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WAKE UP AND SMELL THE GINSENG:
THE RISE OF INCREMENTAL INNOVATION
IN LOW-WAGE COUNTRIES

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ABSTRACT

Increasingly, a small number of low-wage countries such as China and India are involved in innovation -- not 'big ideas' innovation, but the constant incremental innovations needed to stay ahead in business. We provide some 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. We explain why levels of involvement in innovation vary across low-wage countries and even across firms within each low-wage country. We then draw out implications for the location of production, trade, capital flows, earnings and living standards.

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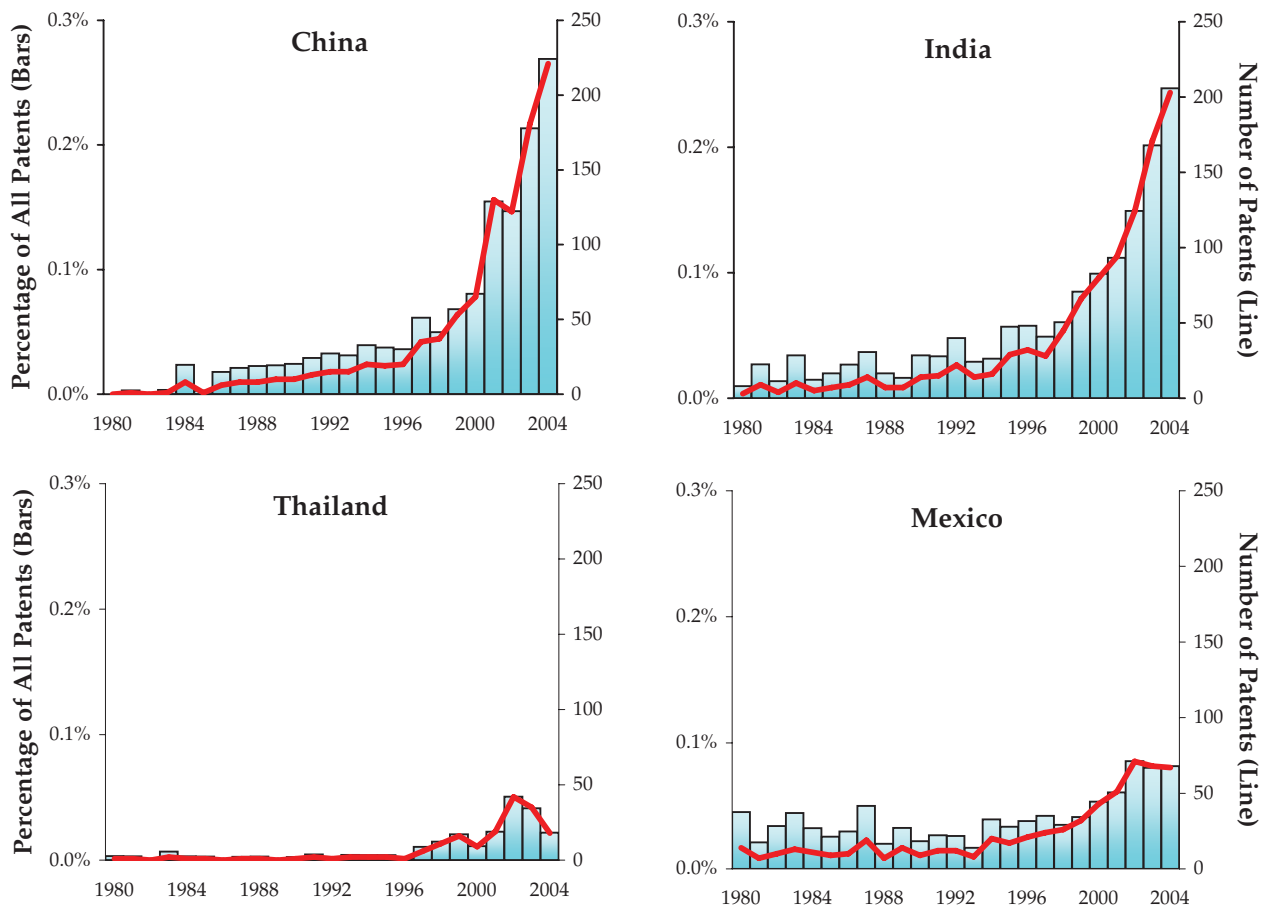
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1. Introduction

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) unsung hero of modern economic growth. This paper is about the rise of incremental innovation in some low-wage countries and how it is revolutionizing the ability of these countries to export high-quality and increasingly sophisticated manufactured goods.

In an attempt to track incremental innovation in low-wage countries we have turned to the US patent database. 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. The top left panel of figure 1 tracks those patents with at least one Chinese inventor. The solid line gives the absolute number of such patents and the bars express this number as a percentage of all US-owned patents. Three features stand out. (1) In recent years there has been an explosion of US-owned patents involving Chinese and Indian inventors. This reflects the increasing role played by these low-wage countries in developing incremental innovations for US corporations. (2) In contrast, Thailand (and many other low-wage countries) have barely been touched by this tide of incremental innovation. (3) Since 2002, patenting has plateaued in Mexico (and some other popular FDI destinations in Eastern Europe and Latin America) as companies such as Delphi have shifted production to China.

Incremental innovation in low-wage countries is not part of the lexicon of international trade. 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



Notes: Bars (left-hand scale) indicate the *percentage* of us-owned patents with at least one inventor who is a resident of the indicated country. Lines (right-hand scale) indicate the *total number* of us-owned patents with at least one inventor who is a resident of the indicated country. Source: Authors' calculations from the United States Patent and Trademark Office website (<http://www.uspto.gov/>).

Figure 1. Share of us-Owned Patents with a Foreign Inventor

offshore to low-wage countries. (See also Krugman, 1979, and the more sophisticated approach of Antràs, 2005.) Grossman and Helpman (1991*b,c*) allow for active knowledge acquisition in low-wage countries. However, this is imitation rather than the incremental innovation of figure 1. To advance beyond the product cycle, we provide a general equilibrium theory of the determinants and implications of incremental innovation in low-wage countries. The theory is centred on a firm's decision to involve local agents in innovation.

One benefit of local involvement is that it allows firms 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. Thus, for ex-

ample, 3com's 8800 high-end network switch and Nokia's 6108 handset were first produced in China with substantial design done locally. Such local involvement can reduce innovation costs as well as production costs at early stages of the product-cycle. A second 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 very difficult for the firm to identify from the outside. These additional improvements allow firms such as Delphi to stay a hair's breadth ahead of the competition.

Against these benefits are some big negatives of involving local agents in incremental innovation. First, the agent's ideas are necessarily different from those of the firm. While differences in ideas are partly a positive in that they allow the firm to exploit additional improvements, they are also partly a negative. In particular, local agents typically supply parts or 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 a parts supplier does not internalize all of the 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. There is a second more familiar cost of involving local components suppliers in incremental innovation. Once the firm involves the local agent in incremental innovation, the agent acquires information and expertise which can be used outside the relationship. This raises the agent's outside option. Therefore, local agents who are involved in an incremental innovation must be paid more. This earnings premium is a cost and the firm must decide if it is justified by the benefits of involving the local agent in incremental innovation.

These costs and benefits of involving local agents in incremental innovation give rise to our theory of when and why product-cycle trade is replaced by trade involving in-

cremental innovation in some low-wage countries. The theory uses the twin concepts of residual incompatibilities and earnings premia to predict which low-wage countries will be involved in incremental innovation and at what level of intensity. The theory embeds the above logic of a single firm and a single local agent into a general equilibrium model of world trade in which incremental innovation drives comparative advantage. This allows us to explain the three features of figure 1 listed above. It also allows us to explain recent developments in international trade that have coincided with the rise of China and India. In particular, while most trade involving countries such as Indonesia, the Philippines and Thailand continues to be product-cycle trade, other countries such as China and India are slowly moving towards trade that embodies local incremental innovation. As noted by Sutton (2001, 2004), this innovation is crucial for understanding the exporting success of China and India.

The paper is organized as follows. The remainder of the introduction provides a literature review as well as a concrete example of residual incompatibilities. Sections 2–3 describe the firm’s problem while sections 4–5 set this problem within a general equilibrium model in order to discuss international trade issues.

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 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) and Trefler (2005) 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, (ii) whether to involve a local agent in incremental innovation, and if so, (iii) whether to delegate control of incremental innovation decisions to the local agent. Notice that we are silent on whether we are dealing with FDI or offshore outsourcing. What matters to us is whether incremental innovation is being done and who controls it.

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 (2005). Weak contract enforcement is one of several possible sources of the earnings premium discussed above. Ethier and Markusen (1996) are interested in the choice between exporting and producing abroad. 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 incremental innovation.

Finally, our paper builds on Aghion and Tirole's (1997) discussion of formal versus real authority inside a firm. In their framework, an agent who is sufficiently better

informed may have real authority despite not having formal authority inside a firm. The principal may retain her authority by gathering better information, but the threat of being overruled by the principal will stifle the agent's initiative. When applied to incremental innovation, this suggests that the intensity of innovation can be increased by delegating control of innovation decisions to an agent. Puga and Trefler (2002) develop this insight in a closed-economy, partial equilibrium model of the internal organization of the firm. They use this model to explain changes in the organization of Sony's cathode ray tube (CRT) production arrangements in the United States in 1997 and Boeing's decision to change its management structure and relocate its corporate headquarter to a city where it had no production facilities in 2001. Marin and Verdier (2002) use the Aghion and Tirole framework to discuss the impact of reduced profit margins on the allocation of power inside firms. Marin and Verdier (2003) combine this with trade-induced changes in factor prices to predict a cross-country convergence to flatter corporate hierarchies.

