ in equations (10) and (6), respectively, into into (13) yields expected *ex ante* utility for an American principal from entering the Chinese auto sector:

$$\mathbf{E}U_p(w,F) = \underbrace{\int_0^{\bar{r}(w)} \frac{1}{2}\frac{(1-\lambda)\pi}{P}(1-r)\mathrm{d}F(r)}_{\text{Agent Innovation}} + \underbrace{\frac{1}{4}\frac{\pi - w}{P}\left[1 - F\left(\bar{r}(w)\right)\right]}_{\text{Principal Innovation}} . \tag{17}$$

Note that $r$ enters equation (17) in two ways. From proposition 1, $r$ determines whether each agent is involved in innovation or not. Second, under agent innovation $\mathbf{E}U_p^{AI}$ also depends on the costs of debugging residual incompatibilities $r$. The principal's corresponding return from entering Indonesia is $\mathbf{E}U_p(w^*, F^*)$.

If principals operate in both China and Indonesia, expected *ex-ante* returns must be equalized across the two countries:

$$\mathbf{E}U_p(w,F) = \mathbf{E}U_p(w^*,F^*) . \tag{18}$$

This equation is also central to our analysis.

***A note on general equilibrium***

For our main results we will not need to make any additional assumptions about preferences. Nor will we need to specify market structure or the entry process for principals. Our main results about the location choices of American principals, local involvement in incremental innovation, wages and well-being can all be obtained on the basis of equations (15), (16), and (18) alone. This is surprising because these three equations contain six endogenous variables: $w$, $w^*$, $m$, $m^*$, $\pi$, and $P$. However, what matters for our results is $w$, $w^*$, and $m/m^*$. We do not need to worry about $P$ because, with free trade, it is the same internationally and cancels out of all three equations. Under our assumption that every successfully developed and debugged incremental innovation yields the same total profit (i.e. all autos produced appear symmetrically in the integrated goods markets), $\pi$ is also common internationally and does not matter for our comparison of China and Indonesia. Finally, we care about the distribution of principals across the two countries ($m/m^*$) rather than absolute values of $m$ and $m^*$. To summarize, for all of our main results, the model can be reduced to three equations, (15), (16), and (18) three unknowns, $w$, $w^*$, and $m/m^*$. We will introduce more structure on entry, market structure, and profits only for some secondary results in our penultimate section 5.

***Wages as an equilibrating mechanism***

The wage $w$ paid under principal innovation is the key equilibrating mechanism in our model. We therefore assume that there is principal innovation in both countries. This simply requires that both countries have positive mass somewhere on the interval $(\bar{r}, 1]$. However, since $\bar{r}$ is endogenous we exclude it from the statement of this assumption by assuming more specifically that $\mathrm{d}F(1)/\mathrm{d}r > 0$ and $\mathrm{d}F^*(1)/\mathrm{d}r > 0$ i.e., there is mass near $r = 1$ in both countries. Also, we need first order stochastic dominance to hold strictly in at least one point where it directly matters to the principal i.e., in at least one point below $\bar{r}$. We again exclude the endogenous $\bar{r}$ from the statement of the assumption by assuming more specifically that $\mathrm{d}F(0)/\mathrm{d}r > \mathrm{d}F^*(0)/\mathrm{d}r$ i.e., there is more mass near $r = 0$ in China. Note that this last assumption implies that $F(\bar{r}) > 0$ i.e., some Chinese agents are involved in innovation.

All our results refer to diversified equilibria, that is, equilibria in which both countries produce both goods. (See the appendix for a discussion of what is required for this to be the case.) While Indonesian agents produce autos in equilibrium, they need not be involved in incremental innovation. We can now state our first result about the key equilibrating mechanism $w$.

