



รายงานวิจัยฉบับสมบูรณ์

การเติบโตผลผลิตภาพปัจจัยการผลิตรวมทางการเกษตรของเอเชีย

ผู้ช่วยศาสตราจารย์ ดร. ศุภวัจน์ รุ่งสุริยะวิบูลย์

เดือน พฤศจิกายน ปี 2551

สัญญาเลขที่ MRG5080063

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คณะเศรษฐศาสตร์
มหาวิทยาลัยเชียงใหม่

สนับสนุนโดยสำนักงานกองทุนสนับสนุนการวิจัย

(ความเห็นในรายงานนี้เป็นของผู้วิจัย สกว.ไม่จำเป็นต้องเห็นด้วยเสมอไป)

กิตติกรรมประกาศ

งานวิจัยเรื่อง “การเติบโตผลิตภาพปัจจัยการผลิตรวมทางการเกษตรของเอเชีย” ได้รับการสนับสนุนเงินทุนวิจัยทุนพัฒนาศักยภาพในการทำงานของอาจารย์รุ่นใหม่ ประจำปี พ.ศ. 2549 จากสำนักงานกองทุนสนับสนุนการวิจัยร่วมกับสำนักงานคณะกรรมการการอุดมศึกษา ผู้เขียนจึงใคร่ขอขอบคุณสำนักงานกองทุนสนับสนุนการวิจัยและสำนักงานคณะกรรมการการอุดมศึกษาที่ได้กรุณาให้การสนับสนุนด้านเงินทุนในการวิจัยครั้งนี้

ผู้เขียนขอขอบคุณคณะเศรษฐศาสตร์ มหาวิทยาลัยเชียงใหม่ ที่ให้การสนับสนุนผู้เขียนเป็นอย่างดีด้วยมาตลอดระยะเวลาในการดำเนินการวิจัยนี้ นอกจากนี้ ผู้เขียนขอขอบคุณ รองศาสตราจารย์ ดร. ทรงศักดิ์ ศรีบุญจิตต์ ที่ให้ความอนุเคราะห์เป็นนักวิจัยที่ปรึกษา และให้คำปรึกษาแนะนำด้วยดีตลอดมา

ผู้เขียนขอขอบคุณ Professor Alfons Balmann ผู้อำนวยการสถาบัน Agricultural Development in Central and Eastern Europe (IAMO) ประเทศสหพันธ์สาธารณรัฐเยอรมนี ที่ได้เชิญให้ผู้เขียนไปบรรยายเกี่ยวกับแบบจำลองที่ผู้เขียนได้พัฒนาขึ้นในงานวิจัยนี้ รวมถึงได้ให้ผู้เขียนนำเสนอผลการศึกษาที่ได้จากงานวิจัยนี้แก่นักวิจัยและนักศึกษาระดับปริญญาเอกของทางสถาบัน นอกจากนี้ ผู้เขียนขอขอบคุณ Dr. Xiaobing Wang ที่ได้ให้ความช่วยเหลือในการจัดเก็บรวบรวมข้อมูลของประเทศจีนที่นำมาใช้ในงานวิจัยนี้ ตลอดจนให้ข้อเสนอแนะและคำแนะนำที่เป็นประโยชน์ต่องานวิจัยเป็นอย่างมาก

สุดท้ายนี้ ผู้เขียนหวังเป็นอย่างยิ่งว่าผลการศึกษาที่ได้จากงานวิจัยนี้จะประโยชน์ไม่มากนักน้อยแก่ผู้สนใจศึกษาเรื่องการวัดประสิทธิภาพและผลิตภาพทางการเกษตรของประเทศต่างๆ ในทวีปเอเชีย นอกจากนี้ แบบจำลองที่ผู้เขียนได้นำเสนอในงานวิจัยนี้ยังสามารถนำไปประยุกต์ใช้กับอุตสาหกรรมอื่นๆ ได้ หากงานวิจัยนี้มีข้อผิดพลาดประการใด ผู้เขียนยินดีน้อมรับคำแนะนำเพื่อนำมาปรับปรุงใช้ในการพัฒนางานวิจัยต่อไปในอนาคต

ศุภวัจน์ รุ่งสุริยะวิบูลย์
พฤศจิกายน 2551

บทคัดย่อ

รหัสโครงการ : MRG5080063

ชื่อโครงการ : การเติบโตผลิตภาพปัจจัยการผลิตรวมทางการเกษตรของเอเชีย

ชื่อนักวิจัย : ผศ. ดร. ศุภวัฒน์ รุ่งสุริยะวิบูลย์ สังกัด คณะเศรษฐศาสตร์ มหาวิทยาลัยเชียงใหม่

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งานวิจัยนี้ได้ศึกษาเพื่อวัดผลการดำเนินการทางการเกษตรของประเทศต่างๆในทวีปเอเชีย สาธารณรัฐประชาชนจีนถือเป็นประเทศที่ประกอบไปด้วยประชากรและทรัพยากรทางการเกษตรมากที่สุดของโลก และในช่วงสองทศวรรษที่ผ่านมาประเทศต่างๆในทวีปเอเชียที่เคยปกครองในระบอบสังคมนิยมได้ทำการปฏิรูประบบเศรษฐกิจมาเป็นระบบเศรษฐกิจแบบเสรีที่ขึ้นอยู่กับกลไกตลาด เพื่อให้เข้าใจถึงผลการดำเนินการทางการเกษตรของประเทศต่างๆในทวีปเอเชีย งานวิจัยนี้ได้ทำการวัดค่าการเติบโตผลิตภาพปัจจัยการผลิตรวมทางการเกษตรโดยแบ่งการศึกษาออกเป็น 2 ระยะ ระยะที่ 1 มีวัตถุประสงค์เพื่อวัดค่าการเติบโตผลิตภาพปัจจัยการผลิตรวมทางการเกษตรของสาธารณรัฐประชาชนจีน โดยอาศัยฐานข้อมูลการผลิตทางการเกษตรของจังหวัดต่างๆจำนวน 28 จังหวัดของประเทศจีนระหว่างช่วงเวลาในปี ค.ศ. 1991-2005 ซึ่งข้อมูลเก็บรวบรวมได้จากรายงานประจำปี China Statistical Yearbook และ Chinese Agricultural Statistical ระยะที่ 2 มีวัตถุประสงค์เพื่อวัดและเปรียบเทียบค่าการเติบโตผลิตภาพปัจจัยการผลิตรวมทางการเกษตรของประเทศต่างๆในทวีปเอเชีย โดยจะมุ่งเน้นถึงผลการดำเนินการที่เกิดขึ้นสำหรับประเทศต่างๆในภูมิภาคนี้ที่ได้ทำการปฏิรูประบบเศรษฐกิจแบบรวมศูนย์อำนาจจากกรรมสิทธิ์ของรัฐมาเป็นระบบเศรษฐกิจแบบเสรีที่ขึ้นอยู่กับกลไกตลาด โดยอาศัยฐานข้อมูลการผลิตทางการเกษตรของประเทศต่างๆในทวีปเอเชียจำนวน 27 ประเทศขององค์การอาหารและการเกษตรของสหประชาชาติ ระหว่างปี ค.ศ. 1980-2004

ผลการศึกษาในระยะที่ 1 ที่ได้จากงานวิจัยนี้พบว่า ค่าเฉลี่ยการเติบโตผลิตภาพปัจจัยการผลิตรวมทางการเกษตรของสาธารณรัฐประชาชนจีนระหว่างปี ค.ศ. 1991-2005 มีค่าเท่ากับ 3.2

เปอร์เซ็นต์ต่อปี และปัจจัยสำคัญที่ส่งเสริมให้เกิดการเจริญเติบโตผลิตภาพปัจจัยการผลิตรวมทางการเกษตรในสาธารณรัฐประชาชนจีน คือ การเปลี่ยนแปลงอันเนื่องมาจากเทคโนโลยี

นอกจากนั้น ผลการศึกษาในระยะที่ 2 ที่ได้จากงานวิจัยนี้พบว่า ค่าเฉลี่ยของการเติบโตผลิตภาพปัจจัยการผลิตรวมของประเทศต่างๆในทวีปเอเชียระหว่างปี ค.ศ. 1980-2004 มีค่าเท่ากับ 2 เปอร์เซ็นต์ต่อปี อย่างไรก็ตาม ค่าการเติบโตผลิตภาพปัจจัยการผลิตรวมของประเทศต่างๆในภูมิภาคเอเชียมีความแตกต่างกันมาก ประเทศที่แสดงค่าการเติบโตของผลิตภาพปัจจัยการผลิตรวมทางการเกษตรอยู่ในเกณฑ์สูง ได้แก่ ประเทศจีน และมองโกเลีย ในขณะที่ประเทศคาซัคสถาน อุซเบกิสถาน ลาว และ เวียดนาม แสดงค่าการเติบโตของผลิตภาพปัจจัยการผลิตรวมทางการเกษตรอยู่ในเกณฑ์ต่ำ

คำหลัก การเกษตรกรรม สาธารณรัฐประชาชนจีน เอเชีย ผลิตภาพปัจจัยการผลิตรวม ประเทศ เปลี่ยนผ่านระบบเศรษฐกิจ

Abstract

Project Code : MRG5080063

Project Title : Total Factor Productivity Growth in Asian Agriculture

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This study aims to investigate interregional and intercountry differences in terms of the magnitude and direction of agricultural growth in Asian countries. Among Asian countries, China is the world's most populous country and contains a substantial share of the world agricultural resources. During the past two decades many Asian countries have undergone a transformation from a centrally planned economy to a free market economy. To understand the state of agricultural productivity growth among Asian countries, this study was carried out in two stages. This first stage was to measure total factor productivity growth in Chinese agriculture using a panel data set of 28 provinces covering the time period of 1991 to 2005. The primary data on agricultural production were extracted from the official data sources-- China Statistical Yearbook and Chinese Agricultural Statistical Yearbook. The second stage of this study was to investigate interregional and intercountry differences of agricultural total factor productivity growth in Asian countries by giving special attention to the transition economies. The most recent Food and Agricultural Organisation (FAO) of the United Nations data set of 27 Asian countries over the period from 1980-2004 was used to measure and compare total factor productivity growth in Asian agriculture.

The findings obtained from the first stage of the study indicate that China on average achieved total factor productivity growth at 3.2 percent per annum which was typically considered as a sign that agriculture was healthy in terms of its improvement in productivity. The decomposition of total factor productivity growth showed convincingly that the relatively high rate of total factor productivity growth in Chinese agriculture was mainly driven by technology improvement.

In addition, the findings obtained from the second stage of this study indicate that Asian countries on average achieved total factor productivity growth at nearly 2 percent per annum. However, there were large differences among the transition countries in terms of the magnitude and direction of total factor productivity growth. Some transition countries such as China and Mongolia exhibited above average growth. Others, such as, Kyrgyzstan, Uzbekistan, Laos, and Vietnam did not do so well.

Keywords : Agriculture, China, Asia, Total Factor Productivity, Transition Countries

Executive Summary

วิกฤติด้านอาหารของโลกได้กลายเป็นประเด็นเชิงนโยบายที่สำคัญของรัฐบาลในหลายๆประเทศ เป็นที่แน่ชัดว่าในแต่ละภูมิภาคของโลกจำเป็นต้องเร่งทำการผลิตสินค้าเกษตรให้ได้เพียงพอ เพื่อที่จะสามารถรองรับต่อความต้องการด้านอาหารที่เติบโตสูงขึ้นในช่วงครึ่งแรกของศตวรรษนี้ เอเชีย ถือได้ว่าเป็นทวีปที่มีขนาดใหญ่และมีจำนวนประชากรมากที่สุดในโลก นอกจากนั้น ทวีปเอเชียประกอบไปด้วยทรัพยากรที่มีศักยภาพสำหรับการผลิตสินค้าทางการเกษตรที่สำคัญของโลก ดังนั้น เอเชียจึงถือได้ว่าเป็นทวีปหนึ่งที่มีศักยภาพในการผลิตสินค้าทางการเกษตรที่จะเป็นส่วนแบ่งที่สำคัญของโลกเพื่อที่จะสามารถรองรับต่อการเติบโตทางด้านอุปสงค์อาหารที่เพิ่มขึ้นอย่างมากในศตวรรษนี้

ในช่วงสองทศวรรษที่ผ่านมาประเทศต่างๆในภูมิภาคนี้ที่เคยปกครองในระบอบสังคมนิยมได้ทำการปฏิรูประบบเศรษฐกิจมาเป็นระบบเศรษฐกิจแบบเสรีที่ขึ้นอยู่กับกลไกตลาด ตัวอย่างเช่น ประเทศในภูมิภาคเอเชียตะวันออก ได้แก่ จีน และ มองโกเลีย เริ่มการปฏิรูประบบเศรษฐกิจในปี ค.ศ. 1979 และ 1991 ตามลำดับ ประเทศในภูมิภาคเอเชียตะวันออกเฉียงใต้ เช่น เวียดนาม และ ลาว เริ่มการปฏิรูประบบเศรษฐกิจในปี ค.ศ. 1986 ในขณะที่ พม่า เริ่มการปฏิรูประบบเศรษฐกิจในปี ค.ศ. 1989 สำหรับประเทศเปลี่ยนผ่านที่ตั้งอยู่ในภูมิภาคเอเชียกลางที่ได้แยกตัวออกจากสหภาพโซเวียต ได้แก่ Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan และ Uzbekistan เริ่มการปฏิรูประบบเศรษฐกิจในปี ค.ศ. 1991

ในระหว่างสองทศวรรษที่ผ่านมา เอเชียประสบผลสำเร็จอย่างมากในการผลิตสินค้าทางการเกษตรภายหลังจากการปฏิวัติเขียวได้เริ่มต้นในช่วงปลายทศวรรษ 1960 ความสำเร็จที่เกิดขึ้นเป็นผลสืบเนื่องมาจากการใช้เมล็ดพันธุ์พืชที่มีคุณภาพที่ให้ผลผลิตสูง การใช้ปุ๋ยเคมีและสารกำจัดศัตรูพืชในกระบวนการผลิต รวมถึงการพัฒนาระบบชลประทาน อย่างไรก็ตาม การใช้ปัจจัยการผลิตแต่ละชนิดที่เพิ่มขึ้นนี้ไม่สามารถเป็นเครื่องประกันได้ว่าอัตราการเติบโตของผลผลิตที่ได้จะมีความยั่งยืน เนื่องจากปัจจัยการผลิตหรือวัตถุดิบต่างๆ รวมทั้งแรงงาน ที่ดิน และทุน เป็นทรัพยากรที่มีอยู่อย่างจำกัดและมีอัตราการขยายตัวอยู่ในเกณฑ์ต่ำ การที่จะรักษาการเติบโตทางการผลิตด้านการเกษตรให้มีความยั่งยืนได้นั้นจะไม่สามารถให้ความสำคัญในเรื่องการเติบโตของปัจจัยการผลิตได้เพียงอย่างเดียว แต่จะต้องคำนึงถึงการเพิ่มผลผลิตการผลิตทางการเกษตรด้วย การเติบโตผลผลิตทางการเกษตรจะเกิดขึ้นได้เป็นผลเนื่องมาจากความก้าวหน้าของเทคโนโลยีสมัยใหม่ การใช้ทรัพยากรในกระบวนการผลิตได้อย่างมีประสิทธิภาพ รวมถึงการเลือกใช้นาของการผลิตให้เป็นไปอย่างเหมาะสมและมีประสิทธิภาพ ดังนั้น การศึกษาเพื่อวัดการเติบโตผลผลิตในภาคการเกษตร รวมถึงองค์ประกอบหรือปัจจัยต่างๆที่ส่งเสริมให้เกิดการเติบโตผลผลิตขึ้นในการผลิตภาคการเกษตรของทวีปเอเชียจึงเป็นหัวข้อที่นักวิจัยให้ความสำคัญ

เนื่องจากค่าการเติบโตผลผลิตภาพที่วัดได้จะเป็นข้อมูลที่มีประโยชน์แก่ผู้กำหนดนโยบายในการนำไปใช้เพื่อวางแผนเชิงนโยบายที่เหมาะสมในการส่งเสริมให้เกิดการเพิ่มผลผลิตภาพภาคการเกษตรของภูมิภาคนี้ต่อไป

ในแวดวงวรรณกรรม การศึกษาเพื่อวัดและเปรียบเทียบค่าการเติบโตผลผลิตภาพปัจจัยการผลิตรวมทางการเกษตรของประเทศต่างๆในทวีปเอเชียไม่ได้รวมเอากลุ่มประเทศเปลี่ยนผ่านที่แยกตัวออกจากสหภาพโซเวียตไว้ในการศึกษา เนื่องจากที่ผ่านมามีข้อมูลด้านการผลิตของประเทศดังกล่าวไม่สามารถจัดหาได้ และถ้าหากพิจารณาประเทศต่างๆในทวีปเอเชียจะพบว่า ประเทศสาธารณรัฐประชาชนจีนมีจำนวนประชากรและประกอบไปด้วยส่วนแบ่งการผลิตทางการเกษตรมากที่สุดในโลก นอกจากนั้น ประเทศจีนยังมีอัตราการเติบโตทางการเกษตรที่สูงมากประเทศหนึ่ง ดังนั้น เพื่อให้เข้าใจถึงผลการดำเนินการทางการเกษตรของประเทศต่างๆในทวีปเอเชีย งานวิจัยนี้ได้ทำการวัดค่าการเติบโตผลผลิตภาพปัจจัยการผลิตรวมทางการเกษตรโดยแบ่งการศึกษาออกเป็น 2 ระยะ

ระยะที่ 1 เป็นการศึกษาเพื่อวัดค่าการเติบโตผลผลิตภาพปัจจัยการผลิตรวมทางการเกษตรของสาธารณรัฐประชาชนจีน โดยอาศัยฐานข้อมูลการผลิตทางการเกษตรของจังหวัดต่างๆจำนวน 28 จังหวัดของประเทศจีนระหว่างช่วงเวลาในปี ค.ศ. 1991-2005 ซึ่งข้อมูลที่น่ามาใช้สามารถเก็บรวบรวมได้จากรายงานประจำปี China Statistical Yearbook และ Chinese Agricultural Statistical Yearbook จังหวัดต่างๆที่ใช้ในการศึกษาถูกแบ่งออกเป็น 2 กลุ่ม ได้แก่ จังหวัดที่มีเทคโนโลยีการผลิตสูงและต่ำ ค่าการเติบโตผลผลิตภาพปัจจัยการผลิตรวมถูกประมาณได้โดยการใช้วิธีการประมาณค่าจากเส้นพรมแดนเปลี่ยนผ่าน (metafrontier) ภายใต้ข้อสมมติฐานที่ว่าหน่วยผลิตที่ทำการผลิตในแต่ละกลุ่มสามารถทำการผลิตอยู่ภายใต้เทคโนโลยีการผลิตของตน ค่าการเติบโตผลผลิตภาพปัจจัยการผลิตรวมที่วัดได้นี้สามารถแยกออกได้เป็นองค์ประกอบต่างๆที่สำคัญ อันได้แก่ การเปลี่ยนแปลงประสิทธิภาพเชิงเทคนิค การเปลี่ยนแปลงประสิทธิภาพของขนาด และการเปลี่ยนแปลงเทคโนโลยี

ผลการศึกษาพบว่า ค่าเฉลี่ยการเติบโตผลผลิตภาพปัจจัยการผลิตรวมทางการเกษตรของสาธารณรัฐประชาชนจีนระหว่างปี ค.ศ. 1991-2005 มีค่าเท่ากับ 3.2 เปอร์เซ็นต์ต่อปี และปัจจัยสำคัญที่ส่งเสริมให้เกิดการเติบโตผลผลิตภาพปัจจัยการผลิตรวมทางการเกษตรในสาธารณรัฐประชาชนจีน คือ การเปลี่ยนแปลงอันเนื่องมาจากเทคโนโลยี ในขณะที่การเปลี่ยนแปลงอันเนื่องมาจากประสิทธิภาพเชิงเทคนิคและขนาดของการผลิตเป็นไปอย่างถดถอย โดยส่วนใหญ่จังหวัดที่มีเทคโนโลยีการผลิตสูงมีค่าเฉลี่ยประสิทธิภาพเชิงเทคนิคสูงกว่าจังหวัดที่มีเทคโนโลยีการผลิตต่ำ ปัจจัยแรงงานและปุ๋ยเป็นองค์ประกอบสำคัญในการผลิต การเพิ่มคุณภาพของเกษตรกรและการใช้ปัจจัยการผลิตที่ทันสมัยจะเป็นตัวแปรสำคัญที่ส่งเสริมให้เกิดการเพิ่มผลผลิต

ระยะที่ 2 เป็นการศึกษาเพื่อวัดและเปรียบเทียบค่าการเติบโตผลผลิตภาพปัจจัยการผลิตรวมทางการเกษตรของประเทศต่างๆในทวีปเอเชีย โดยการศึกษามุ่งเน้นถึงผลการดำเนินการที่เกิดขึ้นสำหรับประเทศต่างๆในภูมิภาคนี้ที่ได้ทำการปฏิรูประบบเศรษฐกิจแบบรวมศูนย์อำนาจจากกรรมสิทธิ์ของรัฐมาเป็นระบบเศรษฐกิจแบบเสรีที่ขึ้นอยู่กับกลไกตลาด โดยอาศัยฐานข้อมูลการผลิตทางการเกษตรของประเทศต่างๆในทวีปเอเชียจำนวน 27 ประเทศที่เก็บรวบรวมได้จากองค์กรอาหารและ

การเกษตรของสหประชาชาติ ระหว่างปี ค.ศ. 1980-2004 ค่าการเติบโตผลิตภาพปัจจัยการผลิตรวมทางการเกษตรของประเทศต่างๆในทวีปเอเชียทำการวัดโดยอาศัยวิธีการประมาณค่าจากฟังก์ชันระยะทางผลผลิต ซึ่งค่าการเติบโตผลิตภาพปัจจัยการผลิตรวมที่วัดได้นี้สามารถแยกค่าออกเป็นองค์ประกอบสำคัญต่างๆที่เป็นปัจจัยส่งเสริมให้เกิดการเจริญเติบโตของผลิตภาพ อันได้แก่ การเปลี่ยนแปลงประสิทธิภาพเชิงเทคนิค การเปลี่ยนแปลงประสิทธิภาพของขนาด และการเปลี่ยนแปลงเทคโนโลยี โดยที่การเปลี่ยนแปลงเทคโนโลยีสามารถแยกค่าออกได้เป็น การเปลี่ยนแปลงเทคโนโลยีที่เบี่ยงเบนในผลผลิตและปัจจัยการผลิตแต่ละชนิด

ผลการศึกษาแสดงให้เห็นว่า ค่าเฉลี่ยของการเติบโตผลิตภาพปัจจัยการผลิตรวมทางการเกษตรของทวีปเอเชีย มีค่าเท่ากับ 2 เปอร์เซ็นต์ต่อปี ระหว่างปี ค.ศ. 1980-2004 ปัจจัยหลักที่ส่งผลต่อการเติบโตผลิตภาพทางการเกษตร คือ การเปลี่ยนแปลงเทคโนโลยี นั้นแสดงว่า ประเทศต่างๆได้มีการนำเอาเทคโนโลยีใหม่ๆมาใช้ในการกระบวนการผลิตเพื่อส่งเสริมให้เกิดการเติบโตผลิตภาพทางการเกษตรขึ้นในภูมิภาค นอกจากนั้น ภายหลังจากที่ได้มีการนำเอาเทคโนโลยีใหม่ๆมาใช้ ประเทศต่างๆในเอเชียโดยส่วนใหญ่ได้มีการใช้ปัจจัยการผลิต ได้แก่ เครื่องจักรกล ปุ๋ย และแรงงานสัตว์ เพิ่มมากขึ้น โดยสามารถผลิตปศุสัตว์ได้เพิ่มขึ้น เมื่อพิจารณาถึงผลการดำเนินการของประเทศต่างๆที่ได้มีการปฏิรูประบบเศรษฐกิจในทวีปเอเชียพบว่า โดยเฉลี่ยอัตราการเติบโตผลิตภาพทางการเกษตรของประเทศดังกล่าวมีค่า 2.4 เปอร์เซ็นต์ ต่อปี ซึ่งผลดังกล่าวสามารถสรุปได้ว่า การเติบโตผลิตภาพทางการเกษตรในทวีปเอเชียถูกขับเคลื่อนโดยประเทศต่างๆที่ได้มีการปฏิรูประบบเศรษฐกิจ ผลการศึกษายังแสดงให้เห็นว่าค่าการเติบโตผลิตภาพปัจจัยการผลิตรวมของประเทศต่างๆในทวีปเอเชียมีความแตกต่างกันมาก ประเทศที่แสดงค่าการเติบโตผลิตภาพปัจจัยการผลิตรวมทางการเกษตรอยู่ในเกณฑ์สูง ได้แก่ ประเทศจีน และมองโกเลีย ในขณะที่ประเทศคาซัคสถาน อุซเบกิสถาน ลาว และเวียดนาม แสดงค่าการเติบโตผลิตภาพปัจจัยการผลิตรวมทางการเกษตรอยู่ในเกณฑ์ต่ำ

เนื้อหางานวิจัย

เพื่อให้สามารถเข้าใจถึงค่าการเติบโตผลิตภาพปัจจัยการผลิตรวมทางการเกษตรของประเทศต่างๆในทวีปเอเชีย เนื้อหางานวิจัยของโครงการวิจัยนี้ได้ถูกนำเสนอในรูปแบบของบทความทางวิชาการจำนวน 2 บทความ

บทความที่ 1 เรื่อง “Recent Evidence on Agricultural Efficiency and Productivity in China: A Metafrontier Approach” วัตถุประสงค์หลักของบทความดังกล่าวเพื่อทำการวัดค่าประสิทธิภาพและการเติบโตผลิตภาพปัจจัยการผลิตรวมทางการเกษตรของสาธารณรัฐประชาชนจีน

บทความที่ 2 เรื่อง “Development, Transition and Agricultural Productivity in Asia” วัตถุประสงค์หลักของบทความดังกล่าวเพื่อทำการวัดและเปรียบเทียบค่าการเติบโตผลิตภาพปัจจัยการผลิตรวมทางการเกษตรของประเทศต่างๆในทวีปเอเชีย

Article One

Recent Evidence on Agricultural Efficiency and Productivity in China: A Metafrontier Approach

Abstract

Economic reform in China helped transform the structure and volume of agricultural production and resulted in significant changes in efficiency and productivity. This paper measures agricultural technical efficiency (TE) and total factor productivity (TFP) in China by allowing all producers in different groups operating under their own technologies. A metafrontier function approach is applied using a panel data set on 28 provinces during 1991-2005. The provinces are categorized into advanced- and low-technology provinces. Based on the metafrontier estimation, TFP growth is decomposed into TE change (TEC), technical change (TC) and scale efficiency change (SEC). Our major findings indicate that TC was mostly attributed to Chinese agricultural TFP growth throughout the period of study. SEC and TEC exhibited negative effects to TFP growth for the advance- and low-technology provinces, respectively. Most of the advanced-technology provinces exhibited higher TE than the low-technology provinces. The comparatively low TE scores in the low-technology provinces imply that the low-technology provinces were operating far from the metafrontier. The results also show that labor and fertilizer still make important contributions to output, and thus improving the quality of farmers and applying modern physical inputs is also crucial to TFP growth.