Residual incompatibilities: An example

Residual incompatibility is a core concept for what follows. It is a measure of the costs imposed on one party (the principal or agent) by the innovative efforts of the other party (the agent or principal). To illustrate the role of residual incompatibilities, consider the key component of a television, namely, the cathode ray tube (CRT).¹ A CRT is basically an electron gun aimed at the phosphor-coated front screen of a glass vacuum tube (see figure 2). In the early 1990s, rising consumer preferences for flatter screens created a tension between electron-gun manufacturers such as Sony and vacuum tube manufacturers such as Asahi Glass. The starting point for Asahi Glass is that domes are better than flat surfaces at withstanding the implosion forces of the vacuum tube. Asahi would thus prefer the solution for a flat-screen CRT illustrated in figure 2, in which the CRT screen is flat from the viewer's perspective, but domed from the electron gun's perspective. This is far simpler from a glass manufacturer's point of view than increasing the physical strength of the glass. Sony would prefer a flat screen from the perspective of both the viewer and the

¹This example is discussed in more detail in the context of Puga and Trefler's (2002) analysis of changes in the organization of Sony's CRT production in 1997.

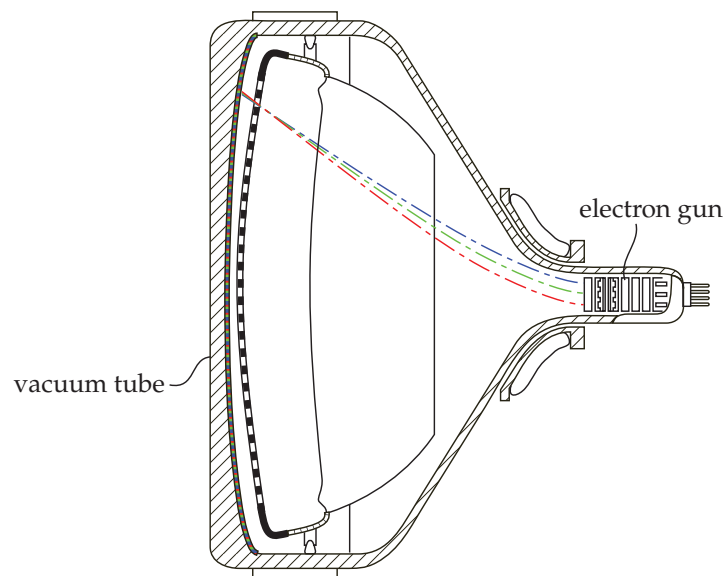


Figure 2. Section of a cathode ray tube

gun because the variable thickness of the glass creates a prism effect that reduces the sharpness of the picture. This distortion can only be remedied by modifying the electron gun. However, unless it designs the vacuum tube itself, Sony does not know the extent to which differences in glass thickness can be safely reduced and at what cost (see us patent 6,121,723, awarded to Asahi Glass in 2000, for a discussion of how excessively reducing differences in thickness increases the risk of implosion). Likewise, Asahi does not know precisely the extent to which modifications to the electron gun can compensate for the varying thickness of the glass and at what cost. Asahi does not fully internalize the costs that its solution imposes on Sony while Sony does not fully internalize the costs that its solution imposes on Asahi. In our terminology, the solutions of Asahi and Sony create residual incompatibilities.

2. Set-up

We have in mind a situation in which a us firm with an existing product that it produces in China sets out to improve it with an *incremental* process or product innovation. Changing market conditions associated with changes in consumer preferences, available technologies, environmental regulations and the evolution of competitors force the us firm to

respond by incrementally improving the product or its production process. We refer to the American firm as the principal, denoted by 'she' or a subscript p . We refer to the Chinese partner 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 or why she has decided to produce abroad. Nor are we concerned here with the mode of entry into China. For our purposes the Chinese agent 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

Turning to the principal-agent problem, for a product to be improved there must be a blueprint for incremental innovation. The American principal can develop the blueprint in the United States and ask the Chinese agent merely to implement it. Alternatively, the American principal can involve the Chinese agent in developing a blueprint. Developing blueprints requires 'innovation' effort. 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 the development of one or more blueprints with probability e_i and to no blueprints with probability $1 - e_i$. There are two key advantages of involving the Chinese agent in incremental innovation. First, local involvement brings fresh ideas to the table, thus increasing the probability of developing a blueprint. Second, local involvement allows the American firm to replace some of her innovation effort with that of her Chinese agent.

There are, however, two disadvantages of involving the Chinese agent in developing a blueprint. First, as in the Sony-Asahi CRT example, a blueprint designed by one party creates residual incompatibilities for the other party. Resolving these residual incompatibilities requires 'debugging' effort by the non-designing party. We assume that the amount

of debugging effort d_i that must be exerted by the non-designing party is decreasing in s where $s \in (0,1)$ is a measure of the similarity of American-developed and Chinese-developed blueprints. (s is for ‘similarity.’) A high value of s captures the notion of low residual incompatibilities and hence of low levels of debugging effort. We also assume that debugging effort is decreasing in e_i since the larger is e_i the more familiar is i with the technical problems at hand. In particular,

$$d_i = \begin{cases} 0 & \text{if } i\text{'s blueprint is implemented,} \\ (1-s)(1-e_i) & \text{if } j\text{'s blueprint is implemented,} \end{cases} \quad (1)$$

For simplicity, we assume that debugging effort is the only characteristic distinguishing blueprints so that, once successfully developed and debugged, all blueprints yield the same total profit. For simplicity, any successfully developed and debugged blueprint allows production of one unit of output with no additional inputs required other than those provided by the principal and the agent.

In addition to residual incompatibilities, there is a second ‘earnings premium’ disadvantage to involving the Chinese agent in developing a blueprint. To develop a blueprint, 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.

The agent’s opportunities outside the relationship are determined by two components: an *endogenous* component that depends on the equilibrium demand for agents and an *exogenous* component that depends on the legal protections afforded to the American principal. The appendix endogenously models the first component. For simplicity, however, in the main text we only model the second (exogenous) component. We do this as follows.

Due to the public goods nature of knowledge that Arrow (1962) emphasized, when knowledge is jointly created it is not possible for an outside observer such as a court to

accurately disentangle the relative contributions of each innovator. Thus, after a blueprint is developed both the principal and the agent can each reasonably claim to have been the primary inventor.² We assume that legal challenges by both the agent and principal are costlessly available and that in the event of a legal challenge, the court awards an exogenous fraction λ of operational profits to the agent and a fraction $1 - \lambda$ to the principal. (Equivalently, one can think of λ as the probability that the court awards all operational profits to the agent.) Letting π be operational profits, it follows that if the agent is involved in an incremental innovation then he receives $\lambda\pi$ and the principal receives $(1 - \lambda)\pi$. For if the agent receives less than $\lambda\pi$ he initiates legal proceedings and if the agent receives more than $\lambda\pi$ the principal initiates legal proceedings.³

Let w be the wage paid to the agent when the agent is not involved in an incremental innovation, that is, when the agent's only responsibility is to produce the improved product using a blueprint developed by the principal. Then income for the agent and principal, conditional on production, is

$$y_a = \begin{cases} w & \text{if } a \text{ is not involved in blueprint development,} \\ \lambda\pi & \text{if } a \text{ is involved in blueprint development,} \end{cases} \quad (2)$$

$$y_p = \pi - y_a .$$

We now have in place our twin pillars — residual incompatibilities as modelled by s and earnings premia as modelled by $\lambda\pi/w$.

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

$$U_i = \frac{y_i}{P} l_i . \quad (3)$$

²Court challenges aimed at obtaining a higher share of the rents from an innovation than that specified in an employment contract are widespread even in the case of major, as opposed to incremental, innovations. A recent example is the successful court challenge against Toshiba by a former employee who claimed main responsibility for the invention of flash memory. This is just one of many recent court cases brought by Japanese and us inventors against their employers. It shows just how prevalent this problem is in rich countries, let alone in poor countries with weak protection of intellectual property rights.

³The emphasis on contract-enforcement in this context was pioneered by Ethier and Markusen (1996).

where l_i is i 's leisure and P is the relevant price index. Both creative effort e_i and debugging effort d_i are costly because they eat into an individual's unit endowment of leisure. Leisure for i ($i = p, a$) is:

$$l_i = 1 - e_i - d_i . \quad (4)$$

Sequence of events

We turn now to the sequence of events. The American principal and Chinese agent match, sign a contract governing their relationship, and begin working together. Initially, the principal does not invite the agent to participate in knowledge creation. The agent is paid w to start up what is best described as a product-cycle relationship in which all of the technology is expected to be developed by the principal in the United States and then transferred to China for use in production by the Chinese agent. In the course of this preliminary work the principal and agent learn more about each other and get a clearer sense of how good the Chinese agent will be at incrementally improving the principal's product. That is, the principal and agent learn about the residual incompatibilities or debugging effort that the principal will bear if the agent develops a blueprint for the incremental innovation. Mathematically, they learn the similarity parameter s . We formalize this learning process in a stylized way. When the principal and agent match they have only a broad sense of their similarity. This is described by a prior cumulative distribution function $F(s)$. After working together they learn s exactly.

If s is close to 0, which is to say that residual incompatibilities are large, the principal will want to continue a product-cycle type of relationship in which the principal does all of the incremental innovation. If s is large the principal may want to engage the agent in designing blueprints. Thus, after learning s both parties may want to amend the contract so that the agent is paid $\lambda\pi$ to be involved in an incremental innovation.⁴

There are three possible degrees of agent involvement in incremental innovation.

⁴This sets up the potential for an interesting dynamic which we do not explore. The principal and agent may wish to start with smaller projects or projects with less uncertainty about s and then, over time, consider more complex projects.