**Proposition 2** (Cross-country wage differences) *Suppose $F^* \succ_{FOSD} F$. Then in any diversified equilibrium, auto wages are higher in China than in Indonesia, $w > w^*$.*

***Proof*** Suppose, contrary to proposition 2, that $w \leqslant w^*$. Differentiating equation (17) yields $\partial \mathbf{E}U_p(w, F)/\partial w = -[1 - F(\bar{r})]/4P$.[12] By assumption, $F$ places positive mass in the neighbourhood of $r = 1$ so that $F(\bar{r}) < 1$ and $\partial \mathbf{E}U_p(w, F)/\partial w < 0$. Hence $w \leqslant w^*$ implies $\mathbf{E}U_p(w, F) \geqslant \mathbf{E}U_p(w^*, F)$. Let

$$u_p(r, w) = \begin{cases} \mathbf{E}U_p^{AI}(r) = \frac{1}{2}\frac{(1-\lambda)\pi}{P}(1 - r) & \text{for } r < \bar{r}, \\ \mathbf{E}U_p^{PI}(w) = \frac{1}{4}\frac{\pi - w}{P} & \text{for } r \geqslant \bar{r}. \end{cases} \tag{19}$$

(See equations 8 and 10.) Note that $u_p(r, w)$ is a non-increasing function of $r$ and is strictly decreasing on $[0, \bar{r})$. Since $F^* \succ_{FOSD} F$, the definition of first-order stochastic dominance implies $\mathbf{E}U_p(w^*, F) = \int_0^1 u_p(r, w^*)\mathrm{d}F(s) > \int_0^1 u_p(r, w^*)\mathrm{d}F^*(s) = \mathbf{E}U_p(w^*, F^*)$. Strict inequality comes from the fact that, by assumption, $\mathrm{d}F(0)/\mathrm{d}r > \mathrm{d}F^*(0)/\mathrm{d}r$, which means that there is a subinterval on which both $F^* < F$ and $u_p$ is strictly decreasing. Combining $\mathbf{E}U_p(w, F) \geqslant \mathbf{E}U_p(w^*, F)$ with $\mathbf{E}U_p(w^*, F) > \mathbf{E}U_p(w^*, F^*)$ implies $\mathbf{E}U_p(w, F) > \mathbf{E}U_p(w^*, F^*)$, a violation of equation (18). Hence $w > w^*$. $\square$

The basic insight is straightforward. Consider the top panel of figure 1. It plots the expected utility for principals facing different values of residual incompatibilities $r$ in China (solid line) and Indonesia (dashed line). That is, the solid line plots $u_p(r, w)$, which equation (19) defines as $\mathbf{E}U_p^{AI}(r)$ to the left of $\bar{r}$ and $\mathbf{E}U_p^{PI}(w)$ to the right of $\bar{r}$. The dashed line is the corresponding curve for Indonesia, $u_p(r, w^*)$. Note that $\mathbf{E}U_p(w, F)$ and $\mathbf{E}U_p(w^*, F^*)$ are integrals over $r$ of these curves. A core feature of the principal's problem is that her expected utility is decreasing in $r$ under agent innovation. This reflects the fact that the principal prefers working with an agent whose involvement

[12] We are using the fact that $\bar{r}(w)$ is defined to satisfy $\frac{1}{2}(1 - \lambda)\pi(1 - \bar{r}) = \frac{1}{4}(\pi - w)$. Thus, the derivative of $\mathbf{E}U_p(w, F)$ with respect to $\bar{r}$ is zero.