Key words: Metafrontier, Agriculture, China, Technical Efficiency, Total Factor Productivity.

Introduction

Food security remains high on China's political economy agenda. Because the nation uses 7% of its land for farming to feed more than 20% of the population in the world, it is thought that it is essential to maintain sufficient levels of food production to feed at least most of its population (Brown, 1995). Achieving self sufficiency, however, will require that China keeps its level of productivity high.

Concerns about maintaining productivity are not new. A number of efforts inside and outside of China have sought to measure the performance of the nation's productivity in agriculture. For example, since the institutional changes and market reforms initiated in 1978, production and productivity rose by 5% and 10% between 1978 and 1985 [McMillan, Walley and Zhu, 1989; Lin 1992]. Using different data sets, Fan (1991) and Huang and Rozelle (1996) also demonstrated that production, yields and overall productivity was strong in the earlier 1980. The most recent paper that calculated productivity estimates that productivity improvement accounts for around 58% of output growth through 1990 (Liu and Wang, 2005). Clearly, during the 1980s and early 1990s improvements to productivity were instrumental in keeping output high.

Although in the past production and productivity rose very fast, there are several reasons to be concerned that growth in recent years (and in the coming years). Most poignantly, in recent years an increased source of input is being exhausted, such as the limited land resource and the shift of rural labor off the farm [Brown 1995; Jin et al. 2007]. Therefore, in the future output growth will not be able to rely on mobilizing inputs,

but will require rising productivity. For productivity to rise, this means that either TC, TE or scale economies need to improve.

Unfortunately, there are several concerns about productivity rises—especially if they need to rely on TE or scale economies. China's agriculture is special in the world in that it is characterized by an extremely egalitarian distribution of cultivated land which means that there are more than 200 million rural households which each are cultivating less than 0.55 hectares. With such small farms, each household might be expected to be unable or unwilling to search for new ways to improve their efficiency. However, at the same time, the extension system has been shown to have collapsed (Hu et al., 2007). Likewise, there is little reason to believe that even if China could expand its average household's holding of land (through the rapidly growing land rental markets—Jin and Deininger, 2002), the literature is clear that there are few positive scale economies in Asian agriculture (Trueblood and Coggins, 2003).

Therefore, a priori, we know that if productivity after the early 1990s was to expand it almost certainly must rely on the expansion of TC. The record, however, is more mixed on TC. On the one hand, China has traditionally maintained high rates of TC as small farmers have always been eager to adopt new technologies when they were available (Jin et al., 2002). However, after the mid-1980s, there was at least a time when research expenditures fell (Dong, 2000). Although China's officials have begun to invest again (Jin et al., 2007), it is possible that this period of relatively low level of investment in agricultural research and development slowed the production of agricultural technologies and this may have undermined rises in productivity.

In the past decade, the number of papers evaluating both efficiency and productivity in Chinese agricultural production keeps pace with the evolvement of the frontier analysis. Two empirical approaches such as a parametric approach known as Stochastic Frontier Analysis (SFA) and a non-parametric approach known as Data Envelopment Analysis (DEA) provide the foundation for the measurement of producer's efficiency and productivity in the literature. A parametric approach of the SFA model has been extensively applied to analyze efficiency and productivity in the Chinese agricultural growth by Fan (1991), Wu (1995), Kalirajan, Obwona and Zhao (1996), Wang, Wailes, and Cramer (1996), Tian and Wan (2000) and Bruemner, Glauben and Lu (2006). However, these studies extended the SFA model to measure the producer's efficiency and productivity by assuming that all producers in different groups of a given industry are identical and thereby facing the same best practice frontier.

To take account into intergroup differences in production technologies, Mao and Koo (1997) defined the provinces in China into two groups such as advanced- and low-technology provinces due to distinctive levels of economic development and production technologies. Without specifying an ex-ante functional form and assuming the behaviour of producers, they employed a non-parametric approach of the DEA model to measure the producer's efficiency and productivity by allowing all producers in different groups of a given industry operating under their own technologies. When all producers in different groups of a given industry are operating on a different part of their technologies but they have a potential access to the same technology, measuring the producer's efficiency and productivity without taking account into intergroup differences

in production technologies may provide a misleading policy implication. Recently, Battese, Rao and O'Donnell (2004) proposed a parametric estimation of metafrontier function to measure the efficiency of producers under regional differences in production technologies.

The overall goal of our paper is to address this lacuna of the literature in the following dimensions. First, the parametric estimation of the metafrontier function model is applied to measure TE and TFP growth for the provinces in China. By following Mao and Koo (1997), the provinces are also categorized into two groups due to distinctive levels of economic development and production technologies. Secondly, to our surprise, the existing literatures except Bruemner, Glauben and Lu (2006) account for TFP growth into only two components: TEC and TC by ignoring the effect from SEC. Bruemner, Glauben and Lu (2006) found the negative SEC growth which is consistent with the general criticism of land fragmentation problem in Chinese agricultural production (Fleisher and Liu 1992). Rungsuriyawiboon and Lissitsa (2007) conducted a similar study for the transition countries and concluded that SEC has negligible effect for TFP growth in the eastern European countries due to the higher land/labor ratio and flexible land rental system. Since the small parcel of cultivated land and thin land rental market, if SEC is still not the essential source of TFP growth, the current land distribution system would be barrier for the health of agricultural economy. Considering the possible potential of scale efficiency, this paper decomposes TFP growth into associated components: TC, TEC and SEC where TFP growth is measured using the defined metafrontier function. This information is useful for policy makers to design

suitable policies to achieve possible TFP growth through the improvement of TC, TEC and SEC. To our knowledge, it is the initial application of this technique into the empirical application under metafrontier estimation. Thirdly, a more recent panel data set of 28 provinces covering the time period of 1991 to 2005 is used in this paper. Since the start of China's WTO agricultural commitments and subsidizing the grain producers in 2002 promoted structural changes in subsequent years, the analysis in this paper will reflect a period of more rapid market-oriented reform and structure changes of agricultural production in China.

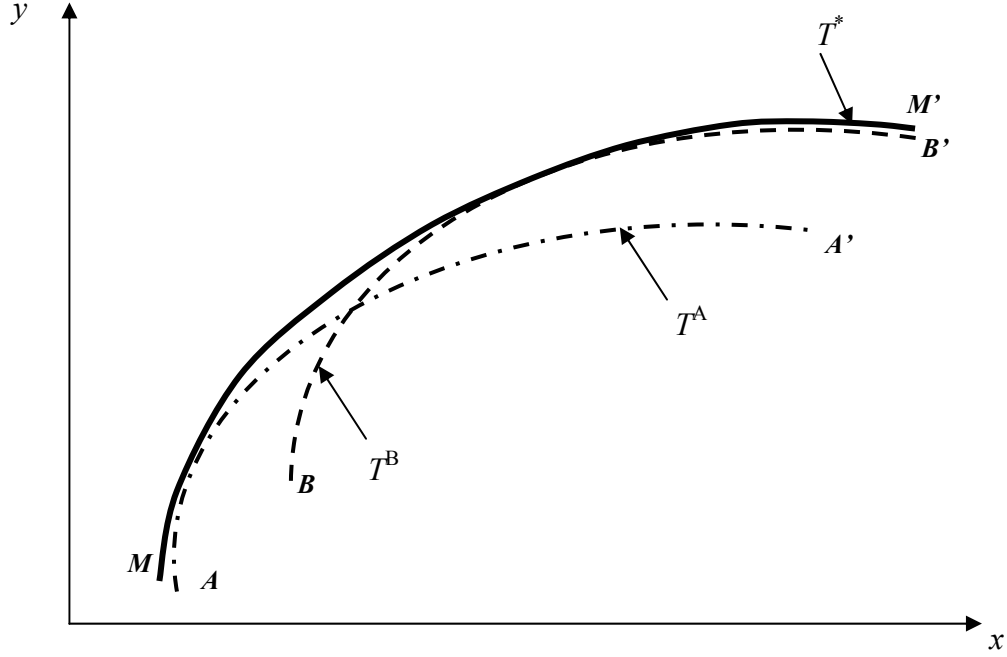
The remainder of this paper is organized as follows. The next section presents a theoretical concept of a metafrontier approach, followed by a discussion of the empirical techniques used to estimate efficiency and productivity using the metafrontier analysis. Then, we describe the data set and the definitions of all variables. The empirical results are presented and discussed, and the final section summarizes our main conclusions.

Model Specification

The SFA model originally proposed by Aigner, Lovell and Schmidt (1977) provides the foundation for the parametric measurement of producer's efficiency in the literature. This model assumes that all producers in different groups of a given industry are operating under the same production technology. When all producers in different groups of a given industry have a potential access to the same technology but each producer may choose to operate on a different part of their technologies depending on

circumstances such as the natural endowments, relative prices of inputs and the economic environment, then the assessment of producer's efficiency and productivity can be measured using a metafrontier concept. Hayami and Ruttan (1970) initially proposed a metaproduction function which is defined as the envelope of commonly conceived neoclassical production functions. Figure 1 illustrates how the metafrontier function is constructed from different groups of production technologies. Consider an industry consists of two different groups of production technologies, namely A and B. A frontier for production technology in group A or T^A which is constructed using the input-output bundles of all producers in group A is represent by line AA' . Similarly, a frontier for production technology in group B or T^B which is constructed using the input-output bundles of all producers in group B is represent by line BB' . If all producers in group A and B have a potential access to the same technology, the grand frontier which envelops the two group-specific frontiers can be represented by line MM' . This line is referred as a metafrontier function and the production technology which is constructed from T^A and T^B is represented by T^* .

Figure 1: Group-Specific Frontier and Metafrontier



Define Group-Specific Technology and Metatechnology

Consider a case where all producers of a given industry are categorized into K groups and producers in each group operate under a group-specific technology T^k where $k=1,\dots,K$ denotes the index of producer groups. For a data set of each group k consisting of a vector of inputs and outputs for each of the i -th producer where $i=1,\dots,I^k$ denotes a producer index. Let the input and output vectors for the i -th producer in the k -th group be denoted $X_i^k = (X_{i1}^k, \dots, X_{iN}^k) \in R_+^N$ and $Y_i^k = (Y_{i1}^k, \dots, Y_{iM}^k) \in R_+^M$, respectively. For any input vector of all producers in the k -th group $X^k \in R_+^N$ and any output vector of all producers in the k -th group $Y^k \in R_+^M$, an input vector X^k is transformed into net outputs Y^k by a production technology T^k .

The technology set for the k -th group technology T^k which satisfies the axioms presented in Färe, Grosskopf and Lovell (1985) is defined as

$$T^k = \{(X^k, Y^k) : X^k \text{ can produce } Y^k\}. \quad (1)$$

Now, consider any input and output vectors of all producers in all groups are given by $X = (X^1 \cup \dots \cup X^K) \in R_+^N$ and $Y = (Y^1 \cup \dots \cup Y^K) \in R_+^M$, respectively. If a particular output $Y \in R_+^M$ can be produced using a given input vector $X \in R_+^N$ in any one of the producer group, a pair (X, Y) is belong to a metatechnology T^* . The T^* is defined as the grand technology which envelops all group-specific technologies, $T^1, \dots, T^K$. The technology set for the metatechnology (T^*) is defined as

$$T^* = \{(X, Y) : X \text{ can produce } Y \text{ in at least one group-specific technology}\}, \quad (2)$$

where the boundary of the metatechnology set indicates the metafrontier.

A measure of TE defined in Farrell (1957) can be analyzed using a distance function. The output distance function of an observed data (X^k, Y^k) relative to the group-specific technology T^k is defined as

$$D_o^k(X, Y) = \min\{\mu^k : Y^k / \mu^k \in T^k\}. \quad (3)$$

$D_o^k(X, Y)$ is equal to output-orientated TE, $TE_o^k(X, Y)$, of the observed data (X^k, Y^k) with respect to T^k , so that $0 \leq TE_o^k(X, Y) = D_o^k(X, Y) \leq 1$. Similarly, the relationship between the output-orientated TE and output distance function of the observed data (X, Y) relative to T^* is defined as $0 \leq TE_o^*(X, Y) = D_o^*(X, Y) \leq 1$ where $D_o^*(X, Y) = \min\{\mu^* : Y / \mu^* \in T^*\}$.

Decomposition of TE under the Metatechnology

Figure 2 shows a decomposition of TE under metatechnology. The metatechnology (T^*) is constructed from the two production technologies, T^A and T^B . The boundary of the metatechnology which indicates a metafrontier is represented by line MM' . Consider the production technology T^A where point A_1 and A_3 lie on the frontier AA' but point A_2 lies below the frontier AA' . TE_o^A of the point A_1 and A_3 corresponding to its own frontier is equal to one whereas TE_o^A of the point A_2 is equal to the ratio of $A_2^* A_2$ to $A_2^* A_2^{***}$. When the metafrontier (MM') is considered, TE_o^* of the point A_1 is still equal to one whereas TE_o^* of the point A_2 is equal to the ratio of $A_2^* A_2$ to $A_2^* A_2^{**}$ and TE_o^* of the point A_3 is equal to the ratio of $A_3^* A_3$ to $A_3^* A_3^{**}$. Similarly, consider the production technology T^B where point B_1 and B_2 lie on the frontier BB' but point B_3 lies below the frontier BB' . TE_o^B of the point B_1 and B_2 corresponding to its own frontier is equal to one whereas TE_o^B of the point B_3 is equal to the ratio of $B_3^* B_3$ to $B_3^* B_3^{**}$. When the metafrontier (MM') is considered, TE_o^* of the point B_2 and B_3 is still the same as TE_o^B whereas TE_o^* of the point B_1 is equal to the ratio of $B_1^* B_1$ to $B_1^* B_1^{**}$. When the TE_o is measured relative to the group-specific technology and metatechnology, it can occur a gap between the two technologies used as a reference. This gap is called a technology gap which is defined as the ratio of the distance function using an observed data based on the metatechnology T^* to the group-specific technology T^k .

Using the output orientation, the technology gap ratio (TGR) can be defined as

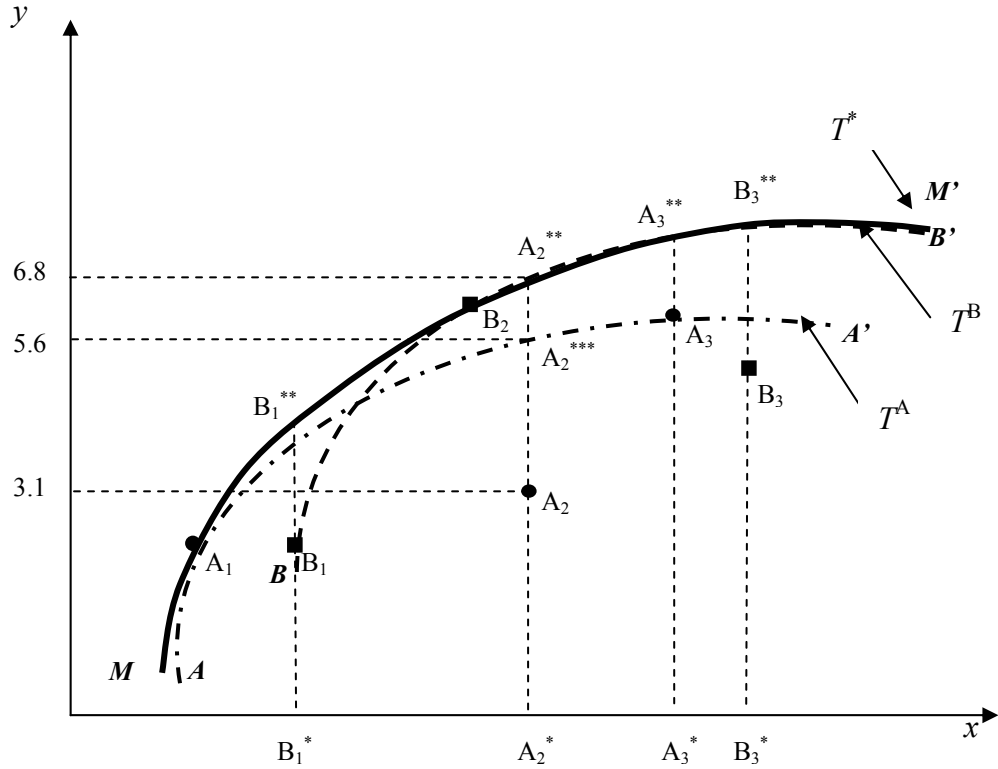
$$TGR_o^k(X, Y) = \frac{D_o^*(X, Y)}{D_o^k(X, Y)} = \frac{TE_o^*(X, Y)}{TE_o^k(X, Y)}, \quad (4)$$

or it can be written as

$$TE_o^*(X, Y) = TE_o^k(X, Y) \times TGR_o^k(X, Y). \quad (5)$$

Equation (5) shows that TE measured with respect to the metatechnology (T^*) can be decomposed into the product of the TE measured with respect to the k -th group technology (T^k) and the technology gap ratio. Note that the value of $TGR_o^k(X, Y)$ will be between zero and one so that $TE_o^*(X, Y) \leq TE_o^k(X, Y)$. For example, consider point A_2 in figure 2, TE with respect to the frontier AA' can be measured by the ratio of the distances between $A_2^* A_2$ to $A_2^* A_2^{***}$. The $TE_o^A(X_{A2}, Y_{A2}) = 3.1/5.6 = 0.554$ implying that all outputs could be possibly produced by 45% more from the given inputs by using the frontier AA' as a reference. The TE with respect to the metafrontier (MM') can be measured by the ratio of the distances between $A_2^* A_2$ to $A_2^* A_2^{**}$. The $TE_o^*(X_{A2}, Y_{A2}) = 3.1/6.8 = 0.456$ implying that all outputs could be possibly produced by 54% more from the given inputs by using the metafrontier (MM') as a reference. Therefore, $TGR_o^k(X, Y) = 0.456/0.554 = 0.823$ implying that the possible output for the frontier AA' is 82.3 percent of that represented by the metafrontier (MM').

Figure 2: Decomposition of Technical Efficiency under the Metafrontier



A Parametric Approach to Estimate the Metafrontier Function

The metafrontier function can be measuring using a parametric approach of the SFA model. The metafrontier function using SFA constructs a smooth production technology by tangencing a specified functional form of production functions from each group-specific technology. It is a smooth function and not a segmented envelope of each group-specific technology¹.

When suitable panel data for each producer in each group during the time period, $t = 1, \dots, T$ are available, the metafrontier estimation using the SFA can be

¹ The metafrontier function can also be measuring using DEA. The metafrontier function using DEA constructs piecewise linear convex production technology by enveloping all observed data from each group-specific technology. It is constructed without specifying a functional form for each group-specific technology and is a segmented envelope of each group-specific technology.

achieved using a two-step procedure. First, the stochastic production frontier for each group is estimated and compared with that for all producers. Then, a statistical test is performed to examine whether all producers in different groups have potential access to the same technology.

If the group k consists of data on I^k producers, the stochastic production frontier model for the i -th producer at time period t based on the group-specific data and the pooled data is given as follows.

$$\ln Y_{it}^c = \ln f(X_{it}^c, t; \beta^c) + v_{it}^c - u_{it}^c, \quad (6)$$

where superscript c refers to a choice of the stochastic production frontier model [If $c = k$, equation (6) refers to the stochastic group-specific production frontier model when the data for the i -th producer in the k -th group at the t -th time period are used, and if $c = p$, equation (6) refers to the stochastic pooled production frontier model when the data for all producers in all groups for all time periods are used]; Y_{it}^c denotes the output quantity for the i -th producer at the t -th time period; X_{it}^c denotes the input quantity for the i -th producer at the t -th time period; β^c s are unknown parameters associated with the X -variables to be estimated; v_{it}^c s are a two-sided random-noise component assumed to be i.i.d. $N(0, \sigma_v^{2c})$ and u_{it}^c s are a non-negative technical inefficiency component. The v_{it}^c and u_{it}^c are distributed independently of each other, and of the regressors. The non-negative technical inefficiency component, u_{it}^c , is

assumed to follow a half normal distribution, $u_{it}^c \sim \text{i.i.d } N^+(0, \sigma_u^{2c})$, and is defined by some appropriate inefficiency model [Battese and Coelli 1992]².

Following Battese and Coelli (1992), the stochastic group-specific and pooled production frontier models, taking the log-quadratic translog functional form under a non-neutral TC assumption can be written as follows.

$$\begin{aligned} \ln Y_{it}^c = & \beta_0^c + \sum_{n=1}^N \beta_n^c \ln X_{nit}^c + \frac{1}{2} \sum_{n=1}^N \sum_{m=1}^N \beta_{nm}^c \ln X_{nit}^c \ln X_{mit}^c \\ & + \sum_{n=1}^N \beta_{nt}^c \ln X_{nit}^c \cdot t + \beta_t^c t + \frac{1}{2} \beta_t^c t^2 + v_{it}^c - u_{it}^c, \end{aligned} \quad (7)$$

where $m, n = 1, \dots, N$ index of input quantities and $u_{it}^c = \{\exp[-\eta(t-T)]\} u_i^c$ where η s are parameters to be estimated and u_i^c s are non-negative random variables which are assumed to account for technical inefficiency in production and are assumed to be i.i.d. as truncations at zero of the $N^+(0, \sigma_u^{2c})$ distribution. Young's theorem requires that the symmetry restriction is imposed so that $\beta_{nm} = \beta_{mn}$ for all $m, n = 1, 2, 3$.

The output-orientated TE for the i -th producer at the t -th time period is given by

$$TE_{oit}^c = \exp\{-u_{it}^c\}. \quad (8)$$

If the stochastic frontiers across groups do not differ, then the stochastic pooled frontier function can be used as a grand technology³. However, if the stochastic frontiers across groups do differ, the metafrontier function will be used as a grand technology for each group. The second step will involve estimating the metafrontier function. The

² We follow the suggestion of Battese and Corra (1977), and replace the two variance parameters with the two new parameters $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2 / \sigma^2$.

³ The likelihood ratio (LR) test statistic is used to perform the hypothesis that the group-specific frontiers are identical.

metafrontier function using SFA does not fall below the deterministic functions for the stochastic group-specific frontier model. In order to obtain estimated parameters of the metafrontier function, we need to ensure that the estimated function best envelops the deterministic components of the estimated stochastic frontiers for the different groups. Battese, Rao and O'Donnell (2004) proposed a method so called the minimum sum of absolute deviations to identify the best envelope. The metafrontier function is estimated by solving the following LP problem.

$$\text{Min}_{\beta^*} \sum_{i=1}^I \sum_{t=1}^T |(x_{it}\beta^* - x_{it}\hat{\beta}^k)| \equiv \bar{x}\beta^* \quad (9)$$

such that $x_{it}\beta^* \geq x_{it}\hat{\beta}^k$,

where x_{it} is the logarithm form of the input quantity for the i -th producer in the t -th time period; $\bar{x}$ denotes the row vector of mean of the elements of the x_{it} vector for all observations in the data set; $\hat{\beta}^k$ s are the estimated coefficients obtained from the stochastic group-specific frontiers obtained from equation (7) and β^* s are parameters of the metafrontier function to be estimated.