1. *Agent-Uninvolved Innovation (AU)*: The us principal tries to develop a blueprint in the United States and, if successful, provides it to the Chinese agent for production. The Chinese agent does no incremental innovation.
2. *Agent-Assisted Innovation (AA)*: Both the us principal and the Chinese agent try to develop blueprints. In the event that several blueprints are developed, the *principal decides* which blueprint will be used.
3. *Agent-Managed Innovation (AM)*: Both the us principal and the Chinese agent try to develop blueprints. In the event that several blueprints are developed, the *agent decides* which blueprint will be used.

Agent-uninvolved innovation is a product-cycle relationship. Agent-assisted and agent-managed innovation are the new types of international relationships described in our introduction e.g., figure 1.

Even if i and j each independently develop multiple blueprints, j 's preferred blueprint is by assumption always a blueprint designed by j . Thus, for fixed levels of innovation effort, the principal prefers agent-assisted to agent-managed innovation. However, the level of innovation effort is not fixed. As in Aghion and Tirole (1997), letting the agent choose the blueprint is an incentive device that makes the agent want to exert more innovative effort. This will be discussed below where we will show that the agent's level of innovation effort is highest under agent-managed innovation, lower under agent-assisted innovation and nonexistent under agent-uninvolved innovation.

We assume that there are several factors that cause contractual incompleteness. First, we make the standard assumption that effort is neither observable nor contractible. Second, we assume that the contract cannot be contingent on any aspect of the blueprint for incremental innovation. We have previously discussed two reasons for this. (a) The blueprint is by definition new knowledge and therefore unknown to the parties at the time of writing the contract. (b) If the principal and the agent are both involved in innovation, then the court is unable to disentangle the relative contribution of each. Thus, a contract

between principal and agent only specifies the type of agent involvement in innovation (i.e., agent-assisted, agent-managed or agent-uninvolved) and the payment conditional on production (i.e., w or $\lambda\pi$).⁵

It may be useful to the reader if we recap this section. The American principal and Chinese agent match and have a prior $F(s)$ about their similarity parameter s . Initially they agree on a contract which pays the agent w for starting up a product-cycle relationship. Once the relationship is started up both parties learn s . If s is large then the principal offers to amend the contract to allow for agent involvement in incremental innovation. In particular, the principal offers the agent $\lambda\pi$ in return for either agent-assisted or agent-managed innovation. The profit share λ is exogenously pinned down by the court system. If the amended contract is accepted by the agent then the principal and agent choose their levels of innovation effort e_p and e_a . Below we ensure that the agent accepts the contract i.e., that incentive compatibility is satisfied. If at least one blueprint is developed then there is production and the agent is paid (either w or $\lambda\pi$). Otherwise, there is no production and no payment to the agent.

3. Contributions to incremental innovation

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

Agent-uninvolved innovation (AU)

Agent-uninvolved innovation means that the principal excludes the agent from the incremental innovation process so that the agent cannot possibly claim to have come up with the crucial ideas. Thus, the agent exerts no innovation effort ($e_a = 0$) and is paid w conditional on the principal developing a blueprint (i.e., with probability e_p). The

⁵We are assuming that the profit share λ is independent of whether there is agent-assisted or agent-managed innovation even though agent involvement is specified in the contract and hence known to the court. This is easily relaxed to allow for two profit shares, λ^{AA} and λ^{AM} . However, this leads to only trivial changes in the model. In particular, the proposition 1 cutoffs \underline{s} and $1/\sqrt{2}$ will then depend on λ^{AA} and λ^{AM} . Aside from this, nothing else changes.

principal chooses innovation effort e_p to maximize her expected utility. From equations (2) and (3) the principal's problem is

$$\max_{\{e_p\}} \mathbf{EU}_p^{AU} \quad \text{where} \quad \mathbf{EU}_p^{AU} = e_p \frac{\pi - w}{P} (1 - e_p). \quad (5)$$

That is, with probability e_p the principal develops a blueprint, receives income $\pi - w$ and has leisure $1 - e_p$. With probability $1 - e_p$ there is no blueprint so that income and hence utility is 0. For the agent,

$$\mathbf{EU}_a^{AU} = e_p \frac{w}{P} s. \quad (6)$$

Since the agent must debug the principal's blueprint, the agent's leisure is $1 - e_a - d_a = 1 - (1 - s) = s$. Thus, with probability e_p the agent receives income w and has leisure s . With probability $1 - e_p$ the principal fails to develop a blueprint so that the agent's income and hence utility is 0. The solution to (5) is trivial ($e_p = 1/2$). For future reference, denote the equilibrium innovation effort levels under agent-uninvolved innovation by

$$e_p^{AU} = 1/2 \quad \text{and} \quad e_a^{AU} = 0. \quad (7)$$

Agent-assisted innovation

Under agent-assisted innovation both the principal and the agent work on blueprints ($e_p > 0, e_a > 0$). The principal chooses which blueprint is used and always prefers her own because this shifts the debugging of residual incompatibilities onto the agent. The principal chooses innovation effort e_p to maximize expected utility

$$\max_{\{e_p\}} \mathbf{EU}_p^{AA} \quad \text{where} \quad \mathbf{EU}_p^{AA} = e_p \frac{(1 - \lambda)\pi}{P} (1 - e_p) + (1 - e_p)e_a \frac{(1 - \lambda)\pi}{P} (1 - e_p)s. \quad (8)$$

That is, with probability e_p the principal develops a blueprint, receives income $(1 - \lambda)\pi$ and has leisure $1 - e_p$. When the principal does not come up with a blueprint, having asked the agent to assist in innovation means that the agent may succeed where the principal failed. Thus, with probability $(1 - e_p)e_a$ only the agent develops a blueprint, the principal receives income $(1 - \lambda)\pi$ and has leisure $(1 - e_p)s$. If no blueprint is developed,

income and hence utility is 0. The agent's problem is

$$\max_{\{e_a\}} \mathbf{EU}_a^{AA} \quad \text{where} \quad \mathbf{EU}_a^{AA} = e_p \frac{\lambda\pi}{P} (1 - e_a)s + (1 - e_p)e_a \frac{\lambda\pi}{P} (1 - e_a). \quad (9)$$

The reaction functions of the principal and the agent under agent-assisted innovation are given by

$$e_p^{AA}(e_a) = \frac{1 - 2se_a}{2(1 - se_a)} \quad \text{and} \quad e_a^{AA}(e_p) = \frac{1 - (1 + s)e_p}{2(1 - e_p)}. \quad (10)$$

Solving these yields the equilibrium levels of innovation effort for the principal and agent:

$$e_p^{AA} = \frac{1}{2 + s} \quad \text{and} \quad e_a^{AA} = \frac{1}{2(1 + s)}. \quad (11)$$

Agent-managed innovation

Under agent-managed innovation again both the principal and the agent work on blueprints ($e_p > 0, e_a > 0$). The agent chooses which blueprint is used and always prefers his own because this shifts the debugging of residual incompatibilities onto the principal.

The principal chooses innovation effort e_p to maximize expected utility

$$\max_{\{e_p\}} \mathbf{EU}_p^{AM} \quad \text{where} \quad \mathbf{EU}_p^{AM} = e_a \frac{(1 - \lambda)\pi}{P} (1 - e_p)s + (1 - e_a)e_p \frac{(1 - \lambda)\pi}{P} (1 - e_p), \quad (12)$$

and the objective for the agent is

$$\max_{\{e_a\}} \mathbf{EU}_a^{AM} \quad \text{where} \quad \mathbf{EU}_a^{AM} = e_a \frac{\lambda\pi}{P} (1 - e_a) + (1 - e_a)e_p \frac{\lambda\pi}{P} (1 - e_a)s. \quad (13)$$

The reaction functions of the principal and the agent under agent-managed innovation are given by

$$e_p^{AM}(e_a) = \frac{1 - (1 + s)e_a}{2(1 - e_a)} \quad \text{and} \quad e_a^{AM}(e_p) = \frac{1 - 2se_p}{2(1 - se_p)}. \quad (14)$$

Solving these yields the equilibrium levels of innovation effort for the principal and the agent:

$$e_p^{AM} = \frac{1}{2(1 + s)} \quad \text{and} \quad e_a^{AM} = \frac{1}{2 + s}. \quad (15)$$

Innovation effort levels

As the Chinese agent becomes more involved in incremental innovation (going from agent-uninvolved innovation to agent-assisted innovation and then to agent-managed innovation), the Chinese agent's innovation effort rises and the American principal's innovation effort falls. That is, $e_p^{AU} > e_p^{AA} > e_p^{AM} > 0$ and $0 = e_a^{AU} < e_a^{AA} < e_a^{AM}$.⁶ The principal is replacing her innovation effort with that of the agent. This is a key benefit that the principal gets from involving the agent in incremental innovation.

Why does the agent exert more effort under agent-managed innovation than under agent-assisted innovation? When the agent chooses the blueprint, it is more likely that the agent's blueprint will be chosen and hence more likely that the agent will avoid the costs of debugging residual incompatibilities. As a result, agent's benefits from innovation effort are higher under agent-managed innovation than under agent-assisted innovation. This builds on Aghion and Tirole's (1997) insight that delegation is an incentive device that induces innovation effort from the agent in settings where monetary incentives are of limited effectiveness.⁷

A second benefit for the American principal from involving the Chinese agent is that the probability of developing a blueprint is higher when their creative efforts are combined. That is, $e_a^{AM} + (1 - e_a^{AM})e_p^{AM} = e_p^{AA} + (1 - e_p^{AA})e_a^{AA} > e_p^{AU}$. This captures the idea that local agents can identify potential improvements on the shop floor that would have been very difficult for an American firm to identify from the outside. Thus, their involvement helps to attain continual product and process upgrades.