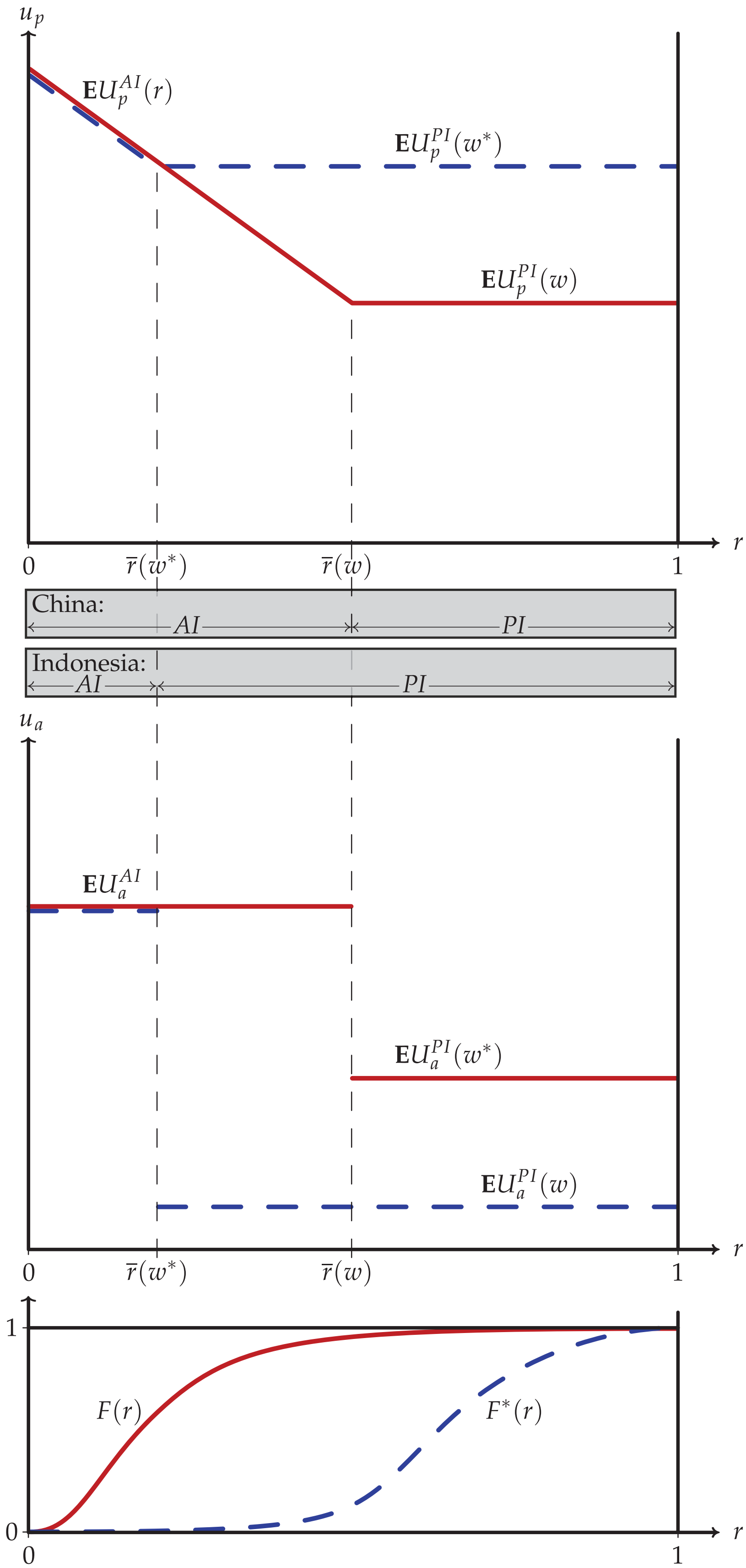


**Figure 1**. Principals' utility, agents' utility and distribution of residual incompatibilities

in innovation creates fewer residual incompatibilities. Since, as illustrated in the bottom panel of figure 1, Indonesia's distribution of residual incompatibilities $F^*$ first order stochastic dominates China's $F$, if $w = w^*$ then each principal would strictly prefer China over Indonesia. To ensure that each principal is *ex-ante* indifferent between locating in these two countries, lower wages are needed in Indonesia to offset the higher expected residual incompatibilities.

***The involvement of Chinese and Indonesian agents in innovation***

We now show that the smaller expected residual incompatibilities created by Chinese agents imply that a higher fraction of Chinese agents is involved in innovation. More remarkably, even among agents who create identical residual incompatibilities, Chinese agents are more involved in incremental innovation than their *identical* Indonesian counterparts.

**Proposition 3** (General equilibrium involvement in innovation) *Suppose $F^* \succ_{FOSD} F$. Then in any diversified equilibrium $\bar{r}(w) > \bar{r}(w^*)$. This implies the following. (1) Chinese agents have a higher probability of being involved in incremental innovation than Indonesian agents. (2) Consider a Chinese match and an Indonesian match that have identical residual incompatibilities $r$ with $\bar{r}(w^*) < r < \bar{r}(w)$. Then only the Chinese agent will be involved in incremental innovation. The Indonesian agent will not be. Further, the Chinese agent will be paid more and have higher utility than the Indonesian agent.*

