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Capital heterogeneity as a source of comparative advantage: Putty-clay technology in a ricardian model☆

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ABSTRACT

This paper considers how heterogeneity in capital goods affects international trade patterns, and shows a novel source of comparative advantage: the magnitude of heterogeneity in capital goods. Capital goods are heterogeneous in their vintage and productivity, and due to capacity constraints, only productive capital goods are activated in the equilibrium. Through this selection, the distribution of capital goods determines industry-level productivity: industry-level productivity is higher in an industry with relatively larger variation in capital goods. Hence in a perfectly competitive two-country, two-good, two-factor equilibrium, the industry has Ricardian comparative advantage. An extension of the model, which includes fixed trade cost, describes a sorting situation in which the most productive production units (which are generally newer vintage) export, the moderately productive units serve the domestic market, and the least productive units (older) do not operate.

1. Introduction

While investment drives several aspects of aggregate economy, trade models frequently abstract investment decisions regarding capital goods by considering an endowment economy. In models that do include investment decisions, capital goods are commonly assumed to be homogeneous. However, heterogeneity in productivity is an important empirical aspect of capital goods: Some capital goods are more productive than others within the same industry.

This paper considers the role of investment and productivity heterogeneity of capital goods in international trade patterns. Specifically, I introduce putty-clay production technology in the style of Gilchrist and Williams (2000, 2005) into an international trade model considered by Baxter (1992), and discover that the magnitude of heterogeneity in capital goods is a source of Ricardian comparative advantage.

Baxter (1992) includes endogenous capital accumulation, intertemporal optimization and neoclassical production function in the classical "2 by 2 by 2" (two-country, two-good, and two-factor) international trade model. She shows that in the steady-state of the dynamic economy, the pattern of comparative advantage is described as a Ricardian model, compared to the classical endowment "2 by 2 by 2" model that implies a Heckscher–Ohlin trade pattern. When capital is endogenous, the amount of capital is fully adjusted so that returns on investment are equalized across industries. As a result, the economy effectively has only one input (labor) as in the Ricardian model. The relative price of goods under autarky is determined by the ratio of productivities across industries, and this relative price predicts the pattern of specialization that occurs when countries are engaged in trade. Baxter's result indicates the importance of explicitly considering investment decisions when capital goods exist. However, her approach does not consider heterogeneity in capital goods.

Considerable empirical evidence shows that even in a narrowly defined industry, the quality (i.e., productivity and capital-intensity) of capital goods differs significantly across firms (Goolsbee, 2004; Foster

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et al., 2008). The quality of capital goods can vary greatly even within a firm (e.g., Goolsbee and Gross, 2000).[1] Theoretically, a productivity difference is partly caused by the capacity constraint and the inflexibility (e.g., irreversibility) of capital goods (Cooper and Haltiwanger, 2006). Without capacity constraint, production occurs only for the most productive capital good. The inflexibility of capital goods is also important: firms would adjust the quality of capital goods according to their economic environment if such an adjustment could be made instantaneously at no additional cost.

One source of heterogeneity in capital goods is vintage. New capital goods tend be more productive than older ones, thanks to technological progress. For example, using U.S. manufacturing plant data, Jensen et al. (2001) show that new entrants in recent years are significantly more productive than past entrants in their entry year. Another source of heterogeneity is idiosyncratic productivity variations among capital goods of the same vintage. For example, among industrial, mining, and farming machines, and office and transportation-related equipment, some machines malfunction, which requires a series of inspections and repairs, and effectively renders them less productive than other machines of the same make and model.[2] Since industrial machines, such as assembly lines, supercomputers, transportation equipment and farm equipment, have become more and more complex and consist of many parts and/or computerized functions, a malfunction in one part of the machinery often leads to a breakdown of the entire machinery ("O-ring" theory: Kremer, 1993; Jones, 2011). Such variation leads to ex post productivity variations among ex ante same capital goods.

Putty-clay production technology is attractive for analyzing heterogeneity in capital goods since the approach incorporates vintage, capacity constraint, investment irreversibility, and endogenous utilization decision. Gilchrist and Williams (2000, 2005) introduce putty-clay technology into a closed-economy, single-industry business cycle model. In their model, capital goods (called "machines") have distinct vintage and idiosyncratic productivity. The machine-level labor-productivity depends on endogenously chosen capital-intensity and an exogenously determined idiosyncratic productivity component. This idiosyncratic productivity component is determined after the determination of capital-intensity. Once a machine is built, it is impossible to change its capital-intensity or to revert to investment goods. Moreover, capacity is constrained: the operational choice is to allocate one worker to each machine or keep the machine idle.[3]

Under this heterogeneous capital setting, the aggregate production function in the steady state is represented as a standard Cobb–Douglas function, but its Solow residual is determined in part by the capital heterogeneity. With machine heterogeneity, less productive machines are not profitable, and hence not used in the equilibrium. Gilchrist and Williams (2005) show that a temporary increase in the idiosyncratic productivity variation provides an economy-wide productivity benefit. This benefit occurs through the optimal reallocation of labor across machines. That is, variations in idiosyncratic productivity lead to a change in the aggregate productivity.