⁶This can be seen from equations (7), (11), and (15) which show that $e_p^{AU} = 2^{-1} > e_p^{AA} = (2 + s)^{-1} > e_p^{AM} = (2 + 2s)^{-1} > 0$ and $e_a^{AM} = (2 + s)^{-1} > e_a^{AA} = (2 + 2s)^{-1} > e_a^{AU} = 0$.

⁷In Aghion and Tirole (1997), monetary incentives are ruled out by the assumption that the agent is infinitely risk-averse. This strikes us as a very strong assumption. By contrast, in our setting the agent is risk neutral and does respond to monetary incentives — in fact, we will see shortly that the principal uses the earnings premium in order to induce the agent to get involved in the innovation process. However, in our model the principal is limited in the range of monetary incentives that she can offer. Monetary incentives that leave the agent with less than $\lambda\pi$ are unacceptable to the agent and monetary incentives that leave the agent with more than $\lambda\pi$ are unacceptable to the principal. Thus, the principal can offer monetary incentives in moving from agent-uninvolved to agent-assisted innovation ($w < \lambda\pi$), but once involved in innovation, the principal can only offer $\lambda\pi$ regardless of the agent's effort level.

The choice of the agent's involvement in innovation

The American principal chooses which of three forms to use in involving the Chinese agent in innovation. We therefore need to know the American principal's returns from each form. Plugging in the Nash effort levels of equations (7), (11) and (15) into the principal's expected utility functions of equations (5), (8) and (12) yields the following values for expected utility (with expectation taken over the probability of developing a blueprint):

$$\begin{aligned} \mathbf{EU}_p^{AU} &= \frac{\pi - w}{P} \frac{1}{4}, \\ \mathbf{EU}_p^{AA} &= \frac{(1 - \lambda)\pi}{P} \frac{1 + s}{2(2 + s)}, \end{aligned} \quad (16)$$

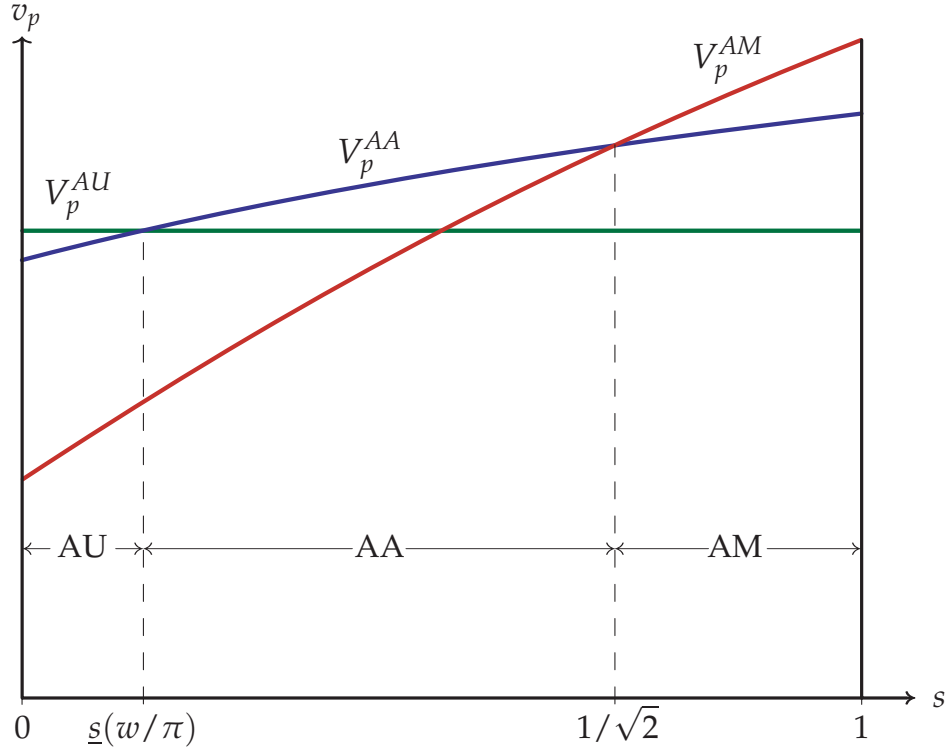
and

$$\mathbf{EU}_p^{AM} = \frac{(1 - \lambda)\pi}{P} \frac{(1 + 2s)^2}{4(1 + s)(2 + s)}.$$

We have repeatedly argued that the twin pillars of the principal's decision are earnings premia ($\lambda\pi/w$) and residual incompatibilities as captured by the blueprints similarity parameter (s). To bring this out we multiply through equation (16) by $\frac{4P}{(1-\lambda)\pi}$. Denoting the resulting scaled utility by $V_p^j \equiv \frac{4P}{(1-\lambda)\pi} \mathbf{EU}_p^j$ ($j = AU, AA, AM$):

$$\begin{aligned} V_p^{AU} &= \frac{1 - w/\pi}{1 - \lambda}, \\ V_p^{AA} &= \frac{2(1 + s)}{2 + s}, \\ V_p^{AM} &= \frac{(1 + 2s)^2}{(1 + s)(2 + s)}. \end{aligned} \quad (17)$$

One can see immediately the role of s . Finding $\frac{\lambda\pi}{w}$ is just a little trickier. Because we are looking at the earnings premium from the principal's perspective, the premium is better expressed as $\frac{(1-\lambda)\pi}{\pi-w}$. But this is just the inverse of $V_p^{AU} = \frac{1-w/\pi}{1-\lambda}$. Now it is clear that the earnings premium and residual incompatibilities are the only two factors determining the principal's decisions. The American principal will (1) involve the Chinese agent in innovation if and only if either V_p^{AM} or V_p^{AA} exceeds V_p^{AU} and (2) delegate management of innovation to the agent if and only if V_p^{AM} exceeds V_p^{AA} and V_p^{AU} .



Notes: AU is agent-uninvolved innovation, AA is agent-assisted innovation and AM is agent-managed innovation.

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

This discussion is graphically summarized in figure 3 which plots the V_p^j against s . The V_p^{AA} and V_p^{AM} curves are both increasing in s and intersect only once, at $s = 1/\sqrt{2}$. Further, $V_p^{AM} > V_p^{AA}$ for $s > 1/\sqrt{2}$. V_p^{AU} is independent of s and intersects the V_p^{AA} curve at $s = \frac{2(\lambda-w/\pi)}{1-2\lambda+w/\pi}$. All of these results follow from exceedingly trivial manipulations of equation (17). We collect these results in the following proposition.

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

$$s > \underline{s} \equiv \frac{2(\lambda - w/\pi)}{1 - 2\lambda + w/\pi}. \quad (18)$$

The principal prefers agent-managed to agent-assisted innovation if and only if $s > \frac{1}{\sqrt{2}}$.

Figure 3 is drawn for the case in which agent-uninvolved, agent-assisted, and agent-managed innovation are all possible preferred choices for the principal depending on the similarity-of-blueprints parameter s . This is the case when $\underline{s} < 1/\sqrt{2}$ or equivalently

$\frac{1-w/\pi}{1-\lambda} < \frac{2+2\sqrt{2}}{1+2\sqrt{2}} \simeq 1.26$. Then the principal prefers agent-uninvolved innovation for $s < \underline{s}$, agent-assisted innovation for $\underline{s} < s < 1/\sqrt{2}$, and agent-managed innovation for $s > 1/\sqrt{2}$.⁸ It follows that when $\underline{s} < 1/\sqrt{2}$, the three ways of organizing innovation can co-exist. Different matches will have different values of s and hence choose different ways of organizing innovation. All that is required for coexistence is sufficient heterogeneity in the cross-match distribution of s . 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. 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.

While it is the American principal who may offer the Chinese agent some involvement in innovation, the Chinese agent can always refuse. That is, we need to check that incentive compatibility is satisfied. The following lemma relates incentive compatibility to the earnings premium.

Lemma 1 (Incentive compatibility) *Incentive compatibility holds for all s if and only if the earnings premium is high enough, $\frac{\lambda\pi}{w} \geq \frac{3}{2}$.*

Proof See the appendix. □

As a final comment on the earnings premium, note that we have set up the model so that innovation effort levels are independent of firm profits π . This allows us to study key aspects of the principal-agent problem independently of profit levels that are

⁸If instead $\frac{2+2\sqrt{2}}{1+2\sqrt{2}} < \frac{1-w/\pi}{1-\lambda} < \frac{3}{2}$, only agent-uninvolved innovation (for low s) and agent-managed innovation (for high s) are possible preferred choices for the principal. Finally, if $\frac{1-w/\pi}{1-\lambda} > \frac{3}{2}$ agent-uninvolved innovation is always preferred by the principal.

determined at the general equilibrium level.⁹ General equilibrium feedbacks enter only via the earnings premium $\lambda\pi/w$ and its effect on the threshold level for the similarity-of-blueprints parameter \underline{s} . 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 of our model for incremental innovation in low-wage countries as well as for international trade and income disparities. In the previous section we focused on the decision by a single US firm about whether and how much to involve her Chinese partner in incremental innovation. We now consider multiple US firms or principals. 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 Thailand. 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.

To bring the results into stark relief we allow for only one difference between China and Thailand. 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 s in China and let F^* be the corresponding cumulative distribution function in Thailand. Both

⁹In contrast, Marin and Verdier (2002) set up a general equilibrium version of Aghion and Tirole (1997) that focuses on the possible effects of changes in firm profit margins on effort levels, and through them on the allocation of power inside the firm. A fall in profit margins increases the loss of market share that a firm suffers from implementing a suboptimal project, so the firm may choose to increase its monitoring effort while at the same time delegating power to lower levels of management so as not to stifle their initiative. This is an important insight. However, since it is quite separate from our main interests in this paper, we have chosen to remove this additional general equilibrium interaction.