***Proof*** By equation (12), $\partial\bar{r}(w)/\partial w > 0$. By proposition 2, $w > w^*$, so that $\bar{r}(w) > \bar{r}(w^*)$. Consider part (1). Since $\bar{r}(w) > \bar{r}(w^*)$, first order stochastic dominance implies that $F$ places more mass on the interval $[0,\bar{r}(w))$ than $F^*$ places on the interval $[0,\bar{r}(w^*))$. That is, Chinese agents have a higher probability of being involved in innovation. Consider part (2). The result that only the Chinese agent will be involved in incremental innovation follows immediately from proposition 1 and $\bar{r}(w^*) < r < \bar{r}(w)$. Regarding utility and income, agents' voluntary participation in innovation implies that $\mathbf{E}U_a^{AI}(w) \geqslant \mathbf{E}U_a^{PI}(w)$ (see lemma 1). Since $w > w^*$, $\mathbf{E}U_a^{PI}(w) > \mathbf{E}U_a^{PI}(w^*)$. Hence, $\mathbf{E}U_a^{AI}(w) = \frac{1}{4}\frac{\lambda\pi}{P} > \frac{1}{2}\frac{w^*}{P} = \mathbf{E}U_a^{PI}(w^*)$, i.e., the Chinese agent has higher utility. Consequently, $\lambda\pi > w^*$, i.e., the Chinese agent is paid more. □

Part (2) of proposition 3 and to some extent part (1) operate through the endogenous general equilibrium wage differences between China and Indonesia. Agents performing basic auto tasks are paid more in China than in Indonesia so that the additional monetary cost of including workers in incremental innovation is lower in China ($\lambda\pi - w < \lambda\pi - w^*$). Thus, the maximum residual incompatibilities under which agents are involved in incremental innovation is also higher in China: $\bar{r}(w) > \bar{r}(w^*)$. Therefore, even agents who create *identical* residual incompatibilities are more involved in incremental innovation in China than in Indonesia. This is a general equilibrium effect and it highlights that the cost of protecting intellectual property rights depends not only on formal institutions but also on income levels. Here formal institutions are part of what determines $\lambda$, the share of profits that agents can capture by threatening to run away with the knowledge acquired while involved in incremental innovation. We have assumed that $\lambda$ is the same in China and Indonesia. Nevertheless, the lower wage for workers performing basic auto tasks in Indonesia means that Indonesian workers have to be paid a higher earnings premium not to try to appropriate the profits from a successful incremental innovation. As a result, workers with a value of $r$ that would have seen them involved in incremental innovation in China are kept out of the innovation process in Indonesia.

We could easily introduce institutional differences across countries by having $\lambda$ differ between China and Indonesia. In that case, a higher $\lambda$ would reduce $r$ (see equation (12)) and, through general equilibrium interactions, also wages (by a similar argument to proposition 2) and the share of auto firms locating in the country (by a similar argument to proposition 4 below). Thus countries with weaker protection of intellectual property (higher $\lambda$) are less involved in incremental innovation, have lower income, and attract less foreign direct investment.

***The location of American principals***

The better distribution of Chinese agents makes China a more attractive location than Indonesia for the same wages. However, wages are lower in Indonesia and this offsets China's advantage from the point of view of principals. We now wish to see how the trade-off between a better distribution of agents in China and lower wages in Indonesia plays out for the relative number of principals in each country.

In principle, to determine the relative number of principals in each country we would need to worry about the effects of free entry. To understand why, suppose that initially China and Indonesia are identical and that we then improve the Chinese distribution. Start by holding the number of US principals fixed. Then US principals move from Indonesia to China and $w$ rises relative to $w^*$. This raises the returns to Chinese agents in the auto sector, leading to a migration of Chinese workers from the apparel to auto sectors. Because of diminishing returns in apparel production, this also raises the Chinese apparel wage $w_A(L-m)$. Conversely, Indonesian workers migrate from the auto to apparel sectors, thus depressing Indonesian apparel wages $w_A(L-m^*)$. Now allow entry of US principals. The improvement in the Chinese distribution together with falling wages in Indonesia make *both* locations more attractive to US principals. This should lead to entry of US principals, which in turn should reduce profits. The next proposition states that, no matter what happens to profits or the total number of US principals (recall that we have not determined either of these), China must end up with more than half of all principals.