Once the β^* parameters of the metafrontier function in equation (9) are estimated, the decomposition of TE under the metafrontier can be calculated. The technology gap for the i -th producer in the k -th group at the t -th time period can be obtained by

$$TGR_{oit}^k(X, Y) = \frac{e^{x_{it}\beta^k}}{e^{x_{it}\beta^*}}. \quad (10)$$

Then, a measure of the output-oriented TE relative to the metafrontier, $TE_o^*(X, Y)$, can be obtained using equation (5).

Data Sources and Descriptions

A balanced panel data set of 28 provinces covering the time period of 1991 to 2005 is used in the empirical analysis. Figure 3 illustrates the location of all provinces in China. Provinces selected for analysis include all provinces in China excluding Hainan and Tibet due to the missing information⁴. Considering regional disparities, all provinces are ranked by using GDP per capita at 2001 according to the definition presented in Mao and Koo (1997). Provinces are divided into two groups of technologies: advanced-technology and low-technology provinces. Each group consists of 14 provinces. A list of the provinces in each group is summarized in figure 3.

Figure 3: The Location of Advanced- and Low-Technology Provinces



⁴ Chongqing is added together with those of Sichuan due to the unavailability of its data before 1998.

The primary data on agricultural production were extracted from the official data sources--*China Statistical Yearbook* and *Chinese Agricultural Statistical Yearbook*. This officially published data have been extensively used to evaluate the efficiency and TFP [Fan 1991; Wu 1995; and Mao and Koo 1997]. The data used in this study contains the measurements of agricultural output and input quantities. In this study, the production technology is represented by one output and six inputs. The definitions of these variables are summarized as follows:

Dependent Variable: The gross output value of farming at 1990 constant prices in billions of yuan (y) is chosen as the dependent variable. The gross output value of farming aggregates physical output from seven grain crops and twelve economic crops. However, it excludes the value of forestry, animal husbandry, handicraft products for self-consumption or for sales as sideline occupations and the total value of industries run by villages and cooperative organizations under villages.

Independent Variable: Following the existing literatures, independent variables include six important physical inputs such as capital, labor, chemical fertilizer, pesticide, plastic film and irrigation (Lin 1992; Wu 1995; Liu and Wang 2005).

Capital input (x_1) denotes farm machinery in the unit of millions of KW, mainly including the big tractor and walking tractors. Other inputs such as draft animals are excluded in this study due to the unavailable information in the provincial statistics.

Labor force denotes the number of total rural labors directly engaged in production of agriculture, forestry, animal husbandry and fishery annually. To measure the labor input in farming sector (x_2), we followed the calculation by Lin (1992) to weight the labor input in agriculture by the value share of farming output in total agricultural output.

Chemical fertilizer (x_3) refers to the pure-content quantity of chemical fertilizers applied in yearly agricultural production in tons. The pure-content gross quantity of chemical fertilizer is calculated to convert the gross weight into weight containing 100 percent of effective components.

Pesticide (x_4) is the quantity of chemical pesticides applied in agriculture reported in tons annually.

Plastic film (x_5) includes those for coving young plants and seeds listed in tons annually.

Irrigation is one of the very important factors in agricultural production. An effectively irrigated area including not only the full sets of technological irrigation facilities but also adequate water sources for the normally agricultural irrigation can be used as an irrigation variable. The irrigation variable (x_6) used in this study is defined as the ratio of effectively irrigated area to total cultivated area. Total cultivated land area refers to land that is plowed constantly for growing crops excluding the land of tea plantations, orchards, nurseries of young plants, forest land, natural and man-made grassland.

Descriptive statistics of the variables used in the study summarized by the two groups of technology defined above is presented in Table 1.

Table 1. Descriptive Statistics of Variables, 1991-2005

<i>Variables</i>	<i>Unit</i>	<i>Advanced-Technology Provinces</i>	<i>Low-Technology Provinces</i>	<i>All Provinces</i>
<i>Dependent Variable</i>				
Output	Billion Yuan	27.678 (19.520)	22.505 (17.094)	25.092 (18.507)
<i>Independent Variables</i>				
Capital	Thousand KW	4615.148 (4453.458)	4160.390 (5604.301)	4387.769 (5060.772)
Labor	Thousand Person	4752.045 (3724.526)	7967.061 (5698.546)	6359.553 (5070.276)
Fertilizer	Million KG	1451.905 (1127.808)	1305.492 (1033.238)	1378.699 (1082.749)
Pesticide	Million KG	48.823 (40.953)	33.195 (31.282)	41.009 (37.228)
Plastic	Million KG	51.025 (52.847)	34.573 (28.218)	42.799 (43.106)
Irrigation	%	64.290 (24.070)	43.490 (18.510)	53.891 (23.837)

Notes: Means are calculated. Standard deviations are presented in parentheses

Results

Discussion of Parameter Estimates and Production Structure

The data described in the previous section were used in the estimation of the stochastic group-specific and pooled production functions shown in equation (7). The stochastic group-specific production functions are estimated using the data of the advanced- and low-technology provinces separately whereas the stochastic pooled production function is estimated using the data of all provinces. The data variables used in the model estimation were normalized by their respective geometric means. The estimated

coefficients for each model are presented in table 2. The estimation results from each model are similar and all first-order coefficients have the expected signs except for the estimated parameters, β_{x4} of the low-technology provinces model.

The likelihood ratio (LR) test statistic for the null hypothesis that the group-specific frontiers are identical is 106.44. The LR test statistic follows a chi-square distribution with 39 degrees of freedom. The null hypothesis was rejected with a p-value less than 0.001. This result implies that the group-specific frontiers are not the same. Therefore, the metafrontier function presented in equation (9) needs to be estimated. Table 2 also presents the estimated coefficients of the stochastic metafrontier function. All first-order coefficients have the expected signs and can also be interpreted as the production elasticities, evaluated at the sample means. The estimates of the input elasticities under the stochastic metafrontier function model are 0.0413, 0.2446, 0.4341, 0.0530, 0.0690 and 0.5285 for capital, labor, fertilizer, pesticide, plastic and irrigation, respectively. The sum of the input elasticities provides information about scale economies and is 1.3705, indicating that the technology exhibits moderately increasing returns to scale at the sample mean. The first order coefficients of the time trend variable provide estimates of the average annual rate in TC. The stochastic metafrontier function model suggest that the technology is improving at a rate of 2.71% per annum.

Table 2. Estimated Parameters of Stochastic Group-Specific Frontier and Metafrontier Models

Variable ^a	Stochastic Frontier						Metafrontier ^b	
	Adv-Tech		Low-Tech		All			
	Provinces		Provinces		Provinces			
β_0	2.6686	(0.0465)	2.5797	(0.0537)	2.5495	(0.0433)	2.6293	(0.0150)
β_{x1}	0.0420	(0.0317)	0.0184	(0.0289)	0.0439	(0.0164)	0.0413	(0.0085)
β_{x2}	0.3646	(0.0614)	0.3304	(0.1202)	0.2947	(0.0356)	0.2446	(0.0060)
β_{x3}	0.2906	(0.0727)	0.5293	(0.1149)	0.3859	(0.0552)	0.4341	(0.0167)
β_{x4}	0.0051	(0.0519)	-0.0140	(0.0658)	0.0358	(0.0312)	0.0530	(0.0113)
β_{x5}	0.0678	(0.0392)	0.0255	(0.0309)	0.0203	(0.0177)	0.0690	(0.0064)
β_{x6}	0.5520	(0.1193)	0.8039	(0.2364)	0.4799	(0.0748)	0.5285	(0.0310)
β_t	0.0421	(0.0059)	0.0207	(0.0078)	0.0365	(0.0033)	0.0271	(0.0010)
β_{x11}	0.0211	(0.0355)	-0.0295	(0.0267)	-0.0067	(0.0204)	-0.0027	(0.0110)
β_{x12}	-0.2059	(0.0510)	0.0128	(0.0575)	-0.0776	(0.0274)	-0.1603	(0.0126)
β_{x13}	0.1199	(0.0520)	-0.0125	(0.0660)	0.0672	(0.0398)	0.0946	(0.0250)
β_{x14}	0.0374	(0.0442)	-0.0420	(0.0339)	-0.0314	(0.0228)	0.0230	(0.0123)
β_{x15}	0.0408	(0.0359)	0.0009	(0.0218)	0.0176	(0.0159)	0.0825	(0.0116)
β_{x16}	-0.1707	(0.0775)	0.1570	(0.1130)	-0.0315	(0.0663)	-0.2160	(0.0231)
β_{x22}	0.3070	(0.1112)	-0.2944	(0.2748)	0.1332	(0.0685)	0.0839	(0.0289)
β_{x23}	-0.0850	(0.1230)	0.1517	(0.3298)	-0.1045	(0.0962)	-0.1217	(0.0589)
β_{x24}	-0.1129	(0.0713)	0.0083	(0.1219)	-0.0074	(0.0420)	0.0834	(0.0308)
β_{x25}	-0.0272	(0.0570)	0.0230	(0.0633)	-0.0007	(0.0282)	0.0424	(0.0130)
β_{x26}	0.7263	(0.1500)	-0.5272	(0.4302)	0.6944	(0.1135)	0.5261	(0.0411)
β_{x33}	-0.1962	(0.2384)	-0.0540	(0.5815)	0.2132	(0.1840)	0.5670	(0.1326)
β_{x34}	0.1590	(0.0900)	0.0428	(0.1775)	-0.0047	(0.0648)	-0.2128	(0.0448)
β_{x35}	0.1951	(0.1022)	-0.1470	(0.1087)	-0.0728	(0.0577)	-0.1915	(0.0198)
β_{x36}	-0.4919	(0.2330)	1.0752	(0.6946)	-0.3362	(0.1899)	-0.3234	(0.0722)
β_{x44}	-0.0311	(0.0210)	-0.1430	(0.1051)	-0.0005	(0.0192)	0.0379	(0.0107)
β_{x45}	-0.0691	(0.0408)	0.0990	(0.0506)	0.0330	(0.0258)	0.0380	(0.0131)
β_{x46}	-0.0037	(0.1043)	0.1337	(0.3230)	-0.0659	(0.0922)	-0.0456	(0.0623)
β_{x55}	-0.1638	(0.0637)	-0.0084	(0.0264)	0.0120	(0.0194)	0.0029	(0.0064)
β_{x56}	0.0586	(0.0959)	-0.3459	(0.1728)	-0.1349	(0.0819)	-0.0458	(0.0607)
β_{x66}	0.4344	(0.5484)	-2.6276	(0.9912)	1.1428	(0.4167)	0.3150	(0.1620)
β_{x1t}	-0.0213	(0.0048)	0.0039	(0.0055)	-0.0050	(0.0027)	-0.0212	(0.0014)

β_{x2t}	0.0324	(0.0085)	-0.0061	(0.0149)	0.0164	(0.0047)	0.0007	(0.0028)
β_{x3t}	-0.0369	(0.0103)	0.0174	(0.0164)	-0.0185	(0.0071)	-0.0024	(0.0023)
β_{x4t}	0.0115	(0.0058)	-0.0033	(0.0100)	0.0074	(0.0038)	0.0109	(0.0031)
β_{x5t}	0.0093	(0.0047)	0.0005	(0.0065)	-0.0003	(0.0033)	0.0087	(0.0022)
β_{x6t}	0.0501	(0.0122)	-0.0318	(0.0369)	0.0546	(0.0106)	0.0448	(0.0057)
β_{tt}	0.0004	(0.0011)	0.0006	(0.0019)	0.0016	(0.0008)	0.0004	(0.0005)
σ^2	0.0146	(0.0019)	0.0122	(0.0016)	0.3107	(0.4543)		
γ	0.7200	(0.0633)	0.6612	(0.0568)	0.9830	(0.0249)		
η	-0.0075	(0.0120)	0.0136	(0.0089)	-0.0082	(0.0056)		
Log-likelihood	256.1712		235.9472		438.8973			

Note: Numbers in parentheses are standard errors.

^a Subscripts on β_x coefficients refer to inputs: 1 = capital; 2 = labor; 3 = fertilizer; 4 = pesticide; 5 = plastic and 6 = irrigation

^b Standard deviations of the metafrontier estimates are calculated using parametric bootstrapping as presented in Battese, Rao and O'Donnell (2004)

Table 3 provides annual average production elasticities of inputs- capital, labor, fertilizer, pesticide, plastic and irrigation- for the year 1991-2005. The production elasticity for capital decreases over the period 1991-2005 by 7.42% per annum. The production elasticity for labor increases during 1991-1993 and decreases during 1994-2005 leading to a decrease by 2.40% per annum. The production elasticity for fertilizer decreases over the period 1991-2002 and increases during the period 2003-2005 leading to an increase by 0.44% per annum. The production elasticities for pesticide and plastic increase throughout the period by 12.79% and 7.84% per annum, respectively. The production elasticity for irrigation increases during 1991-2002 and decreases during 2003-2005 leading to an increase by 2.11% per annum. The results indicate that the annual rates of increase of production elasticities for fertilizer, pesticide,

plastic and irrigation are greater than the rates of decrease for capital and labor. The results also show that labor and fertilizer still make important contributions to output, and thus improving the quality of farmers and applying modern physical inputs is also crucial to TFP growth.

Table 3. Annual Average Production Elasticities for Different Inputs, 1991-2005

<i>Year</i>	<i>Capital</i>	<i>Labor</i>	<i>Fertilizer</i>	<i>Pesticide</i>	<i>Plastic</i>	<i>Irrigation</i>
1991-1993	0.081	0.297	0.434	0.029	0.053	0.471
1994-1996	0.075	0.306	0.426	0.032	0.054	0.489
1997-1999	0.054	0.299	0.412	0.053	0.071	0.537
2000-2002	0.036	0.278	0.399	0.076	0.072	0.650
2003-2005	0.029	0.215	0.453	0.101	0.114	0.589
1991-2005	0.041	0.245	0.434	0.053	0.069	0.529

Discussion of TE Decomposition under the Metafrontier

Table 4 provides average TE scores relative to the stochastic group-specific frontier and metafrontier technologies as well as TGR scores for each group of provinces during 1991-2005. Moreover, table A1 in Appendix reports TE scores relative to the stochastic group-specific frontier and metafrontier technologies as well as TGR score for all 28 provinces over the period 1991 to 2005. TE scores relative to the group-specific technology for the advanced-technology provinces range from 0.688 by Hebei to 0.978

by Guangdong with an average of 0.806. TE scores relative to the group-specific technology for the advanced-technology provinces were decreasing over time. Based on the metafrontier technology as a reference, TE scores for the advanced-technology provinces range from 0.661 by Hebei to 0.940 by Guangdong with an average of 0.764. The average TE score implies that the advanced-technology provinces in this study were, on average, producing 80.6% of the outputs that could be potentially produced from the given inputs by using their own technologies as a reference and 76.4% using the metafrontier technology as a reference. The estimates of TGR for the advanced-technology province range from 0.847 by Shanghai to 0.980 by Helongjian with an average of 0.948. This result implies that the possible outputs for the advanced-technology provinces based on their groups-specific technology is, on average, 94.8% of that represented by the metafrontier technology. Hebei and Tianjin are the two lowest ranked TE scores relative to both group-specific and metafrontier technologies whereas Guangdong and Liaoning are the two highest ranked TE scores relative to both technologies. The ranking of the TE scores from other provinces is not much different relative to both technologies except for Shanghai. Shanghai is the third highest ranked TE score relative to its group-specific technology while it is the fifth lowest ranked TE scores relative to the metafrontier technology.

Turning to the low-technology provinces, TE score relative to their own technology range from 0.581 by Ningxia to 0.979 by Sichuan with an average of 0.732. TE scores relative to the group-specific technology for the low-technology provinces were increasing over time. Based on the metafrontier technology as a reference, TE

scores for the low-technology provinces range from 0.443 by Ningxia to 0.842 by Inner-Mongolia with an average of 0.644. The average TE score implies that the low-technology provinces in this study, on average, could be potentially produced 27% more outputs from the given inputs by using their own technologies as a reference and 36% more outputs using the metafrontier technology as a reference. The estimates of TGR for the low-technology provinces range from 0.764 by Ningxia to 0.975 by Gansu with an average of 0.882. This result implies that the possible outputs for the low-technology provinces based on their group-specific technology is, on average, 88.2% of that represented by the metafrontier technology. Ningxia and Anhui are the two lowest ranked TE scores relative to the group-specific technology while Ningxia is still the lowest ranked TE scores relative to the metafrontier technology and Anhui is the fourth lowest ranked TE scores relative to the metafrontier technology. Sichuan and Inner-Mongolia are the two highest ranked TE scores relative to both technologies. The ranking of the TE scores from other provinces is quite different relative to both technologies.

The empirical findings show that the advanced-technology provinces had average province TE higher than the low-technology provinces. The advanced-technology provinces generally led in terms of TGR and had smaller variation of TGR than the low-technology provinces. The comparatively low TE scores in the low-technology provinces imply that the low-technology provinces were operating far from the metafrontier. The fluctuation of TE measured with respect to the metafrontier

function indicates it is possible that Chinese agricultural TFP growth can be improved through the improvement of TE.

Table 4: TE Scores by the Group-Specific and Metafrontier Technologies and TGR for Each Group, 1991-2005

Year	Advanced-Technology Provinces			Low-Technology Provinces		
	TE ^k	TGR	TE [*]	TE ^k	TGR	TE [*]
1991	0.815	0.911	0.744	0.710	0.904	0.636
	(0.075)	(0.055)	(0.096)	(0.142)	(0.113)	(0.115)
1992	0.814	0.916	0.746	0.714	0.907	0.645
	(0.076)	(0.042)	(0.078)	(0.140)	(0.076)	(0.119)
1993	0.813	0.957	0.778	0.717	0.904	0.646
	(0.076)	(0.042)	(0.078)	(0.139)	(0.073)	(0.126)
1994	0.811	0.966	0.784	0.720	0.909	0.653
	(0.077)	(0.029)	(0.083)	(0.138)	(0.071)	(0.126)
1995	0.810	0.977	0.791	0.723	0.901	0.649
	(0.077)	(0.022)	(0.079)	(0.136)	(0.066)	(0.116)
1996	0.809	0.979	0.792	0.726	0.899	0.651
	(0.078)	(0.014)	(0.077)	(0.135)	(0.067)	(0.123)
1997	0.808	0.973	0.785	0.729	0.885	0.643
	(0.078)	(0.036)	(0.077)	(0.133)	(0.072)	(0.113)
1998	0.806	0.946	0.761	0.732	0.871	0.636
	(0.079)	(0.088)	(0.092)	(0.132)	(0.089)	(0.117)
1999	0.805	0.959	0.771	0.735	0.869	0.637
	(0.079)	(0.055)	(0.084)	(0.131)	(0.098)	(0.122)
2000	0.804	0.963	0.773	0.738	0.817	0.599
	(0.080)	(0.055)	(0.083)	(0.129)	(0.140)	(0.131)
2001	0.802	0.956	0.766	0.741	0.886	0.655
	(0.080)	(0.053)	(0.074)	(0.128)	(0.079)	(0.123)
2002	0.801	0.936	0.749	0.743	0.881	0.656
	(0.081)	(0.066)	(0.086)	(0.127)	(0.076)	(0.129)
2003	0.800	0.940	0.751	0.746	0.869	0.648
	(0.081)	(0.064)	(0.089)	(0.125)	(0.087)	(0.124)

2004	0.799 (0.082)	0.925 (0.075)	0.739 (0.101)	0.749 (0.124)	0.869 (0.090)	0.650 (0.120)
2005	0.797 (0.082)	0.919 (0.080)	0.732 (0.102)	0.752 (0.123)	0.868 (0.098)	0.652 (0.124)
1991-2005	0.806 (0.076)	0.948 (0.058)	0.764 (0.086)	0.732 (0.128)	0.883 (0.089)	0.644 (0.119)

Decomposition of TFP Change

TFP change (TFPC) is generally defined as the residual change in outputs not explained by the change in input use. TFPC can be measured and decomposed after the metafrontier function in equation (9) is estimated. Figure 4 illustrates the TFPC decomposition under variable returns to scale (VRS) production technology. Using an output orientation, measures of the TEC, TE and SEC components in the TFPC are graphically illustrated in input-output space as follows. Let S_t and S_{t+1} be the technology under VRS at the time period t and $t+1$, respectively. Define T_t (T_{t+1}) as a ray from the origin that is at a tangent to the production frontier S_t (S_{t+1}). The T_t and T_{t+1} represent the CRS technology that shifts at the most productive scale size at the time period t and $t+1$, respectively. Consider the time periods t and $t+1$, the observed input-output combinations are located inside the production frontiers, implying that production is not technically efficient in either period. An output-orientated measure of TE defined in Farrell (1957) for the observation at time t , relative to the production frontier S_t , is given by the ratio $(\overline{0a}/\overline{0b})$, while the output-orientated TE for the observation at time $t+1$, relative to the production frontier S_{t+1} , is given by the ratio $(\overline{0h}/\overline{0j})$. TEC which measures the change in the output-orientated TE measure

between periods t and $t+1$ is given by the ratio $\frac{(\overline{0h}/\overline{0j})}{(\overline{0a}/\overline{0b})}$. TC measures the movement of the production frontier from S_t to S_{t+1} . A measure of TC is defined as the geometric mean of the shift in S_t and S_{t+1} at input levels X_t and X_{t+1} is given by the ratio $\left[\frac{(\overline{0h}/\overline{0d})}{(\overline{0h}/\overline{0j})} \times \frac{(\overline{0a}/\overline{0b})}{(\overline{0a}/\overline{0g})} \right]^{1/2}$. The tangent points, A and B, in figure 4 represent maximum possible productivity or technically optimal scale of the production frontier S_t and S_{t+1} , respectively. In figure 4, the firm is operating at non-optimal scale in either period. The firm may still be able to improve its productivity by exploiting scale economies. A measure of SEC represented by the change in output SE between the period t and period $t+1$ data is given by the ratio $\frac{(\overline{0j}/\overline{0k})}{(\overline{0b}/\overline{0c})}$.

Following Orea (2002), a measure of TFPC for each firm between any two time periods can be calculated by using the estimates of the coefficients of the metafrontier and the firm-level sample data. The logarithmic form of the TFPC between period t and $t+1$ for the i -th firm is defined as

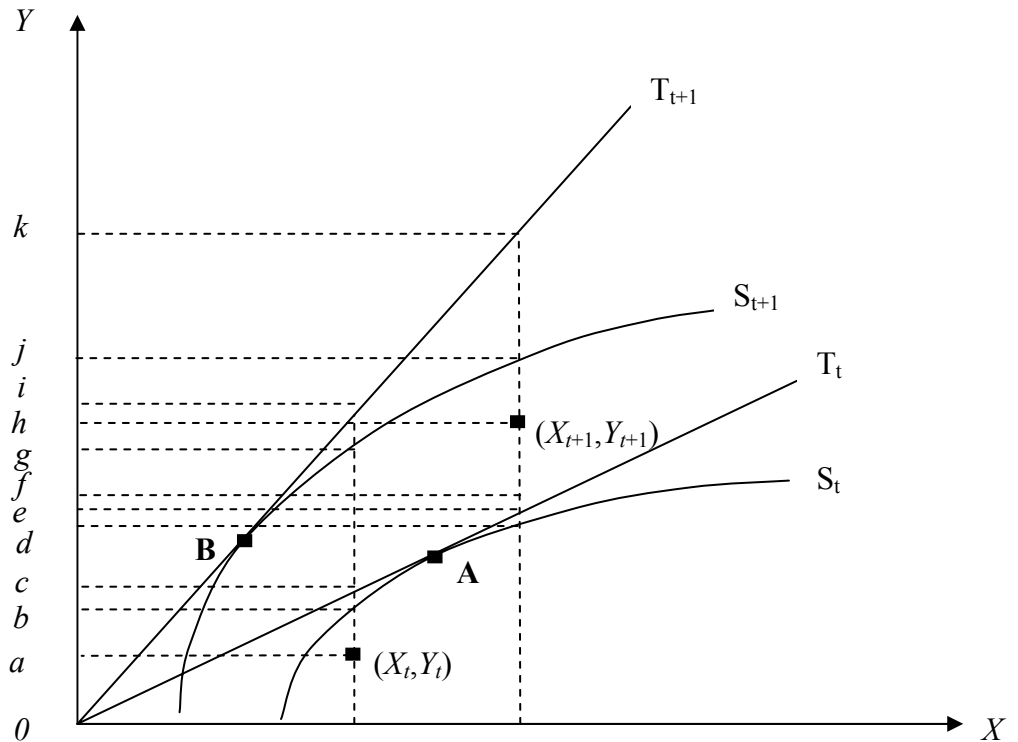
$$\ln\left(\frac{TFP_{it+1}}{TFP_t}\right) = \ln\left(\frac{TE_{oit+1}^*}{TE_{oit}^*}\right) + \frac{1}{2} \left[\frac{\partial \ln f(X_{it+1}^*, t; \beta^*)}{\partial t} + \frac{\partial \ln f(X_{it}^*, t; \beta^*)}{\partial t} \right] + \frac{1}{2} \sum_{n=1}^N \left[(SF_{it+1}^* \cdot E_{nit+1}^*) + (SF_{it}^* \cdot E_{nit}^*) \right] \left(\frac{\ln X_{nit+1}^*}{\ln X_{nit}^*} \right), \quad (11)$$

where the three terms on the right-hand-side of equation (11) represents the output-oriented TEC, TC and SEC, respectively.