F and F^* are assumed differentiable. Asterisks will denote Thai variables throughout. We assume that F first-order stochastically dominates F^* . This means that F is right-shifted relative to F^* : $F \leq F^*$ for all s , with strict inequality for some $s \in (0,1)$. As is well known, first-order stochastic dominance implies $\int_0^1 v(s)dF(s) > \int_0^1 v(s)dF^*(s)$ for every nondecreasing function v .

Although we believe the assumption that F first-order stochastically 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 Thailand, Indonesia and the Philippines. First, relative to Thai 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 Thai, Indonesian or Philippine school makes this list.¹⁰ 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 Thailand, Indonesia and the Philippines combined.¹¹ 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, and Singapore which has invested heavily in bringing Chinese manufacturing plants up to snuff. While hard numbers on the impact of the diaspora are hard to find, there is 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

¹⁰Rankings are published in *Times Higher Education Supplement*, 5 November 2004, available at <http://www.thes.co.uk/worldrankings/>.

¹¹Authors' calculations based on data in Johnson (1998) and <http://sestat.nsf.gov>.

had a stock of almost 100,000 ISO 9001 certificates compared to only 3,449 for Thailand, Indonesia and the Philippines combined.¹²

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. This flips Vernon's (1966) argument on its head, making China an attractive place to locate first production — proximity to discerning consumers is a key driver of Vernon's argument for why innovation occurs in rich countries.

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 s she will encounter in China and in Thailand. However, it is only after she has made her location choice and started working with a particular agent that she learns the value of s 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 Thailand each principal takes expectations over s . 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 s . Notice that we have focused our analysis on the case in which agent-uninvolved, agent-assisted, and agent managed innovation are all possible preferred choices for the principal. This is the richest case in proposition 1 and corresponds to $\underline{s} < 1/\sqrt{2}$. Less rich cases follow trivially. Also note that we have assumed that the condition in lemma 1 (i.e., $\lambda\pi/w \geq 3/2$) is satisfied so that the principal's choice is always incentive compatible for the agent. The appendix shows that $\underline{s} < 1/\sqrt{2}$ and $\lambda\pi/w \geq 3/2$ are easy to simultaneously satisfy in general equilibrium. Expected utility

¹²Data are from ISO Central Secretariat (2003).

from entering the Chinese auto sector is then given by

$$\mathbf{EU}_i = \underbrace{\int_0^{\underline{s}} \mathbf{EU}_i^{AU} dF(s)}_{\text{Agent-Uninvolved}} + \underbrace{\int_{\underline{s}}^{1/\sqrt{2}} \mathbf{EU}_i^{AA} dF(s)}_{\text{Agent-Assisted}} + \underbrace{\int_{1/\sqrt{2}}^1 \mathbf{EU}_i^{AM} dF(s)}_{\text{Agent-Managed}}, \quad i = p, a. \quad (19)$$

s enters equation (19) in two ways. From proposition 1, s determines which of three types of agent involvement in incremental innovation will be adopted in the match. Second, for a given type of involvement, say type j , utility \mathbf{EU}_i^j depends on the costs of debugging residual incompatibilities i.e., \mathbf{EU}_i^j depends on s . The Thai equivalent of equation (19) replaces F with F^* .

The agents' problem

Consider equation (19) from the perspective of a Chinese agent. The $\mathbf{EU}_a^j, j = AU, AA, AM$ are calculated by plugging in the optimal effort levels e_a^j and e_p^j into the agent's expected utility. Specifically, plugging equation (7) into equation (6) yields $\mathbf{EU}_a^{AU} = \frac{ws}{2P}$. Plugging equation (11) into equation (9) yields $\mathbf{EU}_a^{AA} = \frac{\lambda\pi}{4P} \frac{(1+2s)^2}{(1+s)(2+s)}$. Plugging equation (15) into equation (13) yields $\mathbf{EU}_a^{AM} = \frac{\lambda\pi}{2P} \frac{1+s}{2+s}$. In order to emphasize the roles of s and the earnings premium $w/\lambda\pi$, we scale the \mathbf{EU}_a^j and hence \mathbf{EU}_a by multiplying through by $\frac{4P}{\lambda\pi}$. Denoting scaled utility by $V_a^j \equiv \frac{4P}{\lambda\pi} \mathbf{EU}_a^j$ ($j = AU, AA, AM$),

$$\begin{aligned} V_a^{AU} &= 2 \frac{w}{\lambda\pi} s, \\ V_a^{AA} &= \frac{(1+2s)^2}{(1+s)(2+s)}, \\ V_a^{AM} &= \frac{2(1+s)}{2+s}. \end{aligned} \quad (20)$$

It will also help later to have more compact notation. To this end define for $i = a, p$

$$v_i(s, w/\pi) = \begin{cases} V_i^{AU} & \text{for } 0 < s < \underline{s}(w/\pi), \\ V_i^{AA} & \text{for } \underline{s}(w/\pi) \leq s < 1/\sqrt{2}, \\ V_i^{AM} & \text{for } 1/\sqrt{2} \leq s < 1. \end{cases} \quad (21)$$

Then expected *ex ante* utility for a Chinese national from being in the auto sector is

$$\begin{aligned}
V_a(w/\pi, F) &= \int_0^1 v_a(s, w/\pi) dF(s) \tag{22} \\
&= \underbrace{2 \frac{w}{\lambda\pi} \int_0^{\underline{s}(w/\pi)} s dF(s)}_{\text{Agent-Uninvolved}} + \underbrace{\int_{\underline{s}(w/\pi)}^{1/\sqrt{2}} \frac{(1+2s)^2}{(1+s)(2+s)} dF(s)}_{\text{Agent-Assisted}} + \underbrace{\int_{1/\sqrt{2}}^1 \frac{2(1+s)}{2+s} dF(s)}_{\text{Agent-Managed}},
\end{aligned}$$

where, from proposition 1, $\underline{s}(w/\pi) = \frac{2(\lambda-w/\pi)}{1-2\lambda+w/\pi}$. The Thai equivalent of equation (22) replaces F with F^* and w with w^* to yield $V_a(w^*/\pi, F^*)$.

In addition to producing autos, both China and Thailand produce rice. Rice is produced with raw labour i.e., without innovation effort e_i . Rice 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 Thailand 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 rice sector. We choose rice as the numeraire so that its price is unity. Let $w_R(L - m)$ be the marginal product and wage of labour in the rice sector when $L - m$ workers are employed in the rice sector. By diminishing returns to labour $w'_R < 0$.

If China produces both rice and autos then its nationals must obtain the same *ex-ante* expected utility whether they work in the rice sector or are agents in the auto sector. Utility from working in the rice sector is w_R/P . Scaling this by $\frac{4P}{\lambda\pi}$ as we did with the EU_a , the agent is indifferent between working in the rice and auto sectors when

$$V_a(w/\pi, F) = \frac{4}{\lambda\pi} w_R(L - m). \tag{23}$$

The corresponding indifference condition for Thai nationals is

$$V_a(w^*/\pi, F^*) = \frac{4}{\lambda\pi} w_R(L - m^*). \tag{24}$$

These two equations — which state that the agent is indifferent between working in the auto and rice sectors — are central to our analysis.

The principals' problem

Each American principal must employ either a Chinese or Thai agent to produce one unit of autos. In choosing between locating in China and Thailand, each principal compares *ex ante* expected returns of entering each country as given by equation (19). Given that all blueprints yield the same total profit, from the point of view of principals there are only two differences between China and Thailand: (a) their distributions F and F^* and (b) auto sector wages, w and w^* . Plugging equation (16) into (19), scaling by $\frac{4P}{(1-\lambda)\pi}$ and as before defining $V_p \equiv \frac{4P}{(1-\lambda)\pi} \mathbf{E}U_p$ yields

$$\begin{aligned}
 V_p(w/\pi, F) &= \int_0^1 v_p(s, w/\pi) dF(s) & (25) \\
 &= \underbrace{\frac{1-w/\pi}{1-\lambda} F(\underline{s}(w/\pi))}_{\text{Agent-Uninvolved}} + \underbrace{\int_{\underline{s}(w/\pi)}^{1/\sqrt{2}} \frac{2(1+s)}{2+s} dF(s)}_{\text{Agent-Assisted}} + \underbrace{\int_{1/\sqrt{2}}^1 \frac{(1+2s)^2}{(1+s)(2+s)} dF(s)}_{\text{Agent-Managed}}.
 \end{aligned}$$

The scaling is the same as appeared in equation (17). Graphically, v_p is just the upper envelope in figure 3 and V_p is the integral over s of this upper envelope. The principal's corresponding return from entering Thailand is $V_p(w^*/\pi, F^*)$. If principals operate in both China and Thailand, expected *ex-ante* returns must be equalized across the two countries:

$$V_p(w/\pi, F) = V_p(w^*/\pi, F^*). \quad (26)$$

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 (23), (24), and (26) alone. This is surprising because these three equations contain five endogenous variables: m , m^* , w , w^* and π . However, we will not need to know either profits π or the total number of us principals $M = m + m^*$. To establish our main results

we will only need to show two things. First, $m > m^*$ i.e., we do not need to know about entry and its impact on the total number of principals M . Second, $w/\pi > w^*/\pi$ i.e., we do not need to know about market structure and its impact on profits π . Thus, equations (23), (24), and (26) contain just enough information to derive all our main results. We will introduce more structure on entry, market structure, and profits only for the minor results of our penultimate section 6.