**Proposition 4** (Location of American principals) *Suppose $F^* \succ_{FOSD} F$. Then in any diversified equilibrium, more American principals locate in China than in Indonesia, $m > m^*$.*

***Proof*** Differentiating equation (14) yields

$$\frac{\partial \mathbf{E}U_a(w,F)}{\partial w} = \frac{1}{2P}[1-F(\bar{r})] + \left[\frac{1}{4}\frac{\lambda\pi}{P} - \frac{1}{2}\frac{w}{P}\right]\frac{\mathrm{d}F(\bar{r})}{\mathrm{d}\bar{r}}\frac{\partial\bar{r}}{\partial w}\,. \tag{20}$$

By assumption, $F$ places positive mass in the neighbourhood of $r=1$ so that $F(\bar{r})<1$. The term in brackets, $[\lambda\pi/4P - w/2P]$, is $\mathbf{E}U_a^{AI}(w) - \mathbf{E}U_a^{PI}(w)$ which is non-negative (otherwise the agent would turn down the principal's request to assist in innovation). Since $F$ is a cumulative density function, $\mathrm{d}F(\bar{r})/\mathrm{d}\bar{r} \geqslant 0$. By equation (12), $\partial\bar{r}/\partial w > 0$. Hence, $\partial \mathbf{E}U_a(w,F)/\partial w > 0$. By proposition

2, $w > w^*$ so that $\mathbf{E}U_a(w, F) > \mathbf{E}U_a(w^*, F)$. Let

$$u_a(r, w) = \begin{cases} \mathbf{E}U_a^{AI} = \frac{1}{4}\frac{\lambda\pi}{P} & \text{for } r < \bar{r}, \\ \mathbf{E}U_a^{PI}(w) = \frac{1}{2}\frac{w}{P} & \text{for } r \geqslant \bar{r}. \end{cases} \tag{21}$$

Note that, by lemma 1, $u_a(r, w)$ is a non-increasing function of $r$. Since $F^* \succ_{FOSD} F$, the definition of first-order stochastic dominance implies $\mathbf{E}U_a(w^*, F) = \int_0^1 u_a(r, w^*)\mathrm{d}F(s) \geqslant \int_0^1 u_a(r, w^*)\mathrm{d}F^*(s) = \mathbf{E}U_a(w^*, F^*)$. Combining this inequality with $\mathbf{E}U_a(w, F) > \mathbf{E}U_a(w^*, F)$ implies $\mathbf{E}U_a(w, F) > \mathbf{E}U_a(w^*, F^*)$. From equations (15) and (16),

$$\frac{w_A(L - m)}{P} = \mathbf{E}U_a(w, F) > \mathbf{E}U_a(w^*, F^*) = \frac{w_A(L - m^*)}{P}\,. \tag{22}$$

or

$$w_A(L - m) > w_A(L - m^*). \tag{23}$$

By diminishing returns to labour $w_A' < 0$. Hence $m > m^*$. □

**Corollary 4.1** (Apparel wages and utility) *Suppose $F^* \succ_{FOSD} F$. Then in any diversified equilibrium, wages in the apparel sector are higher in China than in Indonesia, $w_A(L - m) > w_A(L - m^*)$, and expected utility in both the apparel and auto sectors is higher in China than in Indonesia.*

The basic insight works off the agent's indifference between the apparel and auto sectors. Consider the middle panel of figure 1, which is the agent's counterpart to the top panel. It plots the expected utility for agents facing different values of residual incompatibilities $r$ in China (solid line) and Indonesia (dashed line). That is, the solid line plots $u_a(r, w)$, which equation (21) defines as $\mathbf{E}U_a^{AI}$ to the left of $\bar{r}$ and $\mathbf{E}U_a^{PI}(w)$ to the right of $\bar{r}$. The dashed line is the corresponding curve for Indonesia, $u_a(r, w^*)$. Note that $\mathbf{E}U_a(w, F)$ and $\mathbf{E}U_a(w^*, F^*)$ are integrals over $r$ of these curves.