Introducing this putty-clay technology into an international model considered by Baxter (1992), I find a novel source of comparative advantage: the heterogeneity of capital goods. In the steady-state of the dynamic "2 by 2 by 2" economy, trade pattern and gains from trade are generally described by Ricardian comparative advantage, as in Baxter (1992). Under autarky, differences in the magnitude of machine-level productivity heterogeneity across industries lead to differences in industry-level productivity. Greater machine-level variation provides an industry-level productivity benefit through the optimal allocation of labor across machines since less productive machines are not used in the equilibrium. Hence, an industry with larger idiosyncratic variation has higher industry-level productivity than an industry with less variation, and the price of the former good is lower than the price of the latter good. Moreover, in the industry-level aggregation, the production is represented as a Cobb–Douglas function, and the contribution of heterogeneity appears in a part of the Solow residual. By considering costless trade equilibrium, since the difference in the relative price under autarky determines the pattern of specialization, a country specializes in an industry with relatively larger capital goods heterogeneity. In this sense, trade is based on the technology-driven (i.e., Ricardian) comparative advantage, and the industry-level Solow residual helps predict trade patterns.

Next, I consider an extended model with a fixed trade cost. This model describes a situation in which the most productive (typically newer) machines export, moderately productive machines serve the domestic market, and the least productive (older) machines do not operate. This sorting implication is closely related to recent empirical findings (e.g., Bernard and Jensen, 1997, 1999; Bernard et al., 2003; Tomiura, 2007). Melitz (2003) developed a popular explanation of this type of sorting. His model appeals to productivity heterogeneity, fixed costs of operation and exporting, and monopolistic competition; however, my model offers a fundamentally different mechanism of sorting based on the combination of productivity heterogeneity, fixed exporting cost, and capacity constraint. Essentially, each machine is used for its most profitable operation within its capacity constraints. If the price of a good is higher in the foreign country, yet delivering the good to the foreign country requires a fixed trade cost, exporting is profitable only for the most productive machines. Moreover, the model provides a prediction regarding sorting and vintage. As technology gradually improves and becomes capital-embodied, newer machines tend to be more productive—and thus more likely to be used for exporting.

Even with the introduction of the fixed trade cost, the overall trade pattern is described as a Ricardian model. In general, a country produces more of the product with comparative advantage. The trade gains arise from two reallocations: across industries (a reallocation that itself arises by exploiting comparative advantage) and across machines within an industry.

This paper offers new insights into three distinct research areas: (1) the source of comparative advantage, (2) firm-level trade, and (3) implications of putty-clay technology and micro-production based theories of aggregate productivity.

The source of comparative advantage has been the central subject of international trade studies (e.g., Feenstra, 2004). Traditionally, the comparative advantage results from a country's industry-level technology and aggregate factor endowment.[4] Emerging literature considers differences in skill distribution across labor as a source of comparative

[1] Goolsbee and Gross, (2000) use data from airline companies. Obviously, capital goods (aircraft) differ in their quality (e.g., capacity and fuel efficiency) even within the same airline company.

[2] Typical examples are transportation, construction and farm equipment (e.g., vehicles, dump trucks and combine harvesters). In the U.S., "lemon laws" (at the federal level, the Magnuson–Moss Warranty Act) protect consumers by ensuring compensatory recourse for defective personal vehicles and certain other purchases. However, the application of lemon laws to business vehicles is limited, and in the case of farming equipment, depends on individual states. This limitation has significant consequences for farmers. Mechanical deficiencies lower the productivity of machines. Moreover, during periods of inspection and repair, the machines cannot be operated, and hence productivity is much lower.

[3] Johansen, (1972, chap. 9), Fuss, (1977), Lasserre, (1985) and Salvanes and Tveteras, (2004) empirically confirm these key characterizations of putty-clay production technology using various micro-level data. In the context of the transportation, construction and farm equipment examples in Footnote 1, putty-clay works as follows. First, before installing or adding equipment, a firm can choose the equipment size, for example, a twelve-ton capacity dump truck. However, the size, which cannot be changed afterwards (e.g., to sixteen-ton capacity), determines capital-intensity. In the case of the dump truck this occurs because the vehicle requires only one operator at a time. Some dump trucks are "lemons" and experience a series of mechanical failures. Productivity over a certain period of time becomes low or zero for these trucks. Other types of machines experiencing mechanical troubles may produce products that do not meet quality standards. These deficiencies also lead to low idiosyncratic productivity.

[4] Costinot, (2009) summarizes traditional theories of comparative advantage, and shows that technological conditions and factor endowment lead to comparative advantages.