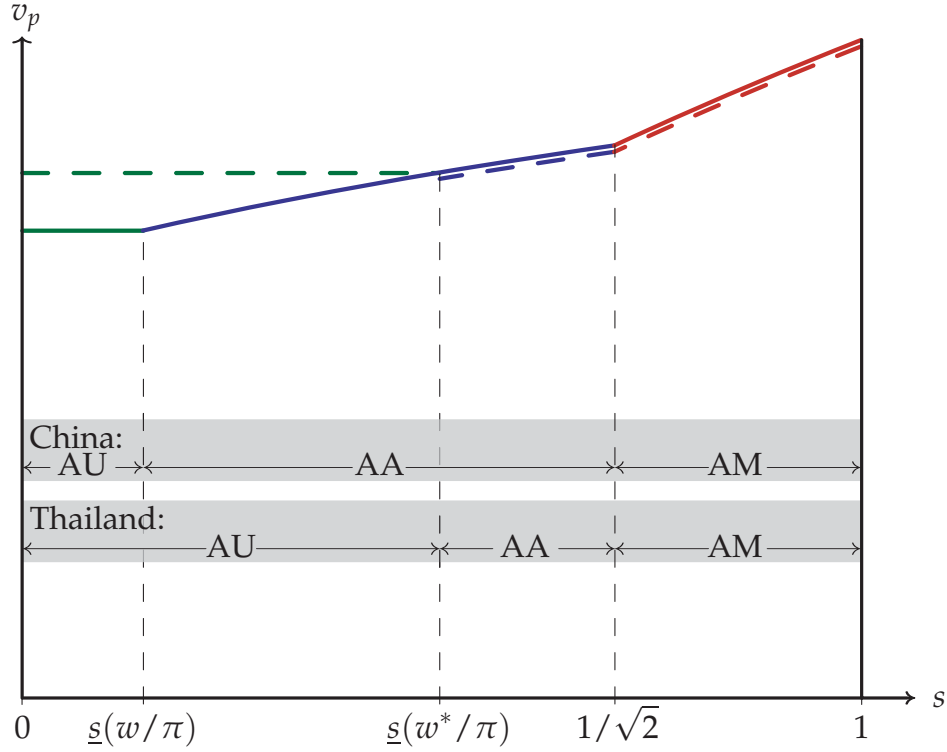
Wages as an equilibrating mechanism

The wage w paid under agent-uninvolved innovation is the key equilibrating mechanism in our model. We therefore assume that there is agent-uninvolved innovation in both countries.¹³ This simply requires that both countries have positive mass somewhere on the interval $(0, \underline{s})$. However, since \underline{s} is endogenous we exclude it from the statement of the assumption by assuming more specifically that $dF(0)/ds > 0$ and $dF^*(0)/ds > 0$ i.e., there is mass near $s = 0$ 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 above \underline{s} . We again exclude the endogenous \underline{s} from the statement of the assumption by assuming more specifically that $F \leq F^*$ for all s , with strict inequality for some $s \in (1/\sqrt{2}, 1)$. Note that this last assumption implies that $F(1/\sqrt{2}) < 1$ i.e., some Chinese agents are involved in agent-managed 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 this requires Thai agents to produce autos in equilibrium, it says nothing about whether or not Thai agents are 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 Thailand, $w > w^*$.*

¹³See, however, the appendix for an alternative specification with no agent-uninvolved innovation and with a now-exogenous λ as the equilibrating mechanism.



Notes: AU is agent-uninvolved innovation, AA is agent-assisted innovation and AM is agent-managed innovation. The solid line is China's $v_p(w/\pi, F)$ and the dashed line is Thailand's $v_p(w^*/\pi, F^*)$.

Figure 4. China's $v_p(w/\pi, F)$ and Thailand's $v_p(w^*/\pi, F^*)$

Proof Suppose, contrary to proposition 2, that $w \leq w^*$. Differentiating equation (25) yields $\partial V_p(w/\pi, F)/\partial w = -F(\underline{s}(w/\pi))/[\pi(1-\lambda)]$.¹⁴ By assumption, F places positive mass in the neighbourhood of $s = 0$ so that $F(\underline{s}(w/\pi)) > 0$ and $\partial V_p(w/\pi, F)/\partial w < 0$. Hence $w \leq w^*$ implies $V_p(w/\pi, F) \geq V_p(w^*/\pi, F)$. From equations (17) and (21), $v_p(s, w^*/\pi)$ is a nondecreasing function of s and is strictly increasing on $(1/\sqrt{2}, 1)$. Since $F \succ_{FOSD} F^*$, the definition of first-order stochastic dominance implies $V_p(w^*/\pi, F) = \int_0^1 v_p(s, w^*/\pi) dF(s) > \int_0^1 v_p(s, w^*/\pi) dF^*(s) = V_p(w^*/\pi, F^*)$. Strict inequality comes from the fact that by assumption, $F < F^*$ somewhere on $(1/\sqrt{2}, 1)$ which means that there is a subinterval on which both $F < F^*$ and v_p is increasing. Combining $V_p(w^*/\pi, F) > V_p(w^*/\pi, F^*)$ with $V_p(w/\pi, F) \geq V_p(w^*/\pi, F)$ implies $V_p(w/\pi, F) > V_p(w^*/\pi, F^*)$, a violation of equation (26). Hence $w > w^*$. \square

¹⁴We are using the fact that $\underline{s}(w/\pi)$ is defined to satisfy $\frac{1-w/\pi}{1-\lambda} = \frac{2(1+s)}{2+s}$. Thus, the derivative of V_p with respect to \underline{s} is zero.

The basic insight is straightforward. Consider figure 4. It plots the upper envelope of figure 3 for China (solid line) and Thailand (dashed line). That is, it plots $v_p(s, w/\pi)$ and $v_p(s, w^*/\pi)$. Recall that $V_p(w/\pi, F)$ and $V_p(w^*/\pi, F^*)$ are integrals over s of these envelopes. A core feature of the principal's problem is that the upper envelope is non-decreasing in s . This reflects the fact that the principal prefers working with an agent whose blueprints create few residual incompatibilities. Since China's distribution of s first order stochastic dominates Thailand's, if $w = w^*$ then each principal prefers China over Thailand. To ensure that each principal is *ex-ante* indifferent between locating in these two countries, lower wages are needed in Thailand to offset the higher expected residual incompatibilities.

The involvement of Chinese and Thai 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* Thai counterparts.

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

Proof By equation (18), $\partial \underline{s}(w/\pi) / \partial w < 0$. Therefore, $\underline{s}(w/\pi) < \underline{s}(w^*/\pi)$. Consider part (1). The results about involvement in innovation follow immediately from proposition 1. By the definition of incentive compatibility, agents always prefer agent-assisted innovation to agent-uninvolved innovation. Thus, Chinese utility is higher. Further, lemma 1 implies that $\lambda\pi > w$ so that $\lambda\pi > w^*$. That is, the Chinese agent is paid

more. Consider part (2). By assumption, F places more mass than F^* does on the interval $(1/\sqrt{2}, 1)$ so that Chinese agents have a higher probability of managing innovation. Since $\underline{s}(w/\pi) < \underline{s}(w^*/\pi)$, first order stochastic dominance implies that F places more mass on the interval $(\underline{s}(w/\pi), 1)$ than F^* places on the interval $(\underline{s}(w^*/\pi), 1)$. That is, Chinese agents have a higher probability of being involved in innovation. \square

Part (1) of proposition 3 and to some extent part (2) operate through the endogenous general equilibrium wage differences between China and Thailand. Agents performing basic auto tasks are paid more in China than Thailand so that the additional monetary cost of including workers in incremental innovation is lower in China. Thus, the minimum similarity of blueprints required for involvement in innovation is also lower in China: $\underline{s}(w/\pi) < \underline{s}(w^*/\pi)$. Therefore, even agents who create *identical* residual incompatibilities are more involved in incremental innovation in China than in Thailand. This is a general equilibrium effect.

The location of American principals

The better distribution of Chinese agents makes China a more attractive location than Thailand. The better distribution also has a number of other implications. To understand these, suppose that initially China and Thailand are identical and that we then improve the Chinese distribution. Start by holding the number of US principals fixed. Then US principals move from Thailand 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 rice to auto sectors. Because of diminishing returns in rice production, this also raises the Chinese rice wage $w_R(L - m)$. Conversely, Thai workers migrate from the auto to rice sectors, thus depressing Thai rice wages $w_R(L - m^*)$. Now allow entry of US principals. The improvement in the Chinese distribution together with falling wages in Thailand 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 Thailand, $m > m^*$.*

Proof Differentiating equation (22) yields

$$\frac{\partial V_a(w/\pi, F)}{\partial w} = \frac{2}{\lambda\pi} \int_0^{\underline{s}} s dF(s) + \left[2 \frac{w}{\lambda\pi \underline{s}} - \frac{(1+2\underline{s})^2}{(1+\underline{s})(2+\underline{s})} \right] \frac{dF(\underline{s})}{d\underline{s}} \frac{\partial \underline{s}}{\partial w}. \quad (27)$$

By assumption, F places positive mass in the neighbourhood of $s = 0$ so that $\frac{2}{\lambda\pi} \int_0^{\underline{s}} s dF(s) > 0$. By equation (20), the term in brackets is $V_a^{AU} - V_a^{AA}$ evaluated at $s = \underline{s}$. By incentive compatibility, $V_a^{AU} \leq V_a^{AA}$ at $s = \underline{s}$. Otherwise, the agent would turn down the principal's request to assist in innovation. Hence, the term in brackets is non-positive. By equation (18), $\partial \underline{s} / \partial w < 0$. Thus, $\partial V_a(w/\pi, F) / \partial w > 0$. By proposition 2, $w > w^*$ so that $V_a(w/\pi, F) > V_a(w^*/\pi, F)$. From equations (20) and (21), $v_a(s, w^*/\pi)$ is an increasing function of s . $F \succ_{FOSD} F^*$ thus implies $V_a(w^*/\pi, F) = \int_0^1 v_a(s, w^*/\pi) dF(s) > \int_0^1 v_a(s, w^*/\pi) dF^*(s) = V_a(w^*/\pi, F^*)$. Combining this inequality with $V_a(w/\pi, F) > V_a(w^*/\pi, F)$ implies $V_a(w/\pi, F) > V_a(w^*/\pi, F^*)$. From equations (23) and (24),