Since Chinese agents are paid more than Indonesian agents under principal innovation ($w > w^*$), the Chinese profile lies above the Indonesian profile for $r > \bar{r}(w)$. Moving left of $r = \bar{r}(w)$ the profile jumps up because of the agent's participation constraint. This raises the Chinese profile even higher above the Indonesian profile in the interval $r \in [\bar{r}(w^*), \bar{r}(w)]$. Thus, Chinese agents are better off than Indonesian agents both because they have a higher profile and because the Chinese distribution puts more weight on the higher outcomes to the left. In other words, Chinese agents are better off than Indonesian agents for two reasons. First, because they are involved in incremental innovation activities more often and these yield an earnings premium. Second, because when they are not involved in innovation they get a higher wage than their Indonesian counterparts. Since an agent's returns must be equalized across the apparel and auto sectors, Chinese apparel wages $w_A(L - m)$ must also be higher than Indonesian apparel wages $w_A(L - m^*)$. In general equilibrium, for wages to be higher in China, there must be more agents and hence more American principals in China than in Indonesia i.e., $m > m^*$. As a corollary, higher Chinese apparel wages also imply that utility in the apparel sector is higher in China than in Indonesia i.e., $w_A(L - m)/P > w_A(L - m^*)/P$. Finally, since agents are indifferent between sectors, expected utility in the auto sector must also be higher in China than in Indonesia.

Notice that a larger share of principals go to where agents are most expensive. This result never occurs in standard product-cycle models where US principals always locate in the lowest-wage country. In our model US firms take into account wages *and* the ability of local agents to participate in incremental innovation. In general equilibrium, there are sufficient additional principals in China relative to Indonesia to make wages differ just enough to offset China's advantages in incremental innovation. These advantages stem from the lower average residual incompatibilities created by Chinese agents and also from the lower general equilibrium earnings premium Chinese agents must be paid to prevent them from walking away. Higher wages and greater chances of becoming involved in incremental innovation attract more Chinese nationals into the auto sector, where they are better off than their Indonesian counterparts. Note also that the higher income and welfare of Chinese agents are driven by more than just China's lower average residual incompatibilities. Open-economy general equilibrium wage adjustments are central. In fact, to use standard international trade terminology, there is no conditional factor price equalization: agents who create identical residual incompatibilities can end up involved in incremental innovation and earning a premium in China but not in Indonesia.

***Production patterns and trade flows***

We finally establish the pattern of world production and trade flows. Since China has a larger number of American investments, China has more auto production and less apparel production than Indonesia. These production patterns together with identical homothetic preferences imply the following result about equilibrium trade flows.

**Corollary 4.2** (Trade flows) *Suppose $F^* \succ_{FOSD} F$. Then in any diversified equilibrium the United States imports more autos from China than from Indonesia and imports more apparel from Indonesia than from China. The United States finances this trade deficit with a capital account surplus against both China and Indonesia. This capital account surplus is comprised of repatriated auto profits from local operations.*

Several elements stand out from this analysis. First, we have not completely specified all equilibrium trade flows, only the novel parts. For this, once again, we did not need to make any assumptions about preferences over the different goods beyond homotheticity. Nor did we need to specify market structure or the entry process for principals. For a complete specification of trade flows, more structure is needed. For example, suppose we assume that apparel is a homogeneous good with a perfectly competitive market structure and that autos are differentiated goods with a symmetric monopolistic competition market structure. Then, in addition to what is established in corollary 4.2, China and Indonesia both export autos to each other and China is a net auto exporter to Indonesia. Further, Indonesia exports apparel both to the United States and China. China exports apparel to the United States only if China is sufficiently large relative to the United States. In this case, China does not import apparel from Indonesia.

Second, in most international trade models the current account must be balanced. In fact, the balanced-trade condition is usually a central modelling ingredient that forces most of the interesting general equilibrium interactions. In contrast, in general equilibrium in our model we have China and Indonesia running a current account surplus against the United States and have the United States running a capital account surplus against China and Indonesia. This allows us to deal with a central feature of the international trading system: there is a huge one-way movement of royalty and innovation-related business-service payments from developing to developed countries.

## 5. From the product cycle to the rise of innovation in low-wage countries

In January 1992, China's Deng Xiaoping visited the nascent special economic zone of Shenzhen as part of his now famous *Nanxun* or Southern Tour. His purpose was revolutionary — to praise the efficiency of capitalist firms operating in this and similar zones. He announced the expansion of the export-processing zone program and the liberalization of the foreign investment regime to allow more foreign companies to operate in China. The rest is history. The new investment regime has led to massive entry of foreigner entrepreneurs into Chinese manufacturing. In addition, as shown in the introduction, Chinese manufacturing facilities are increasingly moving beyond the production of mature goods and getting more and more involved in incremental innovation. In this section, we examine the consequences of China's opening up to foreign investment.