The output-orientated TE measure, (TE_o^*) , in equation (11) is the output-orientated TE prediction of the i -th firm in the t -th time period, and is calculated from

equation (5). The TC measure, (TC_{it+1}) , is the mean of the TC measures evaluated at the period t and period $t+1$ data points. The SEC measure, (SEC_{it+1}) , relates to the change in scale efficiency, which requires calculation of the scale factor (SF) and input elasticity (E_n) evaluated at the period t and period $t+1$ data points. The SF of the i -th firm in the t -th time period $(SF_{it}^*) = (E_{it}^* - 1) / E_{it}^*$ where $E_{it}^* = \sum_{n=1}^N E_{nit}^*$ represents the scale elasticity and $E_{nit}^* = \partial \ln f(X_{it}^*, t; \beta^*) / \partial \ln X_{nit}^*$ is production elasticity for the n -th input.

Figure 4: Output-Orientated MPI Decomposition under VRS Production Frontier



Discussion of TFPC Decomposition

Table 5 presents weighted growth rate of TFPC decomposition by the group of the provinces during 1991-2005. TFPC by all provinces increases by 62.45% over the sample period with a weighted average of about 3.234% per annum. TEC is nearly negligible; it decreases by 0.43% over the sample period (average of about 0.029% per annum). SEC is less important; it increases by 1.46% over the sample period (average of 0.097% per annum). Overall, TC explains most of the TFPC. It increases by 60.79% with a weighted average of 3.166% per annum. The major findings show that TFPC in China agriculture over the study period was mainly driven by technological progress. These aggregate figures dissimulate the diversity of effects across the two groups of provinces, although TC changes are dominant in both of two groups.

The advance-technology provinces show TFPC of 65.6% over the sample period (average of about 3.362% per annum). TC increases by 66.3% (average of about 3.391% per annum) and the technical progress with the highest rate occurred during 2000-2002. TEC increases by 0.57% with a weighted average incline of about 0.038% per annum even though it indicates a decline after the period 1997. SEC decreases by 0.99% with a weighted average decrease of about 0.066% per annum although the entire decline is due to the negative SEC during 1997-2005. TC explains most of the TFPC throughout the period. There is an impressive technical progress during 2000-2002. TEC is a major contribution to TFPC together with TC during 1991-1996 and 2000-2005. However, TEC is negligible relative to TC and SEC during 1997-1999. SEC is negligible relative to TC and SEC throughout the period.

The low-technology provinces countries experience a TFP increase of 58.92% over the sample period (average of about 3.088% per annum). TC and SEC increase by 54.26% (average of about 2.890% per annum) and 4.57% (average of about 0.298% per annum). There is a major deteriorate in SEC during 2000-2002. TEC slightly decreases by 1.48% over the sample period with a weighted average decline of about 0.099% per annum. TC explained most of the TFPC for the entire period. There is an impressive technical progress during 2000-2002. TEC is negligible relative to TC and SEC throughout the period except the period of 1997-1999. SEC is a major contribution to TFPC together with TC during 2000-2002.

Table 5: Weighted Annual Growth Rates of Decomposed TFPC by Provinces Group

<i>Period</i>	<i>TEC</i>	<i>TC</i>	<i>SEC</i>	<i>TFPC</i>
<i>Advanced-technology Provinces (%)</i>				
1991-1993	1.267	1.938	0.158	3.363
1994-1996	1.100	3.612	0.003	4.714
1997-1999	-0.283	3.829	-0.032	3.514
2000-2002	-1.056	4.238	-0.667	2.515
2003-2005	-0.840	3.338	0.206	2.703
1991-2005	0.038	3.391	-0.066	3.362
<i>Low-technology Provinces (%)</i>				
1991-1993	-0.335	1.730	0.958	2.354
1994-1996	0.512	2.957	0.901	4.371
1997-1999	-0.853	3.215	0.463	2.825
2000-2002	0.219	3.671	-1.419	2.471
2003-2005	-0.041	2.875	0.587	3.420
1991-2005	-0.099	2.890	0.298	3.088
<i>All Provinces</i>				
1991-1993	0.529	1.842	0.525	2.897

1994-1996	0.838	3.320	0.403	4.561
1997-1999	-0.537	3.555	0.184	3.202
2000-2002	-0.493	3.983	-1.005	2.484
2003-2005	-0.480	3.132	0.377	3.028
1991-2005	-0.029	3.166	0.097	3.234

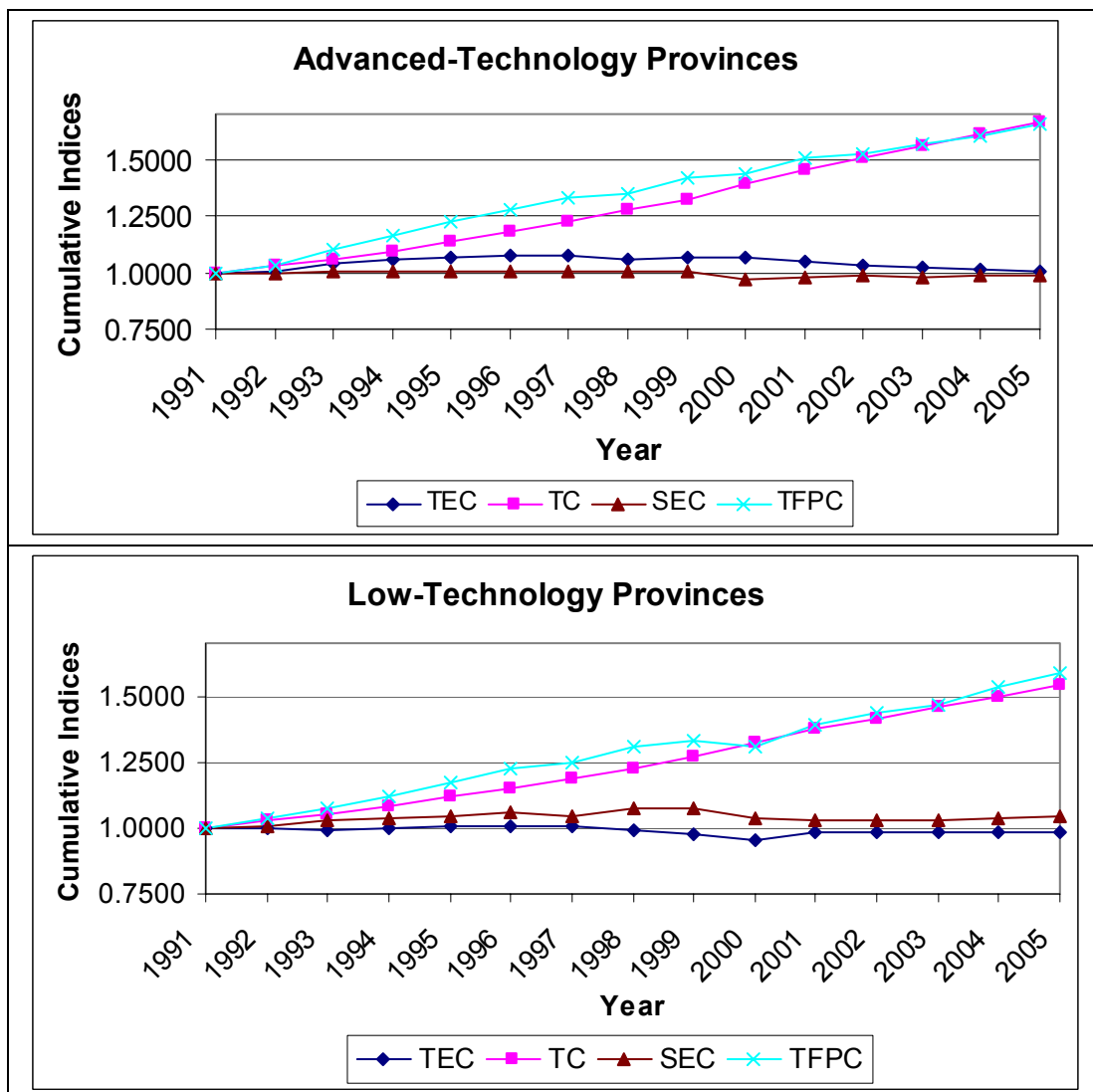
Figure 5 contains a set of the cumulative index plots of the TFPC and its associated components by the group of the advanced- and low-technology provinces over the entire 1991-2005 period. The plot of the advanced-technology provinces shows that there was TFP progress over time and mainly driven by TC. The advanced-technology provinces showed a decline in TFPC during 1991-1993 and 2000-2005 which was resulted from a decline in TEC. There was a significant increase in TEC in 1993 and a major decrease in SEC in 2000. The plot of the advanced-technology provinces shows that TFPC was closely driven by TC throughout the period. The TFPC and TC were steadily improved while TEC and SEC was steadily stable leading to an increase of TFPC for the entire periods. Overall, TC explains most of the TFPC. However, the TEC was attributed to TFPC more than the SEC throughout the period.

The plot of the low-technology provinces shows that TFPC was closely driven by TC. TFPC was steadily improved throughout the period except in 2000. A decrease in TEC led to a decrease in TFPC in 2000. TC change was steadily improved throughout the period. TEC was steadily stable and showed a small decrease during 1999-2000. SEC was steadily stable and showed an increase during 1993-1999. Overall, TC explains most of the TFPC and the SEC was attributed to TFPC more than the TEC throughout the period.

The proportional growth of the average TEC, TC and SEC components constituting the average TFPC for all provinces in each group over the time period of 1992 to 2002 are also reported in table A1 in Appendix. All provinces can be divided into different categories according to their TFPC and what sources are attributed to their TFPC. All advanced-technology provinces except Helongjiang indicated TPF progress over the time period. TFP regress for Helongjiang was driven by a decline of TC and SEC. Hebei is the only province which TFP progress was driven by an increase in TEC, TC and SEC. TFP progress for Beijing, Zhejiang, Fujian and Guangdong was driven by an increase in TEC and TC with a decrease in SEC. TFP progress for Tianjin, Shanghai, Jiangsu, Hubei was mainly attributed by technical progress with a decline in TEC and SEC. Liaoning, Jilin, Shandong and Xijiang showed an increase in TC and SEC but a decrease in TEC attributing to their TFP progress.

Similarly, all low-technology provinces except Inner-Mongolia indicated TPF progress over the time period. TFP regress for Inner-Mongolia was driven by a decline of TEC and TC. TFP progress for all provinces except Qinghai and Ningxia was mainly driven by technical progress. Shanxi, Henan, Guizhou, Yunnan, Shaanxi, Gansu showed an increase in TEC, TC and SEC attributing to their TFP progress. TFP progress for Anhui and Guangxi Guangdong was driven by an increase in TC and SEC but a decrease in TEC. TFP progress for Jiangxi, Hunan and Sichuan was mainly attributed by technical progress with a decline in TEC and SEC.

Figure 5: Cumulative Indices of TEC, TC, SEC and TFPC by Groups of the Provinces, 1991 to 2005



Conclusions

With nearly one quarter of the potential agricultural resources and one-fifth of the world's population, China has the potential to supply a substantial share of the expected growth in food demand forecast for the first half of this century. This study utilizes a parametric metafrontier function approach to measure and decompose Chinese agricultural TE and productivity by allowing all producers in different groups operating under their own technologies. Data on 28 provinces over the period from 1991-2005 are empirically used in this study where the provinces are categorized into advanced- and low-technology provinces due to distinctive levels of economic development and production technologies.

The empirical findings indicate that the weighted average TFPC in the Chinese agriculture over the study period grew at 3.234% per annum, which was driven primarily by a 3.166% increase in TC. SEC exhibited a positive effect to TFPC whereas TEC showed positive in early years, then negative starting in 1997. TC was a major contribution to TFPC in both advanced- and low-technology provinces. SEC and TEC exhibited negative effects to TFPC for the advance- and low-technology provinces, respectively. Most of the advanced-technology provinces exhibited higher TE than the low-technology provinces. The comparatively low TE scores in low-technology provinces were found to be related to the TE measured with respect to its own-group technology and the technology gap ratio. As researchers and policy makers discuss the “pros and cons” of China’s WTO commitments in agriculture, the analysis in this study suggests that there may be benefits through the improvement of TE. The empirical results also

show that labor and fertilizer still make important contributions to output, and thus improving the quality of farmers and applying modern physical inputs is also crucial to TFPC.

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Appendix

Table A1: Average TE, TGR and the TFP Decomposition by Province

<i>Provinces</i>	<i>TE^k</i>	<i>TGR</i>	<i>TE[*]</i>	<i>TEC</i>	<i>TC</i>	<i>SEC</i>	<i>TFPC</i>
Adv-Tech Provinces				(in percentage)			
Beijing	0.820	0.948	0.778	0.180	4.190	-0.173	4.197
Tianjin	0.740	0.938	0.694	-0.286	3.693	-0.024	3.384
Hebei	0.688	0.960	0.661	0.499	2.049	0.534	3.082
Liaoning	0.948	0.948	0.898	-0.239	3.076	0.143	2.979
Jilin	0.784	0.969	0.760	-0.392	0.705	0.325	0.638
Heilongjiang	0.839	0.980	0.822	0.012	-0.410	-0.344	-0.741
Shanghai	0.840	0.847	0.712	-2.439	6.957	-0.034	4.484
Jiangsu	0.793	0.960	0.761	-0.221	3.636	-0.088	3.327
Zhejiang	0.742	0.958	0.710	0.909	4.974	-0.914	4.969
Fujian	0.771	0.943	0.728	0.708	5.556	-0.257	6.007
Shandong	0.797	0.951	0.758	-0.198	3.559	0.225	3.585
Hubei	0.742	0.950	0.705	-0.037	4.486	-0.067	4.382
Guangdong	0.978	0.962	0.940	0.613	4.662	-0.786	4.489
Xijiang	0.806	0.958	0.772	-0.715	2.788	0.359	2.431
Average	0.806	0.948	0.764	-0.115	3.566	-0.079	3.372
Low-Tech Provinces							
Shanxi	0.615	0.903	0.554	0.277	1.188	0.534	2.000
Inner-Mongolia	0.976	0.863	0.842	-1.092	-0.602	1.285	-0.408
Anhui	0.596	0.938	0.558	-0.306	2.435	0.446	2.575
Jiangxi	0.694	0.844	0.584	-1.698	6.440	-0.770	3.972
Henan	0.726	0.858	0.623	0.743	1.378	0.934	3.054
Hunan	0.699	0.789	0.551	-0.895	6.074	-0.724	4.455
Guangxi	0.720	0.934	0.672	-0.588	2.393	0.547	2.351
Sichuan	0.980	0.842	0.825	-0.184	4.642	-0.683	3.774
Guizhou	0.731	0.888	0.650	0.577	3.082	0.043	3.702
Yunnan	0.711	0.941	0.669	0.214	2.231	0.942	3.387
Shaanxi	0.649	0.966	0.627	0.549	0.668	1.160	2.378
Gansu	0.649	0.975	0.633	0.135	0.977	1.401	2.512
Qinghai	0.917	0.851	0.781	3.423	-1.893	0.449	1.980
Ningxia	0.581	0.764	0.443	1.048	-0.692	1.167	1.523
Average	0.732	0.883	0.644	0.157	2.023	0.481	2.661

Article Two

Development, Transition and Agricultural Productivity in Asia

Abstract

With nearly half of the potential agricultural resources and more than half of world population, Asia has the potential to supply a substantial share of the expected growth in food demand forecast for the first half of this century. A number of countries are in the midst of periods of rapid development. A subset of these were affected by and recovered from the Asia crisis in the late 1990s. During the past two decades there is also another set of Asian countries that have undergone a transformation from a centrally planned economy (CPE) to a free market economy. Economic reforms have helped transform the structure and volume of their agricultural production. This study aims to investigate interregional and intercountry differences in terms of the magnitude and direction of agricultural growth in Asian countries. In the paper we give special attention to the transition economies. This study utilizes a parametric output distance function approach to decompose total factor productivity (TFP) growth into its associated components. The most recent Food and Agricultural Organisation (FAO) data set of 27 Asian countries over the period from 1980-2004 is used. Our major finding indicates that Asian countries on average achieved TFP growth at nearly 2 percent per annum. However, there were large differences among the transition countries in terms of the magnitude and direction of TFP growth. Some transition countries such as China and Mongolia exhibited above average growth. Others, such as, Kyrgyzstan, Uzbekistan, Laos, and Vietnam did not do so well.

Keywords: Agriculture, Productivity, Transition Countries, Biased Technical Change, Asia

Introduction

During the past two decades, Asia has experienced impressive growth in rice and wheat production after the Green Revolution was successfully introduced (Pingali and Heisey, 1999). The Green Revolution in Asia was achieved through the application of the high-yielding varieties of major cereals, chemical fertilizers, pesticides and the development of irrigation system. Increased input use, however, cannot guarantee a long-run sustainable growth rate of yields and output (Huang, Pray and Rozelle, 2002). Over time, cultivated land per capita has declined due to population growth, urbanization, industrialization in a set of rapidly developing Asian nations that were already characterized as relatively limited in terms of their land resources. The decline in arable area was exacerbated by a series of land degradation processes (Pingali et al., 1997). Moreover, rapid economic growth in many countries has enhanced the availability of off-farm employment and increased the opportunity cost of rural labor.

In fact, it is possible to paint a fairly pessimistic picture of Asian agriculture. As well-established in the literature, agricultural production depends critically on the factors that contribute to the improved TFP beyond the quantity of resources, including labor, land and fertilizer. Pingali et al. (1997) show that the potential sources of inputs are mostly exhausted in many countries. Hence future agricultural growth in most countries will not rely on the mobilization inputs but will mainly depend on rising productivity, including the adoption of innovations, a more efficient use of inputs and an improved efficiency by the expansion of the scale of production. However, over the long run the record in the literature is not very encouraging. Indeed, in one of the most exhaustive

studies of the productivity of Asian agriculture, Suhariyanto and Thirtle (2001) estimated that between 1965 and 1996 the annual growth rate of TFP was only 0.31 percent, although over their study period the rate was rising somewhat.

For several reasons in our analysis we seek to build on the previous literature and believe it is time to reevaluate TFP in Asia. The literature on the analysis of intercountry differences in agricultural efficiency and TFP growth has expanded significantly in the past two decades due to the availability of new panel data sets and the development of frontier analysis. One type of frontier analysis, Stochastic Frontier Analysis (SFA) which is a parametric approach, allows the analyst to not only calculate TFP, but also decompose changes in TFP into three components: technical change, changes in technical efficiency and scale economy changes.⁵ Previous attempts to examine TFP across a wide number of Asian countries (e.g., Suhariyanto and Thirtle, 2001) used an index approach. Details on the SFA technique are described later in the paper and in Coelli et al (2005).

In our paper, we also pay particular attention to the former Socialist countries that are currently in transition—for example, countries like China and Mongolia in East Asia; Laos, Myanmar and Vietnam in Southeast Asia; and the nations of Central Asia. It is important when trying to sketch a picture of all of Asia that transition countries be included for several reasons. In the past because of data problems (both absence of data and differences in the nature of data between Socialist and non-Socialist countries) many analyses of the economy just ignored most of these countries (e.g., Young, 1995;

⁵ Another type of frontier analysis is called non-parametric or known as Data Envelopment Analysis (DEA) model.

Otsuka, Chuma and Hayami, 1992; Pingali et al., 1997). Yet these countries account for almost half of the regions population and more than half of the land area. In Suhuriyanto and Thirtle (2001), although China and some East and Southeast Asia nations were included, those in Central Asia were not.

Including the transition countries also is important since without them it is difficult to predict what is happening for overall Asia since predicting the direction of TFP change is difficult for transition countries. On the one hand they generally have a long history of investment into pro-technology R&D and, in some cases, may be somewhat behind the rest of the world in terms of level of new technology adoption. As a result of this, it might be expected that there is relative great potential for expanding TFP by improving the technological base of some of the nations and this in turn would suggest that there could be above average shifts in TFP. However, at the same time, these countries are, by definition, in transition. As a result it is possible that in some cases this means that the set of institutions that are needed in agriculture to produce and extend new technologies are weak or deteriorating enough (because they are in transition and there has not been an equilibrium attached) that there has been a fall in technical efficiency. Indeed, in a recent book that examines the impact of the economic reforms on agricultural production in transition countries found that the effect differed widely across countries and over time within countries (Swinnen and Rozelle, 2006). Moreover, given the timing of the analysis in Suhuriyanto and Thirtle (2001), which was conducted in the years soon after the beginning of the reforms (which did examine the cases of China and Vietnam, but not Central Asia), it is possible that it was difficult to

understand the real situation in transition countries since there was still a lot of disequilibrium in the 1970s, 1980s and early 1990s in many transition countries). As a result, making an assessment with data through the mid-2000s may be able to reveal what is happening (and what will be happening) to transition countries.

Finally, increased availability of data on enough variables on enough countries for sufficient years makes it possible to use the new methods to rigorously analyze differences in productivity for a large number of nations over time and update the analysis to a more recent time period. In the past, a number of papers looked at the effect of market-orient reforms on agricultural performance (e.g., Lerman, 2000; Macours and Swinnen, 2002; and Lissitsa, Rungsuriyawiboon and Parkhomenko, 2007). But limited data kept the authors from looking at a broad range of countries and only allowed them to use partial measures of productivity. Swinnen and Rozelle (2006) is one of the only cross regional papers that examines intercountry comparisons (including transition nations) of agricultural TFP. In their work, however, they admit that the coverage of their work is spotty and their use of different productivity measures in different countries does not facilitate comparisons. In our paper, we examine 27 countries for 25 years. The size of this sample allows us to examine TFP for almost all major nations in Asia over time.

To fill these gaps, the main purpose of the paper is to understand the state of productivity improvements in Asia the world's most populated region. To meet this overall goal we have three specific objectives. First, we seek to measure TFP growth in Asia for the years between 1980 and 2004. Second, we will decompose TFP growth

into three of the sources of productivity growth: technical change, changes in technical efficiency and shifts in scale economies. The technical change component is further decomposed to uncover evidence of how input and output intensities shift in response to the adoption of innovations. Finally, because of the importance transition countries, we are going to pay particular attention to their trends and the contribution to overall Asian TFP growth.

The reminder of the paper is organized as follows. The next section presents the methodology used to construct the TFP growth and its decomposition. The following section discusses the data set and the definitions of the variables used in this study. The empirical results are presented and discussed in the next section and the final section concludes and summarizes.

Model Specification

Decomposition of a TFP Growth

TFP growth is theoretically defined as the difference between the growth rate of total output and the growth rate of total inputs. For example, if agricultural output grew by 2.20 percent and total inputs grew by 1.05 percent between 2004 and 2005, then TFP would grow by 1.15 percent during the years between 2004 and 2005. TFP growth in agriculture is important as it is one source for increasing food production, keeping agricultural prices low and raising incomes of farmers.