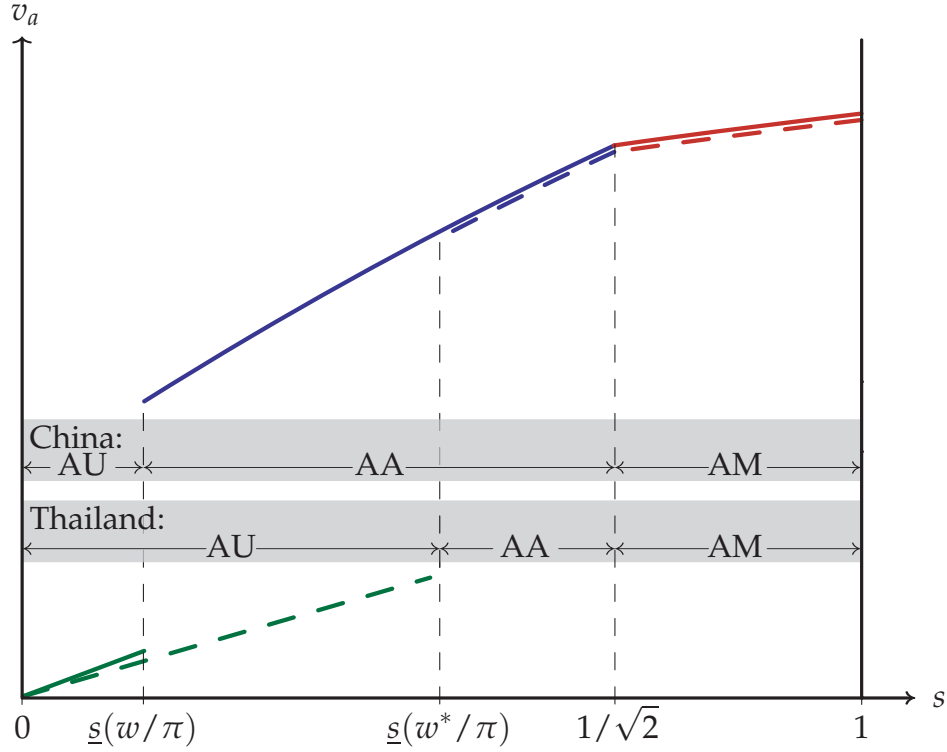
$$\frac{4}{\lambda\pi} w_R(L - m) = V_a(w/\pi, F) > V_a(w^*/\pi, F^*) = \frac{4}{\lambda\pi} w_R(L - m^*). \quad (28)$$

or

$$w_R(L - m) > w_R(L - m^*). \quad (29)$$

By diminishing returns to labour $w'_R < 0$. Hence $m > m^*$. \square

The basic insight works off the agent's indifference between the rice and auto sectors. Consider figure 5 which plots China's $v_p(s, w/\pi)$ with a solid line and Thailand's $v_p(s, w^*/\pi)$ with a dashed line. It is the agent's counterpart to figure 4. The profiles are increasing in both countries because agents are always better off when there are fewer residual incompatibilities. Since Chinese agents are paid more than Thai agents in the



Notes: AU is agent-uninvolved innovation, AA is agent-assisted innovation and AM is agent-managed innovation. The solid line is China's $v_a(w/\pi, F)$ and the dashed line is Thailand's $v_a(w^*/\pi, F^*)$.

Figure 5. China's $v_a(w/\pi, F)$ and Thailand's $v_a(w^*/\pi, F^*)$

agent-uninvolved form ($w > w^*$), the Chinese profile lies above the Thai profile for $s < \underline{s}(w/\pi)$. At $s = \underline{s}(w/\pi)$ the profile jumps up because of the incentive compatibility constraint.¹⁵ This raises the Chinese profile even higher above the Thai profile in the interval $s \in [\underline{s}(w/\pi), \underline{s}(w^*/\pi)]$. Thus, Chinese agents are better off than Thai agents both because they have a higher profile and because the Chinese distribution puts more weight on the higher outcomes to the right. Since an agent's returns must be equalized across the rice and auto sectors, Chinese rice wages $w_R(L - m)$ must also be higher than Thai rice wages $w_R(L - m^*)$. This is only possible if there are more agents and hence more American principals in China than in Thailand i.e., $m > m^*$.

Notice that the principal goes to where agents are most expensive. This result never occurs in standard product-cycle models where us principals always locate in the lowest-

¹⁵Although not obvious, incentive compatibility for all s implies that the incentive compatibility constraint is not binding at $s = \underline{s}$. In particular, it implies that $V_a^{AU} < V_a^{AA}$ at $s = \underline{s}$. See the appendix for details.

wage country. In our model us firms take into account wages *and* the ability of local agents to participate in incremental innovation. Notice also that to obtain proposition 4 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. The above discussion and proof of proposition 4 embodies the next result which we now make explicit.

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

The first part is a re-statement of equation (29). This in turn implies that utility in the rice sector is higher in China than in Thailand i.e., $w_R(L - m)/P > w_R(L - m^*)/P$. Finally, since agents are indifferent between sectors, utility in the auto sector must also be higher in China than in Thailand.

This corollary shows that the greater average ability of Chinese agents to assist in innovation has important welfare consequences. Note that China's higher income and welfare 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 uninvolved in innovation in Thailand, but assisting in innovation and earning a premium in China.

5. The economic consequences of Deng Xiaoping

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 regime has led to massive involvement of foreigner entrepreneurs in Chinese manufacturing. In this section, to paraphrase Keynes, we examine the economic consequences of Deng Xiaoping.

Consider a world in which initially all American principals locate in Thailand because they are not allowed into China. To sharpen the analysis, suppose that the Thai distribution $F^*(s)$ is such that American principals never involve Thai agents in incremental innovation i.e., all Thai mass is below $\underline{s}(w^*/\pi)$. In what follows we state this assumption simply as $F^*(\underline{s}(w^*/\pi)) = 1$. This corresponds to the figure 1 finding that Thai nationals are almost never listed as co-inventors on American-held patents. Similarly low patent numbers are also reported for many countries, including Indonesia and the Philippines. Suppose now that Deng Xiaoping makes his Southern Tour and American principals are allowed to enter China. As argued above, Chinese agents create fewer expected residual incompatibilities than Thai agents ($F \succ_{FOSD} F^*$) so that at least some Chinese agents are involved in incremental innovation.

Production patterns and trade flows

We start by establishing the pattern of world production. American firms are only able to produce if they succeed in creating a blueprint for incremental innovation. Let $\sigma(w/\pi, F)$ denote the expected share of principals locating in China who succeed in developing a blueprint. Let $\sigma(w^*/\pi, F^*)$ be the corresponding success rate for Thailand. The following proposition shows that investments in Thailand are more likely to end in failure because local agents are less able to provide support for incremental innovation. Since China has a larger number of investments and a lower failure rate, China has more auto production and less rice production than Thailand.

Proposition 5 (Production patterns) *Suppose $F \succ_{FOSD} F^*$ and $F^*(\underline{s}(w^*/\pi)) = 1$ i.e., Thai agents are not involved in innovation. Then in any diversified equilibrium, $m\sigma(w/\pi, F) > m^*\sigma(w^*/\pi, F^*)$ and $L - m^* > L - m$. That is, China produces more autos and less rice than Thailand.*

Proof By equation (7), an American principal who attempts to develop a blueprint on her own in the United States succeeds with probability $e_p^{AU} = 1/2$. A principal who instead finds herself working with a particularly capable Chinese agent and asks him to assist in innovation or to manage innovation succeeds with probability $e_p^{AA} + (1 - e_p^{AA})e_a^{AA}$ and $e_a^{AA} + (1 - e_a^{AA})e_p^{AA}$, respectively. By equations (11) and (15), both of these terms exceed $1/2$. This is to be expected: when a principal chooses to involve an agent in incremental innovation it is precisely because the probability of developing a blueprint rises while the principal's effort falls. Under our support assumptions on F and F^* ,

$$\sigma(w/\pi, F) > \frac{1}{2} = \sigma(w^*/\pi, F^*). \quad (30)$$

By proposition 4, $m > m^*$. Thus, $m\sigma(w/\pi, F) > m^*\sigma(w^*/\pi, F^*)$ and $L - m^* > L - m$. \square

These production patterns together with identical homothetic preferences imply the following result about equilibrium trade flows.

Corollary 5.1 (Trade flows) *Suppose $F \succ_{FOSD} F^*$ and $F^*(\underline{s}(w^*/\pi)) = 1$. Then in any diversified equilibrium the United States imports more autos from China than from Thailand and imports more rice from Thailand than from China. The United States finances this trade deficit with a capital account surplus against both China and Thailand. 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 rice 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 5.1, China and Thailand both export autos to each other and China is a net auto exporter to Thailand. Further, Thailand exports rice both to the United States and China. China exports rice to the United

States only if China is sufficiently large relative to the United States. In this case, China does not import rice from Thailand.

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 Thailand running a current account surplus against the United States and have the United States running a capital account surplus against China and Thailand. 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.