Consider a world in which initially all American principals locate in Indonesia because they are not allowed into China. Suppose now that Deng Xiaoping makes his Southern Tour and American principals are allowed to enter China. Once China opens up, what is the equilibrium distribution of American principals between China and Indonesia, to what extent are agents in each country involved in innovation, and what are the consequences of this for income levels and trade patterns? To determine all of this, we must finally deal with free entry of US principals. Given that we are nearing the end of this paper, we avoid modelling details. Suppose that US nationals choose between being principals in the auto sector and working in an alternative occupation. Rather than fully modelling the alternative occupation and providing details about auto-sector market structure and profits, we make two assumptions that come out of most, if not all, standard models. We assume that entry of principals into the auto sector lowers profits $\pi$ and increases principals' earnings in their alternative occupation. This allows us to establish the following results about the consequences of China's entry.

**Proposition 5** (The consequences of China's opening up) *Suppose $F^* \succ_{FOSD} F$. Further assume that entry of principals lowers $\pi$ and raises principals' earnings in their alternative occupation. Suppose that, starting from an initial situation where all American principals locate in Indonesia because they are not allowed into China, China opens up to American firms. Once American principals are allowed to enter China, in any diversified equilibrium, Indonesia ends up with fewer American principals and lower wages in both sectors than before China's opening up to American firms. China ends up with more principals than Indonesia and with higher wages in both sectors. Chinese agents are involved in incremental innovation more often than their Indonesian counterparts. Even agents creating residual incompatibilities $r \in (\bar{r}(w^*), \bar{r}(w))$ are involved in innovation in China but not in Indonesia.*

***Proof*** Initially, Indonesia hosts all principals. After China's opening to American principals, by proposition 4, Indonesia hosts less than one half of all principals. If the total number of principals has not increased, Indonesia must have fewer principals than before. We next show that the same result holds even if the total number of principals increases following China's opening. By assumption, entry of principals increases their earnings in the alternative occupation. To reestablish indifference of US nationals between becoming principals and engaging in an alternative occupation, $\mathbf{E}U_p(w^*, F^*)$ must be higher than before China's opening. By assumption, entry of principals lowers auto sector profits $\pi$. By equation (17), this tends to reduce $\mathbf{E}U_p(w^*, F^*)$. Thus, the only way for $\mathbf{E}U_p(w^*, F^*)$ to end up being higher than before China's opening is by having auto wages in Indonesia $w^*$ fall (recall that $\mathbf{E}U_p(w^*, F^*)$ is decreasing in $w^*$). Recall that $\mathbf{E}U_p(w^*, F^*)$ is increasing in $w^*$, so the reduction of auto wages in Indonesia makes Indonesian agents worse off. By equation (14) so does the fall in profits. Thus, to keep Indonesian nationals indifferent between being agents in the auto sector and working in their alternative occupation in the apparel sector, Indonesian apparel wages $w_A(L - m^*)$ must also fall. Since $w'_A < 0$, this implies that the number of principals operating in Indonesia $m^*$ is lower after than before China's opening. The higher Chinese wages and the greater Chinese involvement in innovation follow from propositions 2 and 3. □

Prior to China's entry, the world looks close to a product cycle model: most innovation is done in the United States and the production of the standardized good is done in Indonesia. After China's opening up to American investments, most American firms locating in Indonesia and some of those locating in China continue this product-cycle pattern of developed-country innovation followed by low-wage standardized production. However, many American firms begin involving their Chinese agents in incremental innovation. These were precisely the patterns implied by our numbers on first locations of innovative new products and on patents in the introduction.

The appearance of China on the world scene has a negative impact on investment in Indonesia. Notice that the proposition does *not* state that China's entry into world markets reduces Indonesian welfare. We have not tracked any of the traditional gains from trade so it is still possible that Indonesia benefits from China's entry. Our main point is simply that these traditional gains from trade for Indonesia will be offset, at least in part, by the departure of American principals from Indonesia. This problem has been commented on by many in the press who point out that many firms are moving operations to China from other low-wage countries such as Indonesia and Mexico (note Mexico's declining share of exports of innovative new goods by value to the United States in table 1).