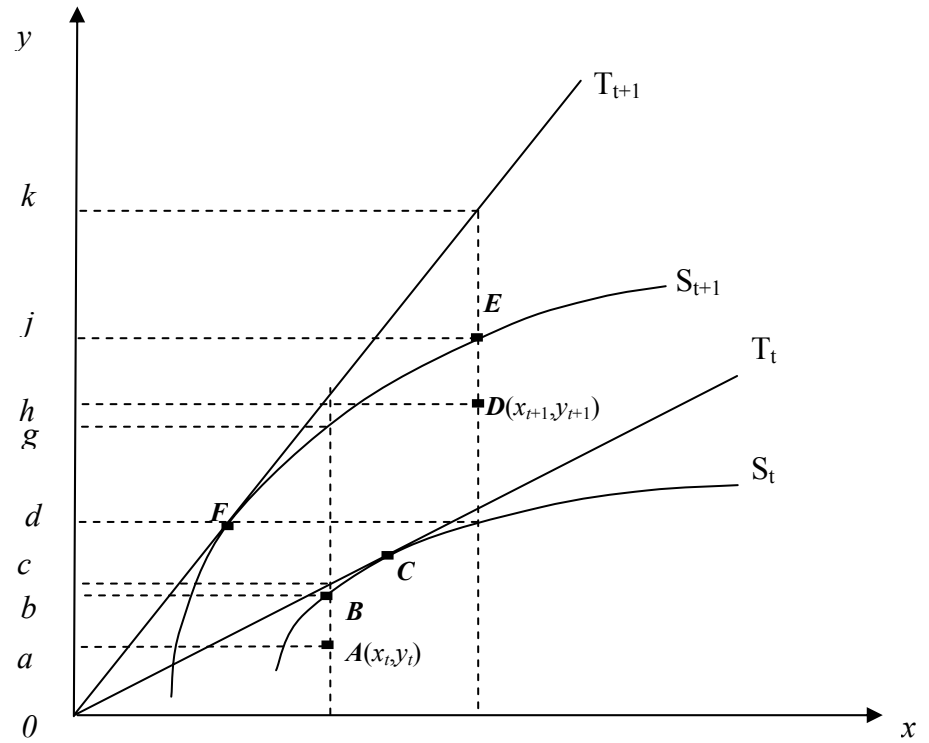
TFP growth, however, is not always easy to track or to predict since there are many different factors that affect its growth. To help understand the forces that affect

the growth of TFP in a given economy, conceptually it is possible to decompose TFP into three part—technical change (TC); changes in technical efficiency (TEC) and changes in scale economies (SEC). The TC-related effect results when the “frontier of production” shifts and there is more output for a given set of inputs, given that producers are already producing efficiently. The TEC-related effect (when it is positive) explains the “catching-up” part of the TFP growth. In other words, TEC occurs when output rises while inputs are constant, given a specific production frontier, because the producer is using the inputs more efficiently. Finally, the SEC-related effect represents the effect of adjusting the optimal farm size to the TFP growth. Understanding which of these components are driving overall TFP growth is important because they provide useful information to policy makers that want to design suitable policies to maintain or achieve greater rates of TFP growth.

Figure 1 illustrates the decomposition of TFP growth into its TEC, TC and SEC components. Consider production technologies of a given industry (e.g., agriculture) for the time period, t and $t+1$. S_t and S_{t+1} are sets constructed using the input-output bundles of all producers in period t and $t+1$, respectively. They represent the production technologies under variable returns to scale (VRS) at the time period t and $t+1$. The boundary of the production technology set indicates the production frontier. The movement of the production frontier from S_t to S_{t+1} represents TFP growth due to TC. A measure of TC can be defined as the geometric mean of the shift in S_t and S_{t+1} at input levels x_t and x_{t+1} which is given by the ratio $\left[\frac{(\overline{0h/0d})}{(\overline{0h/0j})} \times \frac{(\overline{0a/0b})}{(\overline{0a/0g})} \right]^{1/2}$. The shift

of the production frontier from S_t to S_{t+1} in Figure 1 represents technological improvement as a source attributing to TFP growth.

Figure 1: Decomposition of TFP Growth



TFP growth due to TEC and SEC can be illustrated as follows. Consider a producer that is operating at point A and D for the time period t and $t+1$. The observed input-output combinations are located inside the production frontiers, implying that production is not technically efficient in either period. In this scenario it is possible that the producer could produce more outputs from a given set of inputs in either period by adjusting his/her production to points B and E in period t and $t+1$. An output-orientated

measure of TE defined in Farrell (1957) for the observation at time t , relative to the production frontier S_t , is given by the ratio $(\overline{0a}/\overline{0b})$, while the output-orientated TE for the observation at time $t+1$, relative to the production frontier S_{t+1} , is given by the ratio $(\overline{0h}/\overline{0j})$. The producer can increase the productivity by adjusting his/her production to operate at the frontier. This results in an improvement of TFP growth during period t and $t+1$ due to TEC during these periods. TEC which measures the changes in the output-orientated TE measures between periods t and $t+1$ is given by the ratio $(\overline{0h}/\overline{0j})/(\overline{0a}/\overline{0b})$.

Although the producer is operating on the frontier in period t and $t+1$ (point B and E, respectively), the producer could still be operating at a non-optimal scale in either period. In other words, it is possible that the producer might still be able to improve his/her productivity by exploiting scale economies. Taking advantage of scale economies can be done by adjusting production to points C and F in period t and $t+1$. The tangent points, C and F in Figure 1, represent the maximum possible degree of productivity. It also can be called the point of technically optimal scale of the production frontier S_t and S_{t+1} , where T_t (T_{t+1}) is defined as a ray from the origin that is at a tangent to the production frontier S_t (S_{t+1}). The ray T_t (T_{t+1}) can be represented as a distance function when S_t (S_{t+1}) satisfies free disposability, convexity and constant returns to scale (CRS). Therefore, T_t and T_{t+1} represent the CRS technology at the most productive scale size at the time period t and $t+1$. TFP growth between periods t and $t+1$ can rise from progress in SEC in these periods. A measure of SEC

represented by the changes in output SE between the period t and period $t + 1$ data is given by the ratio $(\overline{0j}/\overline{0k})/(\overline{0b}/\overline{0c})$.

A Generalized MPI Change Decomposition and a Parametric Framework

In the literature, TFP growth can be measured by using a productivity index. The most commonly used TFP index is the Malinquist Productivity Index (MPI) presented in Caves, Christensen, and Diewert (1982) and Färe et al. (1994). The MPI has gained more interest in practice because it allows one to identify the various components of TFP growth (specifically, TC, TEC and SEC), which (as discussed above) are often of particular interest to policy makers. The MPI can be empirically calculated using the DEA or SFA technique. Both techniques involve the estimation of a production technology. Färe et al. (1994) initially presented a non-parametric DEA approach to measure the change in the MPI between two time periods. The MPI is defined using an output distance function.⁶ By imposing an assumption of Constant Returns to Scale (CRS) on the production technology, the MPI change can be decomposed into TEC and TC.

Since it is of interest to understand which factors of production are contributing to production (and finding the technologies that enhance those factors), the MPI has another important characteristic. Specifically, Färe et al. (1997) extended the measure of the change in the MPI and is able to show that the TC component can be decomposed into two components: input- and output-biased TC and non-neutral TC.

⁶ It can also be extended using an input distance function.

This decomposition allows one to investigate how the inputs and outputs are reallocated when there is TC. With the availability of new panel data sets and the development of a non-parametric DEA technique, a number of papers decomposing MPI change appeared. However, Färe et al. (1994) raised a fundamental criticism of the decomposition of MPI change using DEA. Fare's work demonstrated that it may not provide an accurate measure of TFP growth because the DEA-based measure ignores shifts in scale economies (SE). Subsequently, Orea (2002) proposed a parametric counterpart of the output-orientated MPI change and produced a way to take shifts in SE into account. Using this new methodology, SEC is considered as an additional component of the TFP growth.

Using Distance Functions to Measure and Decompose TFP Growth

To implement the methods in the literature, one must first introduce the approach of empirical estimation. In our paper, we measure the TFP growth (and decompose the MPI) using an output distance function. The output distance function is defined as a rescaling of the length of an output vector with the production frontier as a reference.

The first step in explaining our approach is to consider a multi-input, multi-output production technology where the i -th producer ($i = 1, \dots, I$) at time period t ($t = 1, \dots, T$) uses a non-negative $K \times 1$ input vector $X_{it} \in R_+^K$ to produce a non-negative $M \times 1$ output vector $Y_{it} \in R_+^M$. The set of all technologically feasible input-output combinations at time period t satisfying the standard properties discussed in Färe and Primont (1995) is $S_t = \{(X, Y) : X \text{ can produce } Y\}$.

The output distance function for the period t is defined as

$$D_t^o(X_t, Y_t) = \inf \{ \theta : (X_t, Y_t / \theta) \in S_t \}, \quad (1)$$

where the superscript o refers to an output orientation of the distance function. The output distance function is non-decreasing, linearly homogenous and convex in Y , and non-increasing and quasi-convex in X . $D_t^o(X_t, Y_t) \leq 1$ if and only if $(X_t, Y_t) \in S_t$. Moreover, $D_t^o(X_t, Y_t)$ is equal to Farrell's the output-orientated TE measured at time t , that is $0 \leq TE_t^o(X_t, Y) \equiv D_t^o(X_t, Y) \leq 1$.

Orea (2002) employs a parametric technique and applies Diewert's (1976) Quadratic Identity Lemma to derive a generalized MPI change decomposition. The logarithmic form of a generalized output-oriented MPI change index between periods t and $t+1$ can be written as

$$\begin{aligned} m_{t,t+1}^{o,v} &= \left(\frac{d_{t+1}^{o,v}}{d_t^{o,v}} \right) - \frac{1}{2} \left[\frac{\partial d_{t+1}^{o,v}(\cdot)}{\partial t} + \frac{\partial d_t^{o,v}(\cdot)}{\partial t} \right] \\ &+ \frac{1}{2} \left[\sum_{k=1}^K \left(-\sum_{k=1}^K e_{kt+1} - 1 \right) \cdot s_{kt+1} + \left(-\sum_{k=1}^K e_{kt} - 1 \right) \cdot s_{kt} \right] \left(\frac{x_{kt+1}}{x_{kt}} \right), \quad (2) \\ &= \ln TEC^{o,v} + \ln TC^{o,v} + \ln SEC^{o,v}, \end{aligned}$$

where the superscript v refers to a measure that is calculated from the distance function corresponding to VRS technology; m^o is the logarithm of the MPI change index between periods t and $t+1$; $d_t^{o,v}$ is the logarithm of output distance term which is equivalent to the logarithm of output-orientated measure of Farrell TE in period t ; $d_t^{o,v}(\cdot)$ is the logarithm of the output distance function; x_{kt} is the logarithm of the k^{th} input in period t ; $e_{kt} = \partial d_t^{o,v}(\cdot) / \partial x_{kt}$ is the distance elasticity for the k^{th} input in period t , and $s_{kt} = e_{kt} / \sum_{k=1}^K e_{kt}$ is the distance elasticity share for the k^{th} input in period t . In

our paper $\ln TEC^{o,v}$ represents the logarithmic form of TEC, $\ln TC^{o,v}$ represents the logarithmic form of TC, and $\ln SCE^{o,v}$ represents the logarithmic form of SEC. Equation (2) is expressed in terms of proportional rates of growth instead of a product of indices.

Estimating the Distance Function

The components of the generalized MPI change can be measured by estimating the output distance function. To estimate the parameters of an output distance function, however, we must first specify a functional form. The output distance function taking the log-quadratic translog functional form can be defined as

$$d_{it}^{o,v}(\cdot) = \beta_0 + \sum_{m=1}^M \beta_{y_m} y_{mit} + \frac{1}{2} \sum_{m=1}^M \sum_{n=1}^M \beta_{y_m y_n} y_{mit} y_{nit} + \sum_{k=1}^K \beta_{x_k} x_{kit} + \frac{1}{2} \sum_{k=1}^K \sum_{l=1}^K \beta_{x_k x_l} x_{kit} x_{lit} \\ + \sum_{k=1}^K \sum_{m=1}^M \beta_{x_k y_m} x_{kit} y_{mit} + \beta_t t + \frac{1}{2} \beta_{tt} t^2 + \sum_{k=1}^K \beta_{x_k t} x_{kit} t + \sum_{m=1}^M \beta_{y_m t} y_{mit} t, \quad (3)$$

Where the β s are unknown parameters to be estimated. Young's theorem requires that the symmetry restriction is imposed so that $\beta_{x_k x_l} = \beta_{x_l x_k}$.

Linear homogeneity in outputs requires the following restrictions:

$$\sum_{m=1}^M \beta_{y_m} = 1, \sum_{n=1}^M \beta_{y_m y_n} = 0 \quad (m=1, \dots, M), \sum_{m=1}^M \beta_{x_k y_m} = 0 \quad (k=1, \dots, K) \text{ and } \sum_{m=1}^M \beta_{y_m t} = 0. \quad (4)$$

Imposing the linear homogeneity in outputs yields the estimating form of the output distance function, in which the distance term, $d_{it}^{o,v}(\cdot)$, can be viewed as an error term as follows:⁷

⁷ Homogeneity can be imposed by estimating the model with $M-1$ output variables normalized by the M^{th} output variable.

$$\begin{aligned}
-y_{Mit} = & \beta_0 + \sum_{m=1}^{M-1} \beta_{y_m} y_{mit}^* + \frac{1}{2} \sum_{m=1}^{M-1} \sum_{n=1}^{M-1} \beta_{y_m y_n} y_{mit}^* y_{nit}^* + \sum_{k=1}^K \beta_{x_k} x_{kit} \\
& + \frac{1}{2} \sum_{k=1}^K \sum_{l=1}^K \beta_{x_k x_l} x_{kit} x_{lit} + \sum_{k=1}^K \sum_{m=1}^{M-1} \beta_{x_k y_m} x_{kit} y_{mit}^* + \beta_z t + \frac{1}{2} \beta_{tt} t^2 \\
& + \sum_{k=1}^K \beta_{x_k t} x_{kit} t + \sum_{m=1}^{M-1} \beta_{y_m t} y_{mit}^* t - d_{it}^{o,v},
\end{aligned} \tag{5}$$

where $y_{mit}^* = (y_{mit} - y_{Mit})$. By replacing the distance term, $-d_{it}^{o,v}$, with a composed error term, $v_{it} - u_{it}$, equation (5) can be estimated as a standard stochastic frontier function where v_{it} s are a two-sided random-noise component assumed to be i.i.d. $N(0, \sigma_v^2)$ and u_{it} s are a non-negative technical inefficiency component assumed to be a half normal distribution, $N^+(0, \sigma_u^2)$. The two terms, v_{it} and u_{it} , are error terms that are assumed to be distributed independently of each other, and of the regressors.

Accounting for the Bias in Technological Change

Following a parametric distance function approach for the period t the MPI decomposition proposed by Fuentes, Grifell-Tatjé, and Perelman (2001) can be used to decompose the TC component of TFP growth into two additional parts: an input- and output-biased TC part; and a non-neutral TC part. The further decomposition into these two subcomponents would allow one to investigate how inputs and outputs which are reallocated when there are shifts in technology can be attributed to TC. The parametric distance function approach of the MPI change decomposition requires that analyst imposes the assumption of CRS on the production technology. The CRS assumption implies homogeneity of degree minus one in inputs, which requires the following

restrictions: $\sum_{k=1}^K \beta_{x_k} = -1$, $\sum_{l=1}^K \beta_{x_k x_l} = 0$ ($k = 1, \dots, K$), $\sum_{k=1}^K \beta_{x_k y_m} = 0$ ($m = 1, \dots, M-1$) and

$$\sum_{k=1}^K \beta_{x_k t} = 0.$$

To impose these CRS restrictions the analyst must make changes to the data. Specifically, the restrictions can be imposed in equation (5) by normalizing input data by one of the K inputs. After doing so, the translog output distance function under the CRS model is

$$\begin{aligned} -y_{Mit} + x_{Kit} = & \beta_0 + \sum_{m=1}^{M-1} \beta_{y_m} y_{mit}^* + \frac{1}{2} \sum_{m=1}^{M-1} \sum_{n=1}^{M-1} \beta_{y_m y_n} y_{mit}^* y_{nit}^* + \sum_{k=1}^{K-1} \beta_{x_k} x_{Kit}^* \\ & + \frac{1}{2} \sum_{k=1}^{K-1} \sum_{l=1}^{K-1} \beta_{x_k x_l} x_{Kit}^* x_{Lit}^* + \sum_{k=1}^{K-1} \sum_{m=1}^{M-1} \beta_{x_k y_m} x_{Kit}^* y_{mit}^* + \beta_z t + \frac{1}{2} \beta_{tt} t^2 \\ & + \sum_{k=1}^{K-1} \beta_{x_k t} x_{Kit}^* t + \sum_{m=1}^{M-1} \beta_{y_m t} y_{mit}^* t - d_{it}^{o,c}, \end{aligned} \quad (6)$$

where $x_{kit}^* = (x_{kit} - x_{Kit})$ and superscript c on $d_{it}^{o,c}$ refers to a measure that is calculated from the distance function corresponding to the CRS technology. By replacing $-d_{it}^{o,c} = v_{it} - u_{it}$, equation (6) can also be estimated as a standard stochastic frontier function.

After equation (6) is estimated, the TC component can be decomposed into a magnitude of TC ($MTC^{o,c}$) and a biased TC ($BTC^{o,c}$). The $BTC^{o,c}$ can be further decomposed into input-biased TC ($IBTC^{o,c}$) and output-biased TC ($OBTC^{o,c}$). The logarithmic form of the $MTC^{o,c}$, $IBTC^{o,c}$ and $OBTC^{o,c}$ are given as

$$\ln MTC^{o,c} = \frac{d_{it}^{o,c}(\cdot)}{d_{t+1}^{o,c}(\cdot)}, \quad (7)$$

$$\ln IBTC^{o,c} = \sum_{k=1}^K \frac{\partial d_{it}^{o,c}(\cdot)}{\partial t \partial x_{kit}} \left(\frac{x_{kt+1}}{x_{kt}} \right), \quad (8)$$

$$\ln OBTC^{o,c} = \sum_{m=1}^M \frac{\partial d_{it}^{o,c}(\cdot)}{\partial t \partial y_{mit}} \left(\frac{y_{mt+1}}{y_{mt}} \right). \quad (9)$$

If $\ln IBTC^{o,c}$ and $\ln OBTC^{o,c}$ are simultaneously equal to zero, the $MTC^{o,c}$ equals the TC under joint Hicks neutrality. The value of $\ln MTC^{o,c}$ can be less than, equal to, or greater than zero, depending upon whether productivity is declining, unchanged, or improving, respectively. The value of $\ln IBTC^{o,c}$ of the k -th input can be greater than (less than or equal to) zero, implying that technology change increases (decreases or remains unchanged) the use of the k -th input. Similarly, the value of $\ln IBTC^{o,c}$ of the m -th output can also be greater than (less than or equal to) zero, implying that technology change leads the firm to produce more (less or unchanged) of the m -th output.

Data

The empirical analysis in this study focuses on agricultural production of 27 Asian countries. The primary source of data is obtained from the website of the FAO of the United Nations (UN). Specifically, the agricultural statistics were acquired from the AGROSTAT system, which is supported by the Statistics Division of the FAO. The data used to measure agricultural performance contain the measurements of agricultural output and input quantities. In this study, the production technology is presented by two output variables (i.e., crop output and livestock output) and five input variables (i.e. land, tractor power, labor, fertilizer and livestock).

Output Variables

In this study, the output series are derived by aggregating detailed output quantity data on 127 agricultural commodities (115 cropping commodities and 12 livestock commodities). The construction of the output data series used two basic steps. First, the Geary-Khamis method was used to construct output aggregates from the output quantity data. To do so, we used average international prices (expressed in US dollars) for the base period 1999 to 2001.⁸ Second, the aggregate output values during the base period were used to generate an aggregate output series from 1992-2002 using the FAO production indices for crops and livestock separately.⁹

Input Variables

Given limitations on the number of input variables that could be used in the analysis (due to lack of data on other variables on the FAO website), only five input variables are used in our study. Our input variables are defined as follows:

Land input variable represents arable land in each country in each year. Arable land includes both land under permanent crops as well as the area under permanent pasture. The variable is measured in hectares.

Tractor input variable represents the total number of wheeled- and crawler tractors that are used in agriculture. We exclude garden tractors.

⁸ Detailed information on how international average prices are constructed can be found in Rao (1993)

⁹ See the FAO STAT (FAO, 2004) for details regarding the construction of production index numbers

Labor variable refers to the number of economically active people in agriculture. It is best thought of as a measure of the number of laborers in the agricultural sector.

Fertilizer input variable sums up, in nutrient-equivalent terms, the commercial use of nitrogen, potassium and phosphate fertilizers. The variable is expressed in thousands of metric tons. The fertilizer input variable is defined by following the approaches of other studies on inter-country comparison of agricultural productivity (Hayami and Ruttan, 1970; Fulginiti and Perrin, 1997).

Livestock input variable is the sheep-equivalent of the six categories of animals used in constructing this variable. The six categories considered are buffaloes, cattle, pigs, sheep, goats and poultry. The total number of each category of these animals is converted into sheep equivalents using a standard conversion factor: 8.0 for buffalos and cattle; 1.00 for sheep, goats and pigs; 0.1 for poultry (Hayami and Ruttan, 1970).

Panel data on 27 Asian countries over the time period of 1980 through 2004 are used in the empirical analysis. These countries account for more than 46 percent of global agricultural outputs and 56 percent of world's population. The countries account for 94 percent of the population of Asia. Only a small number of nations (e.g., Bahrain; Brunei; Bhutan; Cyprus; Jordan; Kuwait; Lebanon; Maldives; Oman; Qatar; Singapore) are excluded due to the absence of data.

Countries selected for analysis are categorized into six regions: Central Asia (CA), Eastern Asia (EA), Southern Asia (SA), Southeast Asia (SEA), Western Asia (WA) and China (CN).¹⁰ In recognition of its size and due to differences in its accounting

¹⁰ The regional groupings are based on their geographical used in [UN Statistics Division](#).

practices over time, China is treated as a region by itself.¹¹ A list of the countries in each region is summarized in Table 1.

Table 1: Classification of Selected Countries

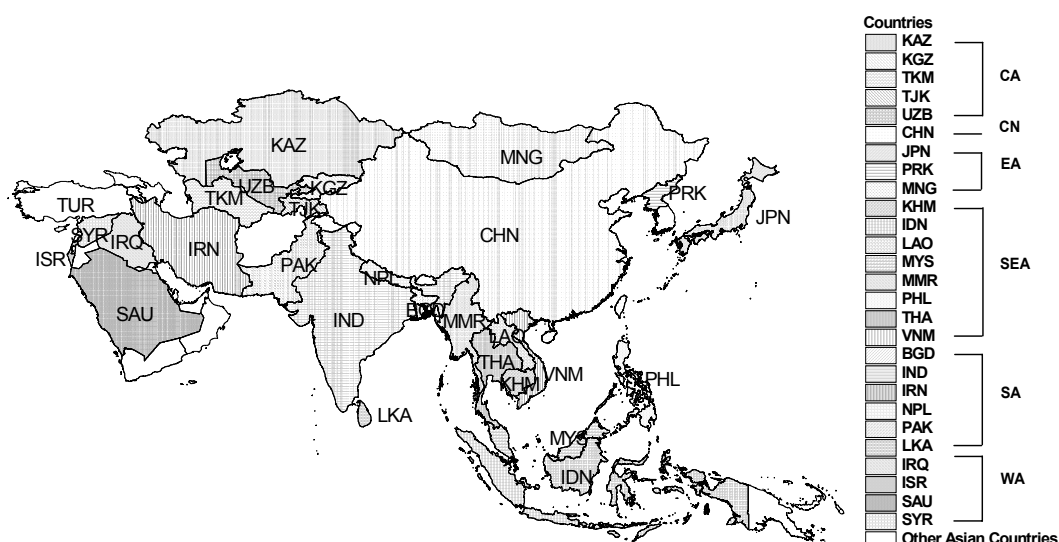
Region	Country	Region	Country
Central Asia (CA)	Kazakhstan (KAZ)	Southeast Asia (SEA)	Cambodia (KHM)
	Kyrgyzstan (KGZ)		Indonesia (IDN)
	Tajikistan (TKM)		Laos (LAO)
	Turkmenistan (TJK)		Malaysia (MYS)
	Usbekistan (UZB)		Myanmar (MMR)
Eastern Asia (EA)	Japan (JPN)		Philippines (PHL)
	Republic of Korea (PRK)		Thailand (THA)
	Mongolia (MNG)		Vietnam (VNM)
Southern Asia (SA)	Bangladesh (BGD)	Western Asia (WA)	Iraq (IRQ)
	India (IND)		Israel (ISR)
	Islamic Rep of Iran (IRN)		Saudi Arabia (SAU)
	Nepal (NPL)		Syrian Arab Republic (SYR)
	Pakistan (PAK)	China (CN)	China (CHN)
	Sri Lanka (LKA)		

Figure 2 presents a map of Asia map indicating the location of each country used in this study. Descriptive statistics of the variables summarized by each region is presented in Table 2. China shows that it produces the highest share of agricultural

¹¹ According to the UN definition, China is located within the EA region.

output values for both crop and livestock commodities.¹² China also accounts for the highest share of agricultural land, labor and fertilizer use. The EA region exhibits the highest share of tractors whereas the SA region shows the highest share of livestock input.¹³

Figure 2. Map of the Countries Used in This Study



¹² Agricultural output values for crops account for 43.78% by CN, 30.13% by SA, 15.3% by SEA, 5.96% by WA, 3.54% by EA and 1.23% by CA, and agricultural output values for livestock account for 43.36% by CN, 33.08% by SA, 7.74% by EA, 7.73% by SEA, 5.77% by WA and 2.32% by CA.

¹³ Agricultural land accounts for 37.30% by CN, 20.43% by SA, 14.43% by WA, 10.72% by CA, 9.53% by EA and 7.58% by SEA. Agricultural labor accounts for 50.84% by CN, 33.25% by SA, 12.97% by SEA, 1.73% by WA, 0.86% by EA and 0.35% by CA. Fertilizer used in agriculture accounts for 49.63% by CN, 29.18% by SA, 10.83% by SEA, 4.86% by WA, 4.56% by EA and 0.93% by CA. Tractor used in agriculture accounts for 34.19% by EA, 28.79% by SA, 14.85% by WA, 13.94% by CN, 4.88% by SEA and 3.36% by CA. Livestock used in agriculture accounts for 58.02% by SA, 25.88% by CN, 8.70% by SEA, 3.78% by WA, 2.08% by EA and 1.54% by CA.

Table 2: Descriptive Statistics of Variables, 1980-2004

Variable	Units	Region						
		CA [*]	EA	SEA	SA	WA	CN	All
Outputs								
- Crops	10 ⁶ US \$	1793 (1446)	4465 (3496)	7267 (6423)	19020 (30127)	4517 (6221)	165817 (44930)	14794 (35694)
- Livestock	10 ⁶ US \$	1282 (1072)	3711 (3369)	1389 (1099)	7926 (11919)	1660 (1844)	62344 (33658)	5616 (14707)
Inputs								
- Land	10 ³ ha	57.31 (78.46)	44.13 (57.43)	13.17 (12.24)	47.33 (63.19)	40.11 (53.12)	518.41 (36.23)	54.29 (107.67)
- Tractors	10 ³	76.46 (64.03)	674.65 (903.59)	36.13 (53.64)	284.01 (514.45)	175.78 (292.12)	825.24 (92.53)	231.25 (476.38)
- Labor	10 ³	1.29 (0.90)	2.72 (2.01)	15.33 (13.67)	52.42 (85.03)	3.28 (5.08)	480.97 (35.18)	36.96 (101.00)
- Fertilizer	10 ⁶ ton ³	206 (350)	871 (734)	775 (840)	2785 (4626)	557 (630)	28418 (9009)	2237 (6096)
- Livestock	10 ⁶	32.86 (26.61)	38.53 (10.89)	60.45 (41.32)	537.65 (850.03)	42.07 (56.95)	1439.04 (272)	217.18 (525.27)

^{*} Data for each country in this region are only available during the time period of 1992 to 2004.

Notes: Means are calculated. Standard deviations are presented in parentheses

Results

The panel data on 27 Asian countries during the time period from 1980 to 2004 were used to estimate the translog output distance function under the VRS model from equation (5) and the CRS model from equation (6). The variables used in the model estimation were each transformed by dividing by their respective geometric means.¹⁴

The maximum likelihood parameter estimates are listed in Table 3.

¹⁴ This transformation does not alter the performance measures obtained, but does allow one to interpret the estimated first-order parameters as elasticities, evaluated at the sample means.

In general, the estimation performed well. All first-order coefficients from both models have the expected signs, implying that the output distance functions are increasing in outputs and decreasing in inputs at the sample mean.¹⁵ The estimates of the distance elasticities with respect to outputs estimated by the VRS model are 0.490 and 0.510 for crops and livestock. The output elasticities estimated by the CRS model are fairly consistent, 0.436 for crops and 0.564 for livestock. The estimates of the distance elasticities with respect to inputs estimated by the VRS model are -0.099, -0.184, -0.192, -0.224 and -0.334 for land, tractors, labor, fertilizer, and livestock, respectively. The point estimate of the sum of the input elasticities from the VRS model is -1.033, indicating that the technology exhibits small to moderately increasing returns to scale at the sample mean. When the CRS model is used, the estimates of the input elasticities are -0.064, -0.202, -0.136, -0.342 and -0.255 for land, tractors, labor, fertilizer, and livestock, respectively, and by definition add to -1.

According to the results of our two models, we find some evidence that there are moderate economies of scale in Asian agriculture. Our hypothesis test that the CRS to scale model accurately captures the nature of the economies of scale in cropping and livestock production was conducted using a likelihood ratio (LR) test. The LR test is rejected at the 90 percent level implying the economies of scale may be marginally significant. Because of this result, in the rest of the analysis the parameter estimates of

¹⁵ Tests of the regularity conditions are checked at each data point in all 615 observations. We find the convexity condition and the monotonicity constraints on outputs are satisfied at all observations in the output distance function for both models. The monotonicity constraints in inputs are violated at 9, 3, 6, 5, and 10% of all observations in the case of land, tractors, labor, fertilizer and livestock inputs, respectively, for the VRS model. In the CRS model, the monotonicity constraints in the corresponding inputs are violated at 11, 5, 12, 3, and 10% of all observations.

the VRS model are used to calculate the components of the MPI change decomposition.¹⁶

Table 3: Estimated Parameters of the Output Distance Model

Parameter ^a	VRS Model		CRS Model	
	Estimates	t-Statistic	Estimates	t-Statistic
β_0	0.277	8.781	0.532	9.438
β_{y1}	0.490	20.114	0.436	15.200
β_{y1y1}	0.331	5.253	0.340	5.524
β_{x1}	-0.099	-7.126	-0.064	-4.128
β_{x2}	-0.184	-15.228	-0.202	-14.205
β_{x3}	-0.192	-8.222	-0.136	-5.153
β_{x4}	-0.224	-16.310	-0.342	-28.582
β_{x5}	-0.334	-11.067		
β_{x1x1}	-0.101	-7.517	-0.098	-6.898
β_{x2x2}	0.033	3.321	0.027	2.272
β_{x3x3}	0.151	2.455	0.220	3.775
β_{x4x4}	-0.022	-3.161	-0.027	-3.405
β_{x5x5}	-0.228	-2.034		
β_{x1x2}	0.043	5.147	-0.006	-0.726
β_{x1x3}	-0.103	-4.426	-0.086	-3.816
β_{x1x4}	0.048	5.470	0.075	7.118
β_{x1x5}	0.035	1.179		
β_{x2x3}	0.195	8.454	0.348	14.712
β_{x2x4}	-0.060	-7.818	-0.095	-10.992
β_{x2x5}	-0.128	-4.866		
β_{x3x4}	-0.214	-10.331	-0.231	-10.274
β_{x3x5}	-0.008	-0.103		
β_{x4x5}	0.296	12.564		
β_{x1y1}	-0.051	-2.115	-0.051	-2.351
β_{x2y1}				

¹⁶ Investigating how the inputs and outputs are reallocated attributed to TC requires the CRS assumption. Hence, the estimates from the CRS model are used to calculate the components of the TC decomposition.

β_{x3y1}	-0.093	-4.688	-0.169	-7.606
β_{x4y1}	-0.182	-3.831	-0.311	-6.767
β_{x5y1}	0.189	10.061	0.216	10.204
β_t	0.114	2.067		
β_{tt}	-0.008	-6.887	-0.006	-4.240
β_{x1t}	-0.001	-2.590	-0.002	-4.654
β_{x2t}	-0.008	-6.996	-0.009	-7.168
β_{x3t}	0.003	3.128	0.002	1.534
β_{x4t}	0.002	0.808	-0.007	-2.748
β_{x5t}	0.001	1.036	0.007	5.569
β_{y1t}	-0.006	-2.564		
σ^2	-0.001	-0.410	-0.002	-0.758
γ	0.062	8.042	0.072	4.819
Likelihood	0.788	11.257	0.581	3.091
Value				
	215.501		81.959	

^a Subscripts on β_x coefficients refer to inputs: 1 = land; 2 = tractors; 3 = fertilizer; 4 = labor; 5 = livestock input and subscripts on β_y coefficients refer to outputs: 1 = crops; 2 = livestock output

Perhaps the most general and important finding in our paper is that over the entire time period of our analysis (1980 to 2004), the annual growth rate of TFP across all of Asia (the 27 countries in our study) was positive and nearly 2 percent (1.902 percent—Table 4, section A, row 6, column 6). A growth rate of 2 percent is typically considered as a sign that agriculture is healthy in terms of its improvement in productivity. It is higher than the rate of growth of the population of Asia during 1990s (around 1.5 percent—Asia Development Bank, 2001). Most developed countries that are considered to have well performing agricultural economies (e.g., the United States, Germany, Australia) have consistently posted TFP growth rates of more than 1.5 percent (Bureau, Färe and Grosskopf, 1995).

The importance of examining productivity shifts over the past decade are important since this fairly robust rate of TFP growth for Asia the entire study period to a large extent are driven by rises in TFP during the past 10 years (Table 4, Section A, column 6). Between 1980 and 1995, TFP growth average only a bit over 1 percent (rising from 0.343 percent in the 1980-85 period to 1.775 (1.857) percent during the 1984-90 (1990-95) period. These numbers are remarkably consistent with those of Suhariyanto and Thirtle (2001) that found the growth of TFP in Asia before 1996 was around 1 percent. After 1995, the rate of growth of TFP accelerates, rising by 2.023 percent in 1995-2000 and by nearly 4 percent in 2000-04.

The findings of the decomposition analysis demonstrate convincingly that the relatively high overall rate of TFP growth and its recovery over the past two decades has relied, in general, on technological change (TC—Table 4, Section A, column 4). In fact, through the entire period (except after 2000), the rate of TC exceeds TFP growth. Between 1980 and 2004, the adoption of new varieties of crops, the extension of new breeds of livestock and other breakthroughs have pushed up the production frontier by 2.321 percent annually. During the past decade TC has grown by nearly 3 percent annually (2.847 percent between 1995 and 2000; and 3.245 percent between 2000 and 2004). While in this paper it is beyond the scope of our analysis to identify the exact sources of TC, according to work by Evensen and Golin (2003), David and Otsuka (1994), and Pingali et al. (1997), the second generation of the Green Revolution appears to be succeeding in keeping the rate of TC high.

Table 4: Weighted Average Growth Rates of the TE Scores and MPI Change for Each Region over the Time Period of 1980 to 2004 (in %)

Region	Period	TEC	TC	SEC	TFP Growth
A) All	1980-1985	-0.598	1.422	-0.481	0.343
	1985-1990	0.371	1.897	-0.494	1.775
	1990-1995	-0.218	2.376	-0.300	1.857
	1995-2000	-0.885	2.847	0.061	2.023
	2000-2004	0.835	3.245	-0.165	3.916
	1980-2004	-0.138	2.321	-0.280	1.902
B) SA	1980-1985	-0.613	1.833	-0.179	1.041
	1985-1990	-0.235	2.154	-0.145	1.774
	1990-1995	-0.121	2.479	-0.085	2.273
	1995-2000	-0.104	2.819	0.019	2.734
	2000-2004	0.285	3.128	0.103	3.516
	1980-2004	-0.176	2.456	-0.064	2.216
C) SEA	1980-1985	0.041	0.199	-0.032	0.208
	1985-1990	1.159	0.607	0.047	1.813
	1990-1995	-0.100	0.872	-0.223	0.549
	1995-2000	0.101	1.105	-0.132	1.074
	2000-2004	0.248	1.472	0.123	1.843
	1980-2004	0.292	0.825	-0.050	1.066
D) WA	1980-1985	0.405	-0.854	0.374	-0.076
	1985-1990	-0.689	-0.295	-0.022	-1.005
	1990-1995	-0.401	0.201	-0.155	-0.355
	1995-2000	-0.705	0.578	-0.077	-0.203
	2000-2004	-0.674	0.949	-0.484	-0.208
	1980-2004	-0.402	0.081	-0.056	-0.376
E) EA	1980-1985	-0.280	-2.083	-3.386	-5.749
	1985-1990	0.163	-1.721	-1.059	-2.617
	1990-1995	0.103	-1.328	-1.016	-2.241
	1995-2000	-0.581	-0.914	-0.032	-1.528
	2000-2004	1.532	-0.607	-2.689	-1.763
	1980-2004	0.131	-1.361	-1.592	-2.822
F) EA+CN	1980-1985	-0.810	1.598	-0.865	-0.077
	1985-1990	0.613	2.189	-0.911	1.892

	1990-1995	-0.381	2.838	-0.475	1.982
	1995-2000	-1.613	3.420	0.186	1.993
	2000-2004	1.430	3.877	-0.388	4.919
	1980-2004	-0.218	2.739	-0.495	2.026
G) CA	1992-1995	1.360	1.612	-0.177	2.795
	1995-2000	-0.623	1.808	-1.083	0.103
	2000-2004	-0.502	2.350	-0.041	1.806
	1992-2004	-0.087	1.940	-0.509	1.344

Rates of TC that exceeded TFP growth, in fact, were needed to keep TFP growing at a healthy rate since our decomposition analysis shows that during the study period TFP has been pulled down due to declining technical efficiency (TEC—Table 4, Section A, column 3). According to our results, TFP growth between 1980 and 2004 would have been 0.138 percent high had efficiency levels not fallen. Over time there has been less of a consistent change in TEC. In the most recent period (2000 to 2004), somewhat surprisingly (given the continued rise in off farm employment—which might be one factor is behind falling efficiencies), TEC rose by 0.835 percent. When combined with TC, it is clear now why TFP growth was so high in the 2000 to 2004.

TFP growth rate during the study period would have been even higher had changes in scale economies (SEC) not deteriorated (Table 4, Section A, column 5). Between 1980 and 2004, the contribution of scale economies to TFP growth was negative (-0.280 percent). In other words, TFP growth would have been 0.280 percent higher had not efficiencies due to economies of scale fallen. The result, with the exception of the 1995 to 2000 period (perhaps associated with the Asian Crisis), most

likely was reflecting the continued tendency for farm sizes in Asia to decline (Kuhnen, 1996).

In summary, then, for Asia as a region as a whole, productivity growth is relatively robust and rising. This is good news for those concerned about keeping balance in Asia and world food markets, especially given the secular declining trends in cultivated land, labor and water (Pingali, 2001). If Asia's food output is going to help contribute to world supplies, productivity is going to need to continue since it is likely that resources will continue to flow out of the sector as development in many of the region's countries continues. The importance of agricultural R&D is clear from our findings as TC accounts for all of the growth in TFP. One implication of the results is that if the factors that are contributing to the falls in TEC and SEC can be reversed, it is possible that TFP could grow even faster.

Sources of TFP Growth in Asia's Major Regions and the Importance of Transition Nations

If we examine TFP growth during the study period in the regions of Asia that have been the focus of most studies in the past it is clear that the aggregate story of TFP growth would be somewhat different than when looking at the region as a whole (as we did in the previous section). The record of the major regions from *traditional Asia* can be seen in Sections B, C, D and E in Table 4. In the table, the results of our TFP analysis are given for each of the study's subperiods as well as the findings of the decomposition analysis.

Interestingly, the patterns of TFP growth in South Asia (SA) parallel those of the rest of Asia (Table 4, Section B). The annual growth rate of TFP is around 2 percent (2.216 percent) and it is rising over time. In addition, the rate of TC exceeds that of TFP growth in all periods, except the period after 2000, meaning that TC in SA, as in Asia as a whole, is responsible for all of the growth. This high rate of TC in SA is needed since the TEC and SEC components are negative (also like that in Asia as a whole). It is clear from these results that the increasingly robust performance of SA is at least one driver of the results found in Asia more generally.

The healthy performance in SA is not matched by the other regions (Table 4, Sections C, D and E). The growth rate of TFP in Southeast Asia (SEA) is only around 1 percent, about half that of Asia as a whole. This rate in SEA, however, is at least positive; those in Western Asia (WA) and Eastern Asia (EA) are negative. Especially in the case of EA, between 1980 and 2004, on average, TFP has fallen by 2.822 percent annually. In the case of all three of these regions, SEC has detracted from productivity (especially in EA where land tenure laws and agricultural support policies discourage farm consolidation). Technological change, although contributing to TFP growth slightly in SEA and WA, drags down TFP growth in EA. Finally, while TEC is negative in WA, it is slightly positive in SEA and EA.

It is clear that the story of Asia, had it relied on these four regions (SA, SEA, WA and EA) alone, would not have been such an encouraging story. In fact, if we had only included the countries in these regions (the nations that were mostly studied in the past), the estimated rate of TFP growth would have been much lower. Although not

reported in the table, the rate of increase in TFP from the four regions between 1980 and 2004 was 1.543 percent. The importance of SA in the record of Asia as a whole is shown by computing the rate of TFP growth with only SEA, WA and EA (0.664 percent). Such low growth rates would be the source of concern for those that worry that Asia is not able to contribute significantly to world food production. If both TFP and input levels are falling, food output in the region would also necessarily fall.

The performance of Asia's productivity growth, however, is greatly enhanced by including the former Socialist countries in East and Central Asia (Table 4, Sections F and G). In fact, the record of China—coupled with its size—shows that it (like SA) also is one of the driving forces behind the rebound of Asian productivity. In fact, the rate of growth of TFP for China for most of the entire period and the rate of growth in the most recent period are nothing short of remarkable. Between 1985 and 2000, there was no five year period in which China's TFP growth fell below 2 percent annually. Between 2000 and 2004 TFP grew at a rate above 5 percent. While extremely high, in fact, these rates are most consistent with those estimated by Jin et al. (2007) which shows (with a completely different set of data) that TFP rates of cropping and livestock are high by international standards and growing over time.

The performance of China's productivity, like that of SA and Asia as whole, are driven by TC—and hurt by TEC and SEC (Table 4, Section F). Indeed, during the entire study period TC rose by 3.209 percent annually. As shown in Jin et al. (2002) most of this growth can be accounted for by investments into R&D. The analysis of China's agricultural economy over the entire reform period, described in Huang, Otsuka and

Rozelle (2007), is able to explain why it is that TEC and SEC falls. Problems with the extension system, disequilibrium from rapid change and the relatively rigid tenure system (as well as pure demographics) have kept farms in China relatively small and inefficient.

While not as spectacular as China, the record of CA nonetheless is a positive one (Table 4, Section G). During the entire period (1992 to 2004 for CA—due to absence of data in earlier periods) the growth rate of TFP reached 1.344 percent. Between 2000 and 2005 TFP rose by a rate of 1.806 percent almost as fast as Asia as a whole for the study period. This area, which is sometimes thought to be an underperformer (Swinnen and Rozelle, 2006), in fact, has not performed that poorly in terms of TFP growth. Like Asia as a whole (and China), shifts in TC are fully responsible for the growth in TFP. TEC and SEC (especially) detracted from TFP growth.

Examining Transition Countries in More Detail

When breaking down the transition countries in more detail, it actually is possible to see that overall they have contributed a lot to the growth of Asia's TFP during the study period (Table 5, Section A). When taking all countries in aggregate, it is clear to see that the record of them is an important part of the Asian experience. Overall TFP growth was 2.419 percent for the whole study period and rising over time. Most of the growth was due to TC, and TEC and SEC were negative. These trends suggest that the former Socialist nations and the leaders of their Transition governments may have been able to

maintain TFP growth mostly through their investments into agricultural R&D or other initiatives to promote technology. At the same time, transition, even a decade or two or after the end of transition may be dragging down TFP growth due to continued disequilibrium (which is inherent in many transition phenomenon).

**Table 5: Weighted Average Growth Rates of the TE Scores and MPI Change
Decomposition by Transition Countries after the Start of Their Market Reform (in %)**

Transition Country	Periods	TEC	TC	SEC	TFP Growth
A) All	1980-1985	-0.737	2.015	-0.438	0.840
	1985-1990	0.622	2.568	-0.818	2.372
	1990-1995	-0.304	3.058	-0.411	2.344
	1995-2000	-1.552	3.520	0.097	2.065
	2000-2004	1.252	3.916	-0.179	4.989
	1980-2004	-0.202	2.978	-0.357	2.419
B) China	1980-1985	-0.895	2.205	-0.440	0.871
	1985-1990	0.679	2.751	-0.883	2.547
	1990-1995	-0.437	3.302	-0.409	2.456
	1995-2000	-1.696	3.791	0.202	2.297
	2000-2004	1.435	4.191	-0.237	5.388
	1980-2004	-0.250	3.209	-0.358	2.600
C) Mongolia	1991-1995	-1.365	3.456	1.777	3.868
	1995-2000	-3.401	4.105	3.102	3.806
	2000-2004	6.232	4.489	-7.315	3.406
	1991-2004	0.078	3.983	-0.347	3.714
D) Vietnam	1986-1990	-1.301	-0.346	-0.143	-1.790
	1990-1995	1.797	-0.101	-1.112	0.583
	1995-2000	0.358	0.153	-1.452	-0.941
	2000-2004	-1.364	0.616	-0.100	-0.848
	1986-2004	-0.062	0.052	-0.734	-0.744
E) Laos	1986-1990	-0.267	-0.032	0.950	0.651
	1990-1995	0.043	0.438	0.935	1.417
	1995-2000	-5.314	0.805	-0.218	-4.728

	2000-2004	0.653	1.059	0.500	2.212
	1986-2004	-1.320	0.542	0.544	-0.234
F) Myanmar	1989-1992	0.275	1.085	-0.153	1.207
	1992-1996	-1.577	1.472	-0.026	-0.131
	1996-2000	-0.372	1.848	0.442	1.917
	2000-2004	1.705	2.410	1.917	6.033
	1989-2004	0.008	1.704	0.545	2.256
G) Kazakhstan	1992-1996	2.977	2.990	-1.297	4.669
	1996-2000	-2.746	3.412	-3.423	-2.757
	2000-2004	0.444	3.833	-0.346	3.932
	1980-2004	0.225	3.412	-1.689	1.948
H) Kyrgyzstan	1992-1996	-0.007	0.247	-0.124	0.117
	1996-2000	-1.621	0.477	0.109	-1.034
	2000-2004	0.969	1.036	-3.045	-1.040
	1980-2004	-0.219	0.587	-1.020	-0.653
I) Tajikistan	1992-1996	0.290	-0.139	-1.469	-1.318
	1996-2000	-1.764	0.323	-0.705	-2.146
	2000-2004	3.027	0.512	2.978	6.518
	1980-2004	0.517	0.232	0.268	1.018
J) Turkmenistan	1992-1996	0.556	1.063	0.150	1.768
	1996-2000	-1.497	1.469	0.110	0.082
	2000-2004	1.149	2.055	1.801	5.004
	1980-2004	0.069	1.529	0.687	2.285
K) Uzbekistan	1992-1996	0.098	0.830	0.278	1.206
	1996-2000	-0.250	1.173	0.094	1.017
	2000-2004	-2.698	1.642	-0.006	-1.062
	1980-2004	-0.950	1.215	0.122	0.387

Because of the danger that the China's record (Table 5, Section B) dominates the findings when aggregating the region as a whole, we also can examine the other 9 transition economies. When doing so we find that there are sharp differences among them. Excluding China, in the case of 5 of them (Mongolia—section C; Myanmar—section F; Kazakhstan—section G; Tajikistan—section I; and Turkmenistan—section J),

there was positive TFP growth above 1 percent. In fact, four of them had rates of growth that were more (or close) to 2 percent annually. Interestingly, in all cases in which the transition nation's experienced positive TFP growth, the rate of growth of TC was positive. In all of these countries, TEC was also positive. Therefore, the negative disequilibrium effect found for China may not have been due to transition, but rather a function of its extremely fast growth rates. All of the countries with positive TFP growth which also had a positive contribution of TEC during the 2000-2004 period, actually experienced negative TEC in an earlier period. What these results suggest is that the disequilibrium of transition which detracted from growth in earlier period was a temporary phenomenon and now growth from TEC is positive.

There were, however, four nations (Vietnam—Section D; Laos—Section E; Kyrgyzstan—Section H; Uzbekistan—Section K) that had either negative or small positive TFP growth rates (Table 5). It is difficult—and beyond the scope of this paper—to determine why some of these countries had TFP growth rates of rose while those of others did not. Swinnen and Rozelle (2006) state that in no large part differences in the performance of the transition countries, in general (including those inside and outside of Asia) are due to differences in pricing, land rights and marketing policies. If this were the case in our sample, it would then lead to the further question about why it is that different countries adopted different policy regimes. Such questions need to be answered in further research.

The Nature of Technological Change

Because of the importance in all nations of TC, in this section we are going to extend our analysis to examine the nature of that change. As discussed in the methodological section above, it is possible to estimate if the technological changes that are occurring in the countries are output biased and/or input biased. It also is possible to estimate what particular factors are being saved and which ones are being used.

According to our analysis, the sum of input-biased TC across all of Asia was larger than that of output-biased TC (Table 6, Sections A). It is clear that technology improvements had increased the efficient use of inputs (input saving) more than they had increased the capability to produce output (output or yield enhancing). Overall, TC was biased toward livestock output but against crops. On the input side, TC was biased toward tractors, fertilizer and livestock input but against land and labor. In summary, technology improvement in Asia used more tractors, fertilizer and livestock input but less land and labor to produce more livestock than crops. The record of Asia as a region as a whole had it relied on the SA, SEA, CN (Table 6, Sections B, C and F).

When investigating the transition countries in more detail, there were large differences among the transition countries in terms of how input and output intensities shift in response to the adoption of innovations. The records of transition countries in EA (Table 7, Section A and B) show that TC was biased toward crops but against livestock output in Mongolia whereas TC was biased toward livestock output but against crops in China. On the input side, the input-biased TC results imply that technology improvement in Mongolia increased use of labor but decreased use of land, tractor,

fertilizer and livestock input while technology improvement used more tractors, fertilizer and livestock input but less land and labor in China. The outcome suggests that China had drastically reduced use of such inputs as land and labor.

Three nations in SEA (Vietnam—Section C; Laos—Section D; Myanmar—Section E) show that technology improvements had increased the capability to produce more livestock in Laos and Myanmar, and more crops in Vietnam. On the input side, technology improvements had increased use of tractor, fertilizer and livestock input in Laos while livestock input increased in Myanmar and land, labor and livestock input increased in Vietnam. Other five nations in CA (Kazakhstan—Section F; Kyrgyzstan—Section G; Tajikistan—Section H; Turkmenistan—Section I and Uzbekistan—Section J) show that TC was biased toward crops but against livestock output in Kazakhstan and Kyrgyzstan whereas TC was biased toward livestock output but against crops in Turkmenistan and Uzbekistan. In Tajikistan, TC was biased against both crops and livestock output. On the input side, the input-biased TC results imply that TC in Kazakhstan increased use of land and labor but decreased use of tractors, fertilizer and livestock input while the direction of TC uses more labor but less land, tractors, fertilizer, and livestock inputs in Kyrgyzstan. The outcomes suggest that these countries had not significantly increased the output except in Turkmenistan and they had reduced use of such inputs as tractors. Land input had also been reduced in Kyrgyzstan and Turkmenistan while labor input had proven to decrease in Tajikistan and Turkmenistan. Fertilizer input had been reduced in Kazakhstan and Kyrgyzstan while livestock input had proven to decrease in Kazakhstan, Kyrgyzstan and Tajikistan.

Table 6: Weighted Average Growth Rates of the TC Decomposition by Regions (%)

Region	Period	MTC	Output-Biased TC		Input-Biased TC				
			crop	livestock	land	tractor	labor	fertilizer	livestock
A) All	1980-1985	-1.052	-0.008	0.011	-0.011	0.010	-0.009	0.043	0.013
	1985-1990	-0.327	-0.005	0.010	-0.007	0.008	-0.008	0.052	0.015
	1990-1995	0.471	-0.005	0.012	0.000	0.004	-0.004	0.028	0.015
	1995-2000	1.316	-0.005	0.008	-0.003	0.011	-0.003	0.005	0.001
	2000-2004	2.136	-0.005	0.008	-0.001	0.003	-0.002	0.025	0.010
	1980-2004	0.441	-0.006	0.010	-0.005	0.007	-0.005	0.031	0.011
B) SA	1980-1985	-1.567	-0.008	0.010	-0.001	0.015	-0.008	0.062	0.011
	1985-1990	-0.954	-0.006	0.007	-0.001	0.016	-0.007	0.047	0.009
	1990-1995	-0.186	-0.005	0.007	0.001	0.009	-0.011	0.022	0.006
	1995-2000	0.607	-0.004	0.007	0.000	0.009	-0.010	0.027	0.001
	2000-2004	1.461	-0.003	0.005	0.000	0.009	-0.010	-0.007	0.002
	1980-2004	-0.194	-0.005	0.007	-0.001	0.012	-0.009	0.032	0.006
C) SEA	1980-1985	-0.404	-0.006	0.010	-0.008	0.009	-0.013	0.076	0.027
	1985-1990	0.313	-0.005	0.009	-0.013	0.017	-0.012	0.039	0.007
	1990-1995	0.966	-0.006	0.009	0.002	0.022	-0.008	0.044	0.010
	1995-2000	1.732	-0.005	0.003	-0.010	0.013	-0.006	0.030	-0.011
	2000-2004	2.660	-0.007	0.010	-0.006	-0.001	-0.004	-0.017	0.011
	1980-2004	0.986	-0.006	0.008	-0.007	0.013	-0.009	0.037	0.009
D) WA	1980-1985	-1.596	-0.010	0.011	-0.006	0.013	0.000	0.105	0.005
	1985-1990	-0.800	-0.005	0.005	-0.007	0.009	0.013	0.033	0.010
	1990-1995	0.233	-0.003	-0.002	-0.015	0.009	0.000	0.005	-0.003
	1995-2000	1.039	0.001	0.010	0.000	0.003	0.002	0.014	0.007
	2000-2004	1.797	-0.008	0.006	0.002	-0.001	0.002	0.028	0.002
	1980-2004	0.065	-0.005	0.006	-0.006	0.007	0.004	0.037	0.004
E) EA	1980-1985	-3.425	-0.004	0.006	0.004	0.019	0.018	0.017	0.027
	1985-1990	-2.742	0.001	0.004	0.005	0.014	0.029	-0.006	-0.004
	1990-1995	-2.005	0.002	0.003	0.009	0.008	0.033	-0.017	0.015
	1995-2000	-1.146	0.001	0.001	0.005	0.006	0.034	-0.021	-0.015
	2000-2004	-0.420	0.003	0.000	0.018	0.002	0.040	0.019	-0.002
	1980-2004	-2.011	0.001	0.003	0.008	0.010	0.030	-0.003	0.005
F) EA+CN	1980-1985	-0.862	-0.009	0.012	-0.019	0.007	-0.009	0.017	0.009
	1985-1990	-0.056	-0.005	0.013	-0.010	0.000	-0.009	0.058	0.023
	1990-1995	0.767	-0.006	0.017	0.000	-0.005	0.000	0.034	0.023
	1995-2000	1.605	-0.006	0.010	-0.004	0.012	0.001	-0.007	0.005
	2000-2004	2.345	-0.006	0.008	-0.001	0.000	0.003	0.047	0.013
	1980-2004	0.694	-0.006	0.012	-0.007	0.003	-0.003	0.029	0.015
G) CA	1992-1995	0.963	0.024	-0.004	0.004	-0.008	0.004	-0.127	-0.011
	1995-2000	2.371	-0.006	-0.004	0.002	-0.014	0.006	-0.176	-0.037
	2000-2004	3.276	-0.008	0.009	0.000	-0.001	0.002	0.161	0.033
	1980-2004	2.321	0.001	0.001	0.002	-0.008	0.004	-0.051	-0.007

Table 7: Weighted Average Growth Rates of the TC Decomposition by Transition Countries after the Start of their Market Reform (in %)

Country	Period	Output-Biased TC		Input-Biased TC				
		crop	livestock	land	tractor	labor	fertilizer	livestock
A) Mongolia	1991-1995	0.033	-0.004	0.010	-0.014	0.001	-0.292	0.013
	1995-2000	0.010	0.011	-0.017	-0.015	0.006	0.078	0.031
	2000-2004	-0.011	-0.017	0.000	0.003	0.004	0.089	-0.077
	1991-2004	0.012	-0.003	-0.002	-0.010	0.004	-0.051	-0.006
B) China	1980-1985	-0.009	0.013	-0.023	0.005	-0.013	0.018	0.006
	1985-1990	-0.006	0.014	-0.012	-0.002	-0.014	0.067	0.026
	1990-1995	-0.007	0.019	-0.001	-0.006	-0.003	0.039	0.024
	1995-2000	-0.007	0.010	-0.004	0.013	-0.002	-0.006	0.006
	2000-2004	-0.006	0.009	-0.002	0.000	0.000	0.049	0.014
	1980-2004	-0.007	0.013	-0.009	0.002	-0.007	0.033	0.016
C) Laos	1986-1990	-0.008	0.012	-0.003	0.005	-0.014	-0.042	0.026
	1990-1995	0.004	0.014	-0.004	0.005	-0.017	0.208	0.027
	1995-2000	-0.021	0.005	-0.013	0.002	-0.016	-0.004	-0.014
	2000-2004	-0.004	0.006	-0.014	0.000	-0.018	0.704	0.021
	1986-2004	-0.007	0.009	-0.008	0.003	-0.016	0.191	0.015
D) Myanmar	1989-1992	-0.004	-0.009	-0.001	-0.008	-0.012	-0.048	-0.011
	1992-1996	-0.010	0.007	-0.002	-0.009	-0.012	0.175	0.012
	1996-2000	-0.009	0.011	-0.006	0.012	-0.010	0.031	0.014
	2000-2004	-0.008	0.014	-0.009	0.000	-0.009	-0.604	0.015
	1989-2004	-0.008	0.006	-0.005	-0.001	-0.011	-0.112	0.008
E) Vietnam	1986-1990	-0.058	-0.007	0.008	0.001	-0.008	-0.018	0.026
	1990-1995	0.413	-0.009	0.009	-0.009	0.047	-0.012	0.115
	1995-2000	0.843	-0.011	0.012	-0.037	0.018	-0.008	0.091
	2000-2004	1.667	-0.008	0.013	-0.018	0.000	-0.009	0.003
	1986-2004	0.666	-0.009	0.010	-0.016	0.015	-0.012	0.062
F) Kazakhstan	1992-1996	0.037	-0.018	0.010	-0.018	0.019	-0.150	-0.061
	1996-2000	-0.008	-0.009	0.005	-0.045	0.023	-0.597	-0.096
	2000-2004	-0.008	0.008	-0.001	0.000	0.013	0.575	0.035
	1992-2004	0.007	-0.006	0.005	-0.021	0.018	-0.057	-0.041
G) Kyrgyzstan	1992-1996	0.003	-0.009	-0.005	-0.010	0.005	0.000	-0.089
	1996-2000	-0.021	0.005	-0.001	0.011	0.001	0.000	0.000
	2000-2004	-0.004	0.001	-0.002	-0.006	-0.001	-0.518	0.006
	1992-2004	-0.007	-0.001	-0.003	-0.002	0.002	-0.173	-0.028
H) Tajikistan	1992-1996	0.010	-0.032	0.003	-0.008	-0.004	-0.291	-0.037
	1996-2000	-0.001	0.000	0.005	-0.009	-0.001	-0.005	-0.018
	2000-2004	-0.019	0.022	0.003	-0.004	-0.005	0.779	0.027
	1992-2004	-0.003	-0.003	0.004	-0.007	-0.003	0.161	-0.009
I) Turkmenistan	1992-1996	0.033	0.014	-0.001	-0.010	-0.016	0.009	0.050
	1996-2000	-0.030	0.012	-0.001	0.000	-0.011	-0.097	0.028
	2000-2004	-0.009	0.016	-0.002	0.000	-0.011	0.266	0.073
	1992-2004	-0.002	0.014	-0.002	-0.003	-0.013	0.060	0.050
J) Uzbekistan	1992-1996	0.004	-0.003	0.001	-0.002	-0.004	-0.053	0.001
	1996-2000	-0.001	0.003	0.000	0.000	-0.002	-0.045	0.000
	2000-2004	-0.007	0.008	0.003	0.000	-0.003	-0.194	0.028
	1992-2004	-0.001	0.003	0.001	-0.001	-0.003	-0.097	0.010

Conclusions

With nearly half of the potential agricultural resources, Asia has the potential to supply an increase in world food demand. More than half of the population in Asia is living in the rural area where agricultural products are the main source of food supply and income of rural households. It has been recognized that during the past two decades, many countries in this continent have undergone a transformation from the CPE to a market-oriented economy. Understanding the magnitude and direction of TFP growth as well as what sources attributing to TFP growth is important because they provide useful information to policy makers that want to design suitable policies to maintain or achieve greater rates of TFP growth in these countries.

To meet this purpose, this study employs a parametric output distance function approach to construct and decompose TFP growth into three of the sources of productivity growth: TC, TEC and SEC. The TC component is further decomposed to uncover evidence of how input and output intensities shift in response to the adoption of innovations. This model is empirically implemented using the most recent FAO data set of 27 Asian countries over the period from 1980-2004. Our major finding indicates that Asian countries on average achieved TFP growth at nearly 2 percent per annum, which is typically considered as a sign that agriculture is healthy in terms of its improvement in productivity. The decomposition of TFP showed convincingly that the relatively high rate of TFP growth was mainly driven by technology improvement. TFP growth rate over the past two decades would have been even higher if TEC had not declined or SEC not deteriorated.

Focusing on the transition economies, there were large differences among the transition countries in terms of the magnitude and direction of TFP growth during the transition process. Market reforms have contributed to the progress achieved to date in most countries in CA, China, Mongolia and Myanmar. Transition countries such as China, Vietnam, Mongolia, Kazakhstan and Kyrgyzstan showed that the impact by adjusting the farm size under the current land allocation system and the thin land rental market did not guarantee the healthy economy through the scale of economy, but through the improvement of technology or the more efficient use of input factors. The innovation adoption resulted in various reallocations of inputs and outputs among the transition countries where land, labor, fertilizer and tractor were the main inputs contributing to TFP growth.

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Output จากโครงการวิจัยที่ได้รับทุนจาก สกว.

1. ผลงานตีพิมพ์ในฐานข้อมูลวารสารวิชาการของสถาบัน IAMO ประเทศ Germany

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2. การนำผลงานวิจัยไปใช้ประโยชน์

ได้รับเชิญเป็นวิทยากรอบรมเชิงปฏิบัติการเรื่อง การวัดประสิทธิภาพและผลผลิตภาพของการผลิตสินค้าเกษตร ณ สำนักวิจัยเศรษฐกิจการเกษตร ระหว่างวันที่ 20-24 กันยายน 2550 และได้รับเชิญไปสอนนักศึกษาปริญญาเอก กระบวนวิชา Efficiency and Productivity Analysis: Deterministic Approaches ร่วมกับ Professor Uwe Latacz-Lohmann ณ The Institute of Agricultural Development in Central and Eastern Europe ประเทศสหพันธ์สาธารณรัฐเยอรมนี ระหว่างวันที่ 17-21 มีนาคม 2551 ในระหว่างการอบรมได้นำเอาแบบจำลองที่พัฒนาขึ้นและผลการศึกษาที่ได้จากงานวิจัยเป็นตัวอย่างที่ใช้ในการบรรยาย

3. การเสนอผลงานในที่ประชุมวิชาการ

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3.1.2 ผลงานเรื่อง Development, Transition and Agricultural Productivity in Asia ในการประชุมวิชาการระดับชาตินักเศรษฐศาสตร์ ครั้งที่ 4 ณ มหาวิทยาลัยเชียงใหม่ ในวันที่ 24 ตุลาคม 2551

3.2 การเสนอผลงานในที่ประชุมวิชาการต่างประเทศ

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3.2.2 ผลงานเรื่อง Development, Transition and Agricultural Productivity in Asia ซึ่งจะนำไปเสนอในที่ประชุมวิชาการนานาชาติ The Asia-Pacific Productivity Conference 2008 (APPC2008) ที่จะจัดขึ้น ณ กรุงไทเป ประเทศ ไต้หวัน ระหว่างวันที่ 17-19 กรกฎาคม 2551

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DISCUSSION PAPER

**Leibniz Institute of Agricultural Development
in Central and Eastern Europe**

**RECENT EVIDENCE ON AGRICULTURAL
EFFICIENCY AND PRODUCTIVITY IN CHINA:
A METAFRONTIER APPROACH**

SUPAWAT RUNGSURIYAWIBOON, XIAOBING WANG

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ABSTRACT

Economic reform in China helped transform the structure and volume of agricultural production and resulted in significant changes in efficiency and productivity. This paper measures agricultural technical efficiency (TE) and total factor productivity (TFP) in China by allowing producers operating under their own technologies. A metafrontier function approach is applied using a panel data set on 28 provinces during 1991-2005. The provinces are categorized into advanced-technology and low-technology provinces. Based on the metafrontier estimation, TFP growth is decomposed into TE change (TEC), technical change (TC) and scale efficiency change (SEC). This information is useful for policy makers to design suitable policies in enhancing agricultural TE and TFP growth in China. Our major findings indicate that TC was mostly attributed to Chinese agricultural TFP growth throughout the period of study. SEC and TEC exhibited negative effects to TFP growth for the advance- and low-technology provinces, respectively. Most of the advanced-technology provinces exhibited higher TE than the low-technology provinces. The comparatively low TE scores in the low-technology provinces imply that the low-technology provinces were operating far from the metafrontier. The fluctuation of TE measured with respect to the metafrontier function indicates it is possible that Chinese agricultural TFP growth can be improved through the improvement of TE. The results also show that labor and fertilizer still make important contributions to output, and thus improving the quality of farmers and applying modern physical inputs is also crucial to TFP growth.

JEL: Q16, Q18, P27

Keywords: Metafrontier, Agriculture, China, Technical Efficiency, Total Factor Productivity.

ZUSAMMENFASSUNG

NEUE ANHALTSPUNKTE FÜR EFFIZIENZ UND PRODUKTIVITÄT IN DER CHINESISCHEN
AGRARPRODUKTION: EINE METAFRONTIER UNTERSUCHUNG

Chinas wirtschaftliche Reformen halfen der Landwirtschaft, die Struktur und dem Umfang der landwirtschaftlichen Produktion umzubauen. Signifikante Erhöhungen der Effizienz und der Produktivität waren die Folge. Die vorliegende Arbeit misst technische Effizienz (TE) und total factor productivity (TFP) in China unter der Annahme individueller Technologien der Landwirte. Mit Hilfe eines Paneldatensatzes für 28 Provinzen über den Zeitraum 1991-2005 wird ein metafrontier Ansatz angewandt. Die Provinzen werden in technologisch fortschrittliche und weniger entwickelte Regionen eingeteilt. Auf der Basis des metafrontier Ansatzes wird das TFP Wachstum in Änderung der technischen Effizienz (TEC), technischen Fortschritt (TC) und Änderung der Skaleneffizienz (SEC) zerlegt. Daraus abgeleitete Informationen sind für die Entwicklung angepasster Politiken zur Förderung technischen Fortschritts und TFP-Wachstums in der chinesischen Landwirtschaft erforderlich. Zentrale Ergebnisse der Analyse zeigen, dass das Wachstum der TFP hauptsächlich durch den technischen Fortschritt erklärt wird. Dagegen weisen SEC und TEC negative Effekte auf das Wachstum der TFP in beiden Provinz-Untergruppen auf. Die Mehrzahl der technisch weiterentwickelten Provinzen weisen eine höhere technische Effizienz als die weniger entwickelten Regionen auf. Die vergleichsweise niedrigen TE-Werte der letzteren deuten auf

die weiter entfernte Lage dieser Provinzen von der Metafrontier hin. Die Ergebnisse zeigen, dass Chinas TFP-Wachstum durch eine Steigerung der TE erhöht werden kann. Des Weiteren leisten die Faktoren Arbeit und Düngemittel einen wichtigen Beitrag zur Produktion. Somit sind zusätzlich die Ausbildung der Landwirte und die Bereitstellung moderner Produktionsmittel für die Steigerung der TFP von Bedeutung.

JEL: Q16, Q18, P27

Schlüsselwörter: Metafrontier, Landwirtschaft, Stochastic Frontier Schätzung, China, Technische Effizienz, Technischer Fortschritt, Skaleneffizienz, Total Factor Productivity.

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1 INTRODUCTION

Given the important role of agriculture in the economy and trade, the pursuit of efficiency and productivity in agricultural production with better access to food security has posed major issues for the Chinese policy makers and WTO accession negotiation. The impressive growth of agricultural production in 1978-1984 acknowledged to the successful reform from the collective system to household responsibility system (HRS). Subsequently, an unexpected stagnation of grain yield and a drop in agricultural production occurred in the later 1980s. Though the market-oriented reform through 1990s has been a start-and-stop affair (BRUEMMER et al., 2006), the direction of policy implication is to explore the potential TE, increase the capital improvement and expand the new technology in production (HUANG et al., 2002; HUANG et al., 2002; LIU and WANG, 2005). By the end of 1990s, it is witnessed that China's leader decided to make another push at grain marketing reform with the goal of increasing the efficiency of farming and allowing farmers to pursue activities in which they have a comparative advantage. At the same time, the government actively promoted the shift of farmers into non-grain crops, such as cash crops, fruit and vegetables. After fifteen years of negotiations, China ratified an agreement committing itself to one of the most liberalized international trade regimes in the world. Further, the nation has adopted numerous trade-policy-oriented measures in preparation. Tariffs had been lowered from more than 60 % in 1990s to around 20 % in 2000. From 2002, the government began to subsidize the grain producers instead of collecting agricultural tax. Subsidies, although just beginning, are mostly thought to be decoupled (SONNTAG et al., 2005).

Much public attention has been paid to production and its enormous potential for higher efficiencies evolved in those undergoing sustained agricultural growth. Evaluating both the efficiency and productivity in Chinese agricultural production keeps pace with the evolution of the frontier methodology. A bulk of conclusions has surrounded the arbitrary selection and merits of a specific methodology, and the availability of the data sources. Efficiency measurements draw the supports from frontier functions using two approaches: Parametric and nonparametric approaches. Initially, a parametric estimation on the efficiency and productivity of Chinese agricultural production date back to a study by FAN (1991). Using the aggregated provincial data, FAN (1991) showed that the gaps of TE across regions inlay in the development of local economy and technology expansion. Moreover, 63 % of productivity growth could be devoted to the improvement of TE obtained from the unique impact of institutional reform over 1965-85. Following a time-varying TE model proposed by CORNWELL et al. (1990), WU (1995) assumed TE consists of linear and quadratic time-trend and province-specific components. The main finding of his study is that TFP growth differs largely among regions through the regional variation of TE. With a more flexible form of the varying coefficients frontier function model, KALIRAJAN et al. (1996) revealed that TE improved greatly after the reform but turned to negative during the stagnation of yield in 1984-987.

In order to identify the determinants of TE scores, the studies turn to apply frontier models to farm household-level datasets. Vesting in a profit frontier functions, WANG et al. (1996) defined a shadow-price profit frontier model to examine production efficiency of Chinese rural households. Their study showed that the profit efficiency score in agriculture production ranges from 0.06 to 0.93, with the average of 0.62. Factors such as educational level, family size and net income are positively related to production efficiency. TIAN and WAN (2000) employed deterministic frontiers into one-sided components of stochastic variation estimated by the traditional stochastic frontier functions. TE scores for several crops were evaluated and decomposed. They found that TE is responsive to crop varieties and planting system, which is

under the influence of technology improvement. Recently, BRUEMMER et al. (2006) estimated a multiple-output distance functions for individual households data attained from Zhejiang province. Their study showed that the difference in productivity prior to and post-1990s resulted from the difference in TE in the two periods, which could owe to the land policy and the frequent adjustment of market policies. CHEN et al. (2006) applied the traditional stochastic frontier analysis (SFA) model proposed by BATTESE and COELLI (1992) and used the same fixed-point survey data sources as BRUEMMER et al. (2006). They concluded that TE is determined by the farm size and the village intrinsic characteristics.

The implicit assumption of the parametric estimation on TE is the frontier function can be estimated under functional form specification. Without specifying an ex-ante functional form and assuming the behavior of producers, some studies seek to a nonparametric method using index accounting approaches. MAO and KOO (1997) applied a data envelopment analysis (DEA) model to decompose Malmquist index into TC and TEC indices. They identified that TE did not perform identically among provinces and potential for the further improvement of TE is still great, even for the important agricultural provinces.

All the above-mentioned studies followed the frontier production function approach initiated by FARRELL (1957). The foundation for the measurement of TE using a parametric approach is a stochastic frontier model originally proposed by AIGNER et al. (1977). This approach has been expanded by various models of measuring and computing production functions and TE (KUMBHAKAR and LOVELL, 2000). These models assume that all producers in different groups of a given industry have access to the same technology, and thereby facing the same best practice frontier. However, each producer may choose to operate on a different part of its technology due to the geographic influences, resources endowment and policy implication on technology. When the resource is endowed differently in the regions, the empirical evaluation without considering the location specific factors of production and TC can not provide useful policy application. To take account of the technology variation, BETTESE et al. (2002) recently presented a metafrontier function model using the parametric estimation to allow measuring the TE for each producer operating under different production frontiers.

This paper extends the empirical analysis on TE of Chinese agricultural production in several dimensions. First, the parametric estimation of the metafrontier function model is applied to investigate TE of the provinces in China. The provinces are categorized into two groups due to distinctive levels of economic development and production technologies. Secondly, a more recent panel data set of 28 provinces covering the time period of 1991 to 2005 is used in this paper. Since the start of China's WTO agricultural commitments and subsidizing the grain producers in 2002 promoted structural changes in subsequent years, the analysis in this paper will reflect a period of more rapid market-oriented reform and structure changes of agricultural production in China. Thirdly, TFP growth is measured using the defined metafrontier function and TFP growth is decomposed into associated components. This information is useful for policy makers to design suitable policies in enhancing agricultural TE and TFP growth in China. To our knowledge, it is the initial application of this technique into the empirical application.

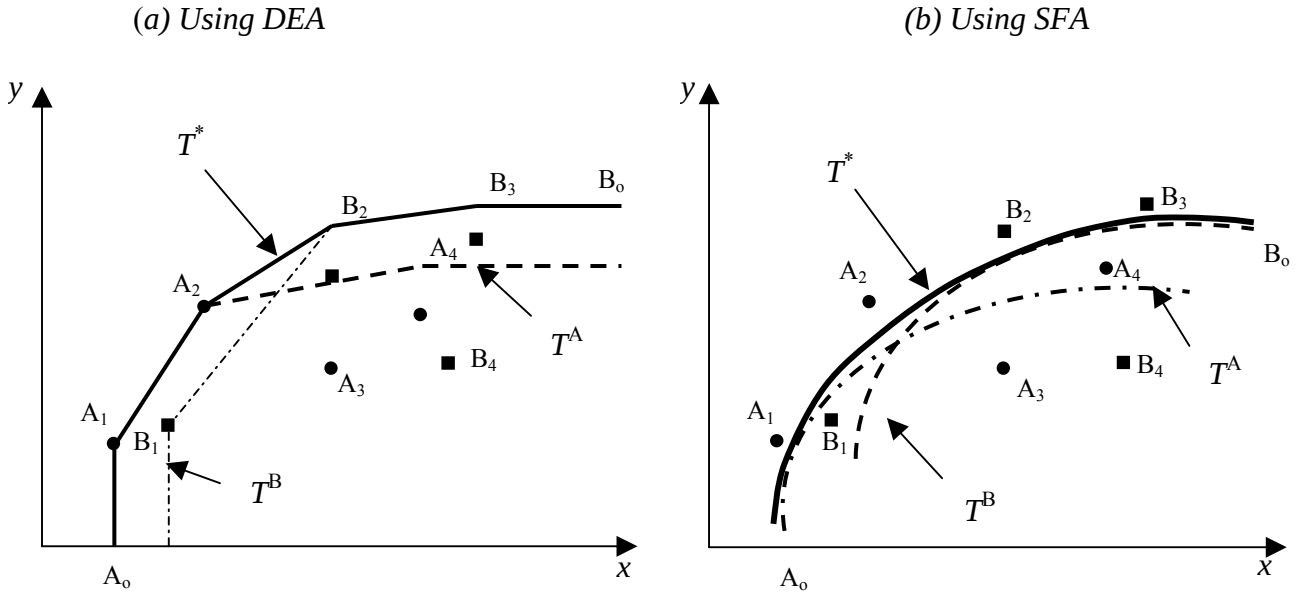
The remainder of this paper is organized as follows. The next section presents a theoretical concept of a metafrontier approach, followed by a discussion of the empirical techniques used to estimate efficiency and productivity using the metafrontier analysis. Then, we describe the data set and the definitions of all variables. The empirical results are presented and discussed, and the final section summarizes our main conclusions.

2 MODEL SPECIFICATION

When all producers in different groups of a given industry have a potential access to the same technology but each producer may choose to operate on a different part of their technologies depending on circumstances such as the natural endowments, relative prices of inputs and the economic environment, then the assessment of producer's efficiency and productivity can be measured using a metafrontier concept. HAYAMI and RUTTAN (1970) initially proposed a metaproduction function which is defined as the envelope of commonly conceived neoclassical production functions. Thus, it is a common underlying production function that is used to represent the input-output relationship of a given industry.

The metafrontier function can be measuring using both nonparametric and parametric approaches. The nonparametric approach is known as DEA and the parametric approach is known as SFA. Figure 1 (a) and (b) illustrate how the metafrontier function is constructed using the DEA and SFA approaches, respectively. Consider there are two different groups of technologies, namely A and B. Let points A_1, A_2, A_3 and A_4 indicate the input-output bundles of four producers in group A. These points are used to construct a frontier for production technology in group A or T^A . Similarly, points B_1, B_2, B_3 and B_4 show the input-output bundles of four producers in group B. These points are used to construct a frontier for production technology in group B or T^B . If each group of producers has potential access to the same technology, the grand frontier which envelops the two group-specific frontiers can be represented by line $A_0A_1A_2B_2B_3B_0$. This line is referred as a metafrontier function or T^* . The metafrontier function using DEA constructs piece-wise linear convex production technology by enveloping all observed data from each group-specific technology. It does not require specified functional form for each group-specific technology. On the other hand, the metafrontier function using SFA constructs a smooth production technology by tangencing a specified functional form of production functions from each group-specific technology. The metafrontier using SFA is a smooth function and not a segmented envelope of each group-specific technology.

Figure 1: Group-specific frontier and metafrontier



2.1 Define group-specific technology and metatechnology

Consider the case where all producers are categorized into K groups and producers in each group operate under a group-specific technology T^k where $k=1,...,K$ denotes the index of producer groups. For a data set of each group k consisting of a vector of inputs and outputs for each of the i -th producer where $i=1,...,I^k$ denotes a producer index. Let the input and output vectors for the i -th producer in the k -th group be denoted $x_i^k = (x_{i1}^k, ..., x_{iN}^k) \in R_+^N$ and $y_i^k = (y_{i1}^k, ..., y_{iM}^k) \in R_+^M$, respectively. For any input vector of all producers in the k -th group $x^k \in R_+^N$ and any output vector of all producers in the k -th group $y^k \in R_+^M$, an input vector x^k is transformed into net outputs y^k by a production technology T^k . The technology set for the k -th group technology T^k which satisfies the axioms presented in FÄRE et al. (1985) is defined as

$$T^k = \{(x^k, y^k) : x^k \text{ can produce } y^k\}. \quad (1)$$

Now, consider any input and output vectors of all producers in all groups are given by $x = (x^1 \cup ... \cup x^K) \in R_+^N$ and $y = (y^1 \cup ... \cup y^K) \in R_+^M$, respectively. If a particular output $y \in R_+^M$ can be produced using a given input vector $x \in R_+^N$ in any one of the producer group, a pair (x, y) is belong to a metatechnology T^* . The T^* is defined as the grand technology which envelops all group-specific technologies, $T^1, ..., T^K$. The technology set for the metatechnology (T^*) is defined as¹

$$T^* = \{(x, y) : x \text{ can produce } y \text{ in at least one group-specific technology}\}, \quad (2)$$

where the boundary of the metatechnology set indicates the metafrontier.

A measure of TE defined in FARRELL (1957) can be analyzed using a distance function. The distance function is defined as a rescaling of the length of an input or output vector with the production frontier as a reference. Because either inputs or outputs can be scaled, the distance function can have an input or output orientation. The output distance function of an observed data (x^k, y^k) relative to the group-specific technology T^k is defined as

$$D_o^k(x, y) = \min\{\mu^k : y^k / \mu^k \in T^k\}. \quad (3)$$

$D_o^k(x, y)$ is equal to output-orientated TE, $TE_o^k(x, y)$, of the observed data (x^k, y^k) with respect to T^k , so that $0 \leq TE_o^k(x, y) = D_o^k(x, y) \leq 1$. Similarly, the relationship between the output-orientated TE and output distance function of the observed data (x, y) relative to T^* is defined as $0 \leq TE_o^*(x, y) = D_o^*(x, y) \leq 1$ where $D_o^*(x, y) = \min\{\mu^* : y / \mu^* \in T^*\}$.

2.2 Decomposition technical efficiency under metatechnology

Figure 2 shows a decomposition of TE under metatechnology. The metatechnology (T^*) which is constructed from the two production technologies, T^A and T^B , is represented by line $A_0A_1A_2B_2B_3B_{00}$. The boundary of the metaechnology represents a metafrontier. Consider the production technology T^A where point A_1 , A_2 and A_4 lie on the frontier but point A_3 lies below

¹ This metatechnology T^* satisfies all the production axioms in FÄRE et al. (1985) except the convexity axiom. In order to ensure the convexity property, the metatechnology is defined as the convex hull of the union of each group-specific technology as $T^* = \text{Convex Hull} \{T^1 \cup T^2 \cup ... \cup T^K\}$.

the frontier. TE_o^A of the point A_1 , A_2 and A_4 corresponding to its own frontier is equal to one whereas TE_o^A of the point A_3 is equal to the ratio of $A_3^*A_3$ to $A_3^*A_3^{***}$. When the metafrontier (T^*) is considered, TE_o^* of the point A_1 , A_2 is still equal to one whereas TE_o^* of the point A_3 is equal to the ratio of $A_3^*A_3$ to $A_3^*A_3^{**}$ and TE_o^* of the point A_4 is equal to the ratio of $A_4^*A_4$ to $A_4^*A_4^{**}$. Similarly, consider the production technology T^B where point B_1 , B_2 and B_3 lie on the frontier but point B_4 lies below the frontier. TE_o^B of the point B_1 , B_2 and B_3 corresponding to its own frontier is equal to one whereas TE_o^B of the point B_4 is equal to the ratio of $B_4^*B_4$ to $B_4^*B_4^{**}$. When the metafrontier (T^*) is considered, TE_o^* of the point B_2 , B_3 and B_4 is still the same as TE_o^B whereas TE_o^* of the point B_1 is equal to the ratio of B_0B_1 to $B_0B_1^{**}$. When the TE_o is measured relative to the group-specific technology and metatechnology, it can occur a gap between the two technologies used as a reference. This gap is called a technology gap which is defined as the ratio of the distance function using an observed data based on the metotechnology T^* to the group-specific technology T^k .

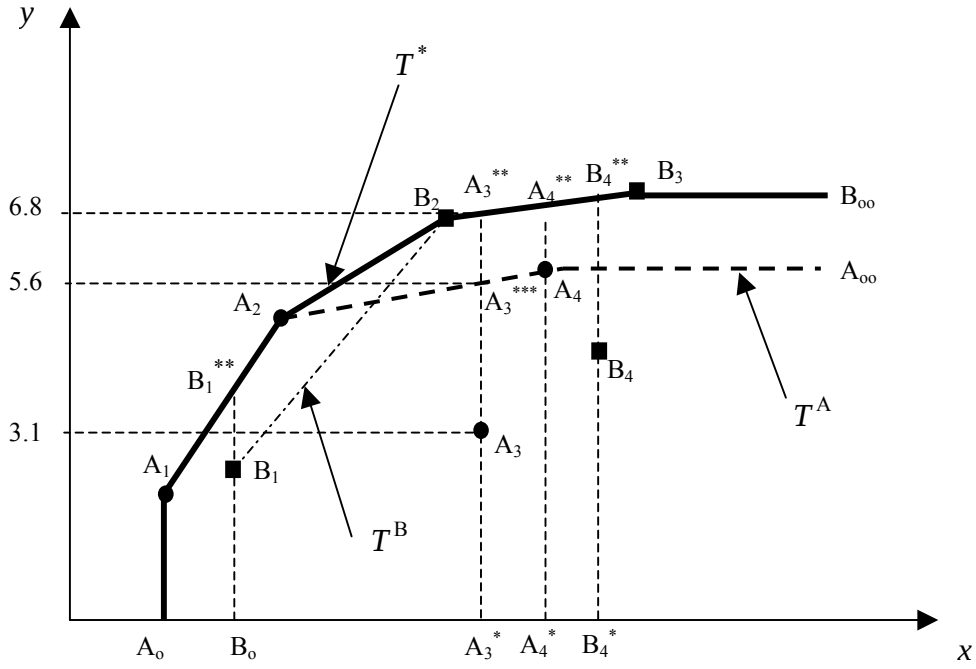
Using the output orientation, the technology gap ratio (TGR) can be defined as

$$TGR_o^k(x, y) = \frac{D_o^*(x, y)}{D_o^k(x, y)} = \frac{TE_o^*(x, y)}{TE_o^k(x, y)}, \quad (4)$$

or it can be written as

$$TE_o^*(x, y) = TE_o^k(x, y) \times TGR_o^k(x, y). \quad (5)$$

Equation (5) shows that TE measured with respect to the metafrontier (T^*) can be decomposed into the product of the TE measured with respect to the k -th group technology (T^k) and the technology gap ratio. Note that the value of $TGR_o^k(x, y)$ will be between zero and one so that $TE_o^*(x, y) \leq TE_o^k(x, y)$. For example, consider point A_3 in Figure 2, TE with respect to T^A can be measured by the ratio of the distances between $A_3^*A_3$ to $A_3^*A_3^{***}$. The $TE_o^A(x_{A_3}, y_{A_3}) = 3.1/5.6 = 0.554$ implying that all outputs could be possibly produced by 45 % more from the given inputs by using T^A as a reference. The TE with respect to T^* can be measured by the ratio of the distances between $A_3^*A_3$ to $A_3^*A_3^{**}$. The $TE_o^*(x_{A_3}, y_{A_3}) = 3.1/6.8 = 0.456$ implying that all outputs could be possibly produced by 54 % more from the given inputs by using T^* as a reference. Therefore, $TGR_o^k(x, y) = 0.456/0.554 = 0.823$ implying that the possible output for the T^A is 82.3 percent of that represented by the metafrontier (T^*).

Figure 2: Decomposition of technical efficiency under the metafrontier

2.3 SFA approach to metafrontier

When suitable panel data for each producer in each group during the time period, $t = 1, \dots, T$ are available, the metafrontier estimation using the SFA can be achieved using a two-step procedure. First, the stochastic production frontier for each group is estimated and compared with that for all producers. Then, a statistical test is performed to examine whether all producers in different groups have potential access to the same technology.

If the group k consists of data on I^k producers, the stochastic production frontier model for the i -th producer at time period t based on the group-specific data and the pooled data is given as follows.

$$\ln Y_{it}^c = \ln f(X_{it}^c, t; \beta^c) + v_{it}^c - u_{it}^c, \quad (6)$$

where superscript c refers to a choice of the stochastic production frontier model [If $c = k$, equation (6) refers to the stochastic group-specific production frontier model when the data for the i -th producer in the k -th group at the t -th time period are used, and if $c = p$, equation (6) refers to the stochastic pooled production frontier model when the data for all producers in all groups for all time periods are used]; Y_{it}^c denotes the output quantity for the i -th producer at the t -th time period; X_{it}^c denotes the input quantity for the i -th producer at the t -th time period; β^c s are unknown parameters associated with the X -variables to be estimated; v_{it}^c s are a two-sided random-noise component assumed to be i.i.d. $N(0, \sigma_v^{2c})$ and u_{it}^c s are a non-negative technical inefficiency component. The v_{it}^c and u_{it}^c are distributed independently of each other, and of the regressors. The non-negative technical inefficiency component, u_{it}^c , is assumed to

follow a half normal distribution, $u_{it}^c \sim \text{i.i.d. } N^+(0, \sigma_u^{2c})$, and is defined by some appropriate inefficiency model [see, BATTESE and COELLI (1992, 1995)]².

Following BATTESE and COELLI (1992), the stochastic group-specific and pooled production frontier models, taking the log-quadratic translog functional form under a non-neutral TC assumption can be written as follows.

$$\begin{aligned} \ln Y_{it}^c = & \beta_0^c + \sum_{n=1}^N \beta_n^c \ln X_{nit}^c + \frac{1}{2} \sum_{n=1}^N \sum_{m=1}^N \beta_{nm}^c \ln X_{nit}^c \ln X_{mit}^c \\ & + \sum_{n=1}^N \beta_{nt}^c \ln X_{nit}^c \cdot t + \beta_t^c t + \frac{1}{2} \beta_t^c t^2 + v_{it}^c - u_{it}^c, \end{aligned} \quad (7)$$

where $m, n = 1, \dots, N$ index of input quantities and $u_{it}^c = \{\exp[-\eta(t-T)]\}u_i^c$ where η s are parameters to be estimated and u_i^c s are non-negative random variables which are assumed to account for technical inefficiency in production and are assumed to be i.i.d. as truncations at zero of the $N^+(0, \sigma_u^{2c})$ distribution. Young's theorem requires that the symmetry restriction is imposed so that $\beta_{nm} = \beta_{mn}$ for all $m, n = 1, 2, 3$.

An estimate of output-orientated TE for the i -th producer at the t -th time period is given by

$$TE_{oit}^c = \exp\{-u_{it}^c\}. \quad (8)$$

If the stochastic frontiers across groups do not differ, then the stochastic pooled frontier function can be used as a grand technology for each group. However, if the stochastic frontiers across groups do differ, the metafrontier function will be used as a grand technology for each group. The second step will involve estimating the metafrontier function. The metafrontier function using SFA does not fall below the deterministic functions for the stochastic group-specific frontier model as shown in Figure 2. In order to obtain estimated parameters of the metafrontier function, we need to ensure that the estimated function best envelops the deterministic components of the estimated stochastic frontiers for the different groups. BATTESE et al. (2004) proposed a method so called the minimum sum of absolute deviations to identify the best envelope. The parameter estimates of the metafrontier function are estimated by solving the following LP problem.

$$\text{Min } \sum_{i=1}^I \sum_{t=1}^T |(x_{it} \beta^* - x_{it} \hat{\beta}^k)| \equiv \bar{x} \beta^* \quad (9)$$

such that $x_{it} \beta^* \geq x_{it} \hat{\beta}^k$,

where $\bar{x}$ denotes the row vector of mean of the elements of the x_{it} vector for all observations in the data set; x_{it} is the logarithm form of the input quantity for the i -th producer in the t -th time period; $\hat{\beta}^k$ s are the estimated coefficients obtained from the stochastic group-specific frontiers obtained from equation (7) and β^* s are parameters of the metafrontier function to be estimated.

² We follow the suggestion of BATTESE and CORRA (1977), and replace the two variance parameters with the two new parameters $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2 / \sigma^2$. By doing this we can search the parameter space of γ between 0 and 1, to provide good starting values for the iterative maximization routine which is used to calculate the maximum likelihood parameter estimates.

Once the β^* parameters of the metafrontier function in equation (9) are estimated, the decomposition of TE under the metafrontier can be calculated. The technology gap for the i -th producer in the k -th group at the t -th time period can be obtained by

$$TGR_{oit}^k(x, y) = \frac{e^{x_{it}\beta^k}}{e^{x_{it}\beta^*}}. \quad (10)$$

Then, a measure of the output-oriented TE relative to the metafrontier, $TE_o^*(x, y)$, can be obtained using equation (5).

2.4 Decomposition of total factor productivity change

TFP growth is generally defined as the residual growth in outputs not explained by the growth in input use. TFP growth can be measured and decomposed into associated components attributing to the TFP growth after the metafrontier function in equation (9) is estimated. This information is useful for policy makers to design suitable policies in enhancing the productivity growth in the industry.

Following OREA (2002), a measure of TFP change (TFPC) for each firm between any two time periods can be calculated by using the estimates of the coefficients of the metafrontier and the firm-level sample data. The logarithmic form of the TFPC between period t and $t + 1$ for the i -th firm is defined as

$$\begin{aligned} \ln\left(\frac{TFP_{it+1}}{TFP_t}\right) &= \ln\left(\frac{TE_{oit+1}^*}{TE_{oit}^*}\right) + \frac{1}{2}\left[\frac{\partial \ln y_{it+1}}{\partial t} + \frac{\partial \ln y_{it}}{\partial t}\right] \\ &\quad + \frac{1}{2} \sum_{n=1}^N [(SF_{it+1} \cdot E_{nit+1}) + (SF_{it} \cdot E_{nit})] \left(\frac{\ln x_{nit+1}}{\ln x_{nit}}\right), \end{aligned} \quad (11)$$

where the three terms on the right-hand-side of equation (11) represents the output-oriented TEC, TC and SEC, respectively.

The output-orientated TE measure, (TE_o^*) , in equation (11) is the output-orientated TE prediction of the i -th firm in the t -th time period, and is calculated from equation (5). The TC measure, (TC_{itt+1}) , is the mean of the TC measures evaluated at the period t and period $t + 1$ data points. The SEC measure, (SEC_{itt+1}) , relates to the change in scale efficiency, which requires calculation of the scale factor (SF) and input elasticity (E_n) evaluated at the period t and period $t + 1$ data points. The SF of the i -th firm in the t -th time period $(SF_{it}) = (E_{it} - 1)/E_{it}$

where $E_{it} = \sum_{n=1}^N E_{nit}$ represents the scale elasticity and $E_{nit} = \partial \ln y_{it} / \partial \ln x_{nit}$ is production elasticity for the n -th input.

3 DATA SOURCE AND DESCRIPTIONS

A balanced panel data set of 28 provinces covering the time period of 1991 to 2005 is used in the empirical analysis. Figure 3 illustrates the location of all provinces in China. Provinces selected for analysis include all provinces in China excluding Hainan and Tibet due to the

missing information³. Considering regional disparities, all provinces are ranked by using GDP per capita at 2001 according to the definition presented in KOO and MAO (1997)⁴. Provinces are divided into two groups of technologies: Advanced-technology and low-technology provinces. Each group consists of 14 provinces. A list of the provinces in each group is summarized in Figure 3.

Figure 3: The location of advanced- and low-technology provinces



The primary data on agricultural production were extracted from the official data sources – *China Statistical Yearbook* and *Chinese Agricultural Statistical Yearbook*. The data used in this study contains the measurements of agricultural output and input quantities. In this study, the production technology is represented by one output and six inputs. The definitions of these variables are summarized as follows:

Dependent variable: The gross output value of farming at 1990 constant prices in billions of yuan (y) is chosen as the dependent variable. The gross output value of farming aggregates physical output from seven grain crops and twelve economic crops. However, it excludes the value of forestry, animal husbandry, handicraft products for self-consumption or for sales as sideline occupations and the total value of industries run by villages and cooperative organizations under villages.

Independent variable: Following the existing literatures, independent variables include six important physical inputs such as capital, labor, chemical fertilizer, pesticide, plastic film and irrigation (LIN, 1992; WU, 1995; LIU and WANG, 2005).

Capital input (x_1) denotes farm machinery in the unit of millions of KW, mainly including the big tractor and walking tractors. Other inputs such as draft animals are excluded in this study due to the unavailable information in the provincial statistics.

³ Although Chongqing is separated from Sichuan as a municipal administrative city, data series of Chongqing were added together with those of Sichuan due to the unavailability of its data before 1998. In addition, Macao, Hong Kong and Taiwan are not included in this study.

⁴ <<http://www.demographia.com/db-china-reggdp-2001.htm>>.

Labor force denotes the number of total rural labors directly engaged in production of agriculture, forestry, animal husbandry and fishery annually. To measure the labor input in farming sector (x_2), we followed the calculation by LIN (1992) to weight the labor input in agriculture by the value share of farming output in total agricultural output.

Chemical fertilizer (x_3) refers to the pure-content quantity of chemical fertilizers applied in yearly agricultural production in tons. The pure-content gross quantity of chemical fertilizer is calculated to convert the gross weight into weight containing 100 percent of effective components.

Pesticide (x_4) is the quantity of chemical pesticides applied in agriculture reported in tons annually.

Plastic film (x_5) includes those for coving young plants and seeds listed in tons annually.

Irrigation is one of the very important factors in agricultural production. An effectively irrigated area including not only the full sets of technological irrigation facilities but also adequate water sources for the normally agricultural irrigation can be used as an irrigation variable⁵. The irrigation variable (x_6) used in this study is defined as the ratio of effectively irrigated area to total cultivated area. Total cultivated land area refers to land that is plowed constantly for growing crops excluding the land of tea plantations, orchards, nurseries of young plants, forest land, natural and man-made grassland.

Table 1 presents the descriptive statistics of the variables used in the study summarized by the two groups of technology defined above. The advance-technology provinces show higher mean for each variable than the low-technology provinces except for the labor input. However, the low-technology provinces exhibit lower standard deviation for each variable than the advance-technology provinces except for the capital and labor inputs.

Table 1: Descriptive statistics of variables, 1991-2002

<i>Variables</i>	<i>Unit</i>	<i>Advanced-technology provinces</i>	<i>Low-technology provinces</i>	<i>All provinces</i>
<i>Dependent variable</i>				
Output	Billion Yuan	27.678 (19.520)	22.505 (17.094)	25.092 (18.507)
<i>Independent variables</i>				
Capital	Thousand KW	4615.148 (4453.458)	4160.390 (5604.301)	4387.769 (5060.772)
Labor	Thousand Person	4752.045 (3724.526)	7967.061 (5698.546)	6359.553 (5070.276)
Fertilizer	Million KG	1451.905 (1127.808)	1305.492 (1033.238)	1378.699 (1082.749)
Pesticide	Million KG	48.823 (40.953)	33.195 (31.282)	41.009 (37.228)
Plastic	Million KG	51.025 (52.847)	34.573 (28.218)	42.799 (43.106)
Irrigation	%	64.290 (24.070)	43.490 (18.510)	53.891 (23.837)

Notes: Means are calculated. Standard deviations are presented in parentheses.

⁵ The increased quantity of irrigation power may be used as a better proxy of the increasing and improving irrigated technique and project rather than the expended irrigated area. However, this variable can not been found in official statistical yearbooks, and thus can not be included in the specified models.

4 RESULTS

4.1 Discussions of parameter estimates and production structure

The data described in section 3 were used in the estimation of the stochastic group-specific and pooled production functions shown in equation (7). The stochastic group-specific production functions are estimated using the data of the advanced- and low-technology provinces separately whereas the stochastic pooled production function is estimated using the data of all provinces. The data variables used in the model estimation were normalized by their respective geometric means. This transformation does not alter the performance measures obtained, but does allow one to interpret the estimated first-order parameters as elasticities, evaluated at the sample means. The estimated coefficients for each model are presented in Table 2. The estimation results from each model are similar and all first-order coefficients have