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

Prior to China's arrival, our model looks just like a product-cycle model: all innovation is done in the United States and the production of the standardized good is done in Thailand. After China's opening up to American investments, American firms locating in Thailand and some of those locating in China continue this product-cycle pattern of developed-country innovation followed by low-wage standardized production. However, some American firms begin involving their Chinese agents in incremental innovation and others even delegate to their Chinese agents management of the innovation process. These were precisely the patterns implied by our patent numbers in figure 1.

Finally, in our model the distributions F and F^* , summarizing the distribution of likely residual incompatibilities in each country, act as a source of comparative advantage. When China opens up, the greater average ability of its nationals to assist in innovation makes it a more attractive location for American auto producers despite relatively higher Chinese wages.

6. Free Entry and the Flight from Thailand

To model free entry of US principals, suppose that US nationals chose between being principals in the auto sector and working in an alternative occupation. Given that we are nearing the end of this paper, we avoid modelling details. 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 π and increases principals' earnings in their alternative occupation.

Proposition 6 (China's entry forces the Thai auto sector to contract) *Suppose $F \succ_{FOSD} F^*$ and $F^*(\underline{s}(w^*/\pi)) = 1$. Further suppose that entry of principals lowers π and raises principals' earnings in their alternative occupation. Then in any diversified equilibrium, Thailand has fewer principals m^* and lower wages in both sectors than before China's opening up to American principals.*

Proof Initially, Thailand hosts all principals. After China's opening to American principals, by proposition 4, Thailand hosts less than one half of all principals. If the total number of principals has not increased, Thailand 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, $V_p(w^*/\pi, F^*)$ must be higher than before China's opening. Under our support assumptions on F^* , by equation (25), $V_p(w^*/\pi, F^*) = \frac{1-w^*/\pi}{1-\lambda} F^*(\underline{s}(w^*/\pi))$, which is a decreasing function of w^*/π . Recall that \underline{s} is decreasing in w^*/π . By assumption, entry of principals lowers auto sector profits π , so the only way for $V_p(w^*/\pi, F^*)$ to rise is by having auto wages in Thailand w^* fall. Let μ^* denote the Thai mean of s . Under our support assumptions on F^* , by equations (22) and (24), the indifference of Thai nationals between becoming principals and working in the rice sector requires $2w^*\mu^*/\lambda\pi = 4w_R(L - m^*)/\lambda\pi$ or $w_R(L - m^*) = w^*\mu^*/2$. Hence

when Thai auto wages w^* fall, Thai rice wages $w_R(L - m^*)$ must also fall. Since $w'_R < 0$, this implies that the number of principals operating in Thailand m^* is lower after than before China's opening. \square

The appearance of China on the world scene has a negative impact on investment in Thailand. Notice that the proposition does *not* state that China's entry into world markets reduces Thai welfare. We have not tracked any of the traditional gains from trade so it is possible that Thailand benefits from China's entry. Our main point is simply that these traditional gains from trade for Thailand will be offset, at least in part, by the departure of American principals from Thailand. This problem is apparent in the Thai and Mexican patent data of figure 1 — see the dip after 2001 — and 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.

7. 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 patent data. See figure 1 in the introduction.

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 there were two thresholds. The first, \underline{s} , demarcated

matches that involve local agents in innovation from those that do not. The second, $s = 1/\sqrt{2}$, demarcated matches in which the agent assists in innovation from those in which the agent manages innovation. 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^* . We argued that relative to Thailand, Indonesia, the Philippines and many other low-wage countries, China and India have better engineers, a more committed diaspora, and a larger domestic market. For Chinese and Indian engineers, these factors reduce the costs and raise the benefits of making investments that right-shift F . As a result, the liberalizing of the international trade regime in China and India 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 Thailand 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

Proof of lemma 1

The initial contract pays the agent w for starting up a product-cycle relationship i.e, one with agent-uninvolved innovation. Once the relationship is started up, both parties learn s . If s is large then the principal offers to amend the contract to allow for agent involvement in incremental innovation in exchange for an earnings premium $\lambda\pi/w$. The agent could in principle turn down the principal's offer. We now derive the minimum earnings premium required for agents to always accept getting involved in innovation when asked to do so

i.e., a necessary and sufficient condition for incentive compatibility. The agent accepts the principal's offer of agent-assisted innovation if and only if $V_a^{AA} \geq V_a^{AU}$ and the principal's offer of agent-managed innovation if and only if $V_a^{AM} \geq V_a^{AU}$. By equation (20), V_a^{AU} is a ray through the origin in figure 5. Also by equation (20), both V_a^{AA} and V_a^{AM} lie above V_a^{AU} at $s = 0$ and are increasing and concave in s . Now look at figure 5 and imagine increasing the slope of V_a^{AU} starting from 0 until it intersects either V_a^{AA} or V_a^{AM} . The first intersection occurs at $s = 1$ when $V_a^{AU} = V_a^{AM}$. By equation (20) this implies $2 \frac{w}{\lambda\pi} s = \frac{2(1+s)}{2+s}$ for $s = 1$ or equivalently $\lambda\pi/w = 3/2$. This establishes that $\lambda\pi/w \geq 3/2$ is necessary and sufficient for V_a^{AU} to be below V_a^{AA} and V_a^{AM} for all s . Equivalently $\lambda\pi/w \geq 3/2$ is necessary and sufficient for incentive compatibility to hold for all s . \square

Parameter restrictions

Our analysis has focused on the richest possible case in which agent-uninvolved, agent-assisted and agent-managed innovation can all arise for some value of s , incentive compatibility is always satisfied, and production remains diversified in both China and Thailand. This appendix discusses what is required to ensure this. As shown following proposition 1, agent-uninvolved, agent-assisted and agent managed innovation are all possible preferred choices for a principal for some value of s if and only if $\underline{s} < \frac{1}{\sqrt{2}}$ (where \underline{s} is given by proposition 1). As shown above in lemma 1, agents always accept this choice if and only if $\lambda \frac{\pi}{w} \geq \frac{3}{2}$. These two conditions put together reduce to $1 - (1 - \lambda) \frac{2+2\sqrt{2}}{1+2\sqrt{2}} < \frac{w}{\pi} \leq \frac{2}{3}\lambda$. For this to be satisfied, we must have $1 - (1 - \lambda) \frac{2+2\sqrt{2}}{1+2\sqrt{2}} < \frac{2}{3}\lambda$, which simply requires $\lambda < \frac{3}{2(2+\sqrt{2})} \simeq 0.44$. In addition, we need $\frac{w}{\pi}$ to fall somewhere in the interval $(1 - (1 - \lambda) \frac{2+2\sqrt{2}}{1+2\sqrt{2}}, \frac{2}{3}\lambda]$. From equations (23) and (24), we know that the agent's wage w is directly related to the wage in the alternative rice sector w_R . Thus, by changing the endowment of (rice-sector) land we can always shift w_R so that $\frac{w}{\pi}$ lies in the required interval. Finally, we have also focused on situations in which both China and Thailand keep some production in the auto and the rice 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 rice-sector wage with respect to employment.

Endogenizing λ

A country with a lower value of λ is more attractive to principals because a principal's returns under the agent-assisted and agent-managed forms is $(1 - \lambda)\pi$. If differences across countries in λ are of interest, we can easily endogenize λ with virtually no extra work. To this end, assume that λ differs across countries so that we have λ and λ^* . Also assume that there is never an agent-uninvolved form i.e., that there are only agent-assisted and agent-managed forms. Then w is no longer part of the model and we can write the Chinese agent indifference condition (equation 23) as

$$\int_0^{1/\sqrt{2}} \frac{(1+2s)^2}{(1+s)(2+s)} dF(s) + \int_{1/\sqrt{2}}^1 \frac{2(1+s)}{2+s} dF(s) = \frac{4}{\lambda} \frac{w_R(L-m)}{\pi}. \quad (\text{A1})$$

The Thai agent indifference (equation 24) is

$$\int_0^{1/\sqrt{2}} \frac{(1+2s)^2}{(1+s)(2+s)} dF^*(s) + \int_{1/\sqrt{2}}^1 \frac{2(1+s)}{2+s} dF^*(s) = \frac{4}{\lambda^*} \frac{w_R(L-m^*)}{\pi}. \quad (\text{A2})$$

To obtain principal indifference between markets recall that $V_p \equiv \frac{4P}{(1-\lambda)\pi} \mathbf{EU}_p$. Using \mathbf{EU}_p in place of V_p in equation (25) yields

$$\begin{aligned} & \frac{(1-\lambda)\pi}{4P} \left\{ \int_0^{1/\sqrt{2}} \frac{2(1+s)}{(2+s)} dF(s) + \int_{1/\sqrt{2}}^1 \frac{(1+2s)^2}{(1+s)(2+s)} dF(s) \right\} \\ &= \frac{(1-\lambda^*)\pi}{4P} \left\{ \int_0^{1/\sqrt{2}} \frac{2(1+s)}{(2+s)} dF^*(s) + \int_{1/\sqrt{2}}^1 \frac{(1+2s)^2}{(1+s)(2+s)} dF^*(s) \right\}. \end{aligned} \quad (\text{A3})$$

By first-order stochastic dominance, the term in braces is larger in China than in Thailand. Hence $\frac{(1-\lambda)\pi}{4P} < \frac{(1-\lambda^*)\pi}{4P}$ or $\lambda > \lambda^*$. In equations (A1)-(A2), first-order stochastic dominance implies that the left-hand side is larger in China than Thailand. Hence $\frac{4}{\lambda\pi} w_R(L-m) > \frac{4}{\lambda^*\pi} w_R(L-m^*)$. This together with $\lambda > \lambda^*$ implies $w_R(L-m) > w_R(L-m^*)$ or $m > m^*$. This establishes almost equivalent versions of our two main propositions 2 and 4: more principals locate in China than in Thailand and earnings $\lambda\pi$ are higher in China than in Thailand.

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