## 6. Conclusions

To our mind, a central feature behind the recent success of China and India in international markets has been the ability of these countries to deliver shop-floor incremental innovation to foreign buyers operating complex supply chains. Firms in rich countries need their suppliers to produce high-quality goods — goods that are reliable, have low failure rates and incorporate the latest demands of an ever-changing marketplace.

In the old product-cycle view, all innovation, including incremental innovation, is done in the North. The Northern-designed factory is shipped to the South without any ensuing technical problems. However, the claim that all innovation is done in the North is no longer tenable. We provided the first systematic evidence on incremental innovation in low-wage countries using data on the location of first production for innovative new goods and data on patents developed by low-wage country inventors for US corporations.

In our view, and that of Sutton (2001), countries have a capacity to deliver a quality level. If this capacity is above a certain threshold then the country becomes a player in international trade. In our model this threshold is the level of residual incompatibilities $\bar{r}$ that demarcated matches that involve local agents in innovation from those that do not. This resulted in a model in which the heterogeneity of matches induced a heterogeneity of incremental innovation across countries and even within countries.

Differences across countries are due to differences in the distribution of residual incompatibilities i.e., due to differences between $F$ and $F^*$. Improvements in information and communication technologies will allow principals to better communicate with agents and reduce residual incompatibilities everywhere. Thus, we expect to se a trend where product-cycle trade is replaced to some extent by trade in which agents are involved in incremental innovation and new products are first produced in low-wage countries. However, some countries such as China and India have developed world-class engineering schools, send more students for training to the United States, have a more committed diaspora, emphasize standards and quality control, or get a head-start in working with foreign multinationals by developing products catered to a particularly large local market. All of these developments shift the distribution of matches in these countries towards lower values of residual incompatibilities much faster, and serve to simultaneously attract more foreign firms and to increase the proportion of those firms that involve locals in innovation relative to other low-wage countries. As a result, the liberalizing of the international trade regime in China and India has led to a vast inflow of foreign investments into these countries. This has led to the growth of increasingly sophisticated, high-quality Chinese and Indian exports. It has also led to problems for countries such as Indonesia and Mexico that were once the major recipients of Western FDI.

The rise of incremental innovation in some low-wage countries is today a central fact. This paper is the first to explain its implications for international trade. As we have shown, the implications are huge — it's time to wake up and smell the ginseng.

## Appendix

### *Parameter restrictions*

Our analysis has focused on the richest possible case in which agent innovation and principal innovation can both arise for some values of $r$, agents willingly participate in innovation when asked, and production remains diversified in both China and Indonesia. This appendix discusses what is required to ensure this. By proposition 1, a principal chooses agent innovation over principal innovation if and only if $r < \bar{r}$. Since $r \in [0,1]$, with $\bar{r} < 0$ a principal would prefer principal innovation for all $r$, while with $\bar{r} > 1$ a principal would prefer agent innovation for all $r$. Thus, agent innovation and principal innovation are both possible preferred choices for a principal for some values of $r$ if and only if $0 < \bar{r} < 1$, where $\bar{r}$ is given by proposition 1. This requires $0 < 1 - \frac{1}{2}\frac{1-w/\pi}{1-\lambda} < 1$. As shown in lemma 1, agents always accept this choice if and only if $\frac{\lambda\pi}{w} \geqslant 2$. These two conditions put together reduce to $1 - 2\lambda < \frac{w}{\pi} \leqslant \frac{\lambda}{2}$. For this to be satisfied, we must have $1 - 2\lambda < \frac{\lambda}{2}$, which simply requires $\lambda < \frac{2}{5}$. In addition, we need $\frac{w}{\pi}$ to fall somewhere in the interval $(1 - 2\lambda, \frac{\lambda}{2}]$. From equations (15) and (16), we know that the agent's wage $w$ is directly related to the wage in the alternative apparel sector $w_A$. Thus, by changing the endowment of (apparel-sector) land we can always shift $w_A$ so that $\frac{w}{\pi}$ lies in the required interval. Finally, we have also focused on situations in which both China and Indonesia keep some production in the auto and the apparel sectors. This is akin to the usual restriction in trade models of being inside the cone of diversification. In our case, it simply requires a sufficiently high elasticity of the apparel-sector wage with respect to employment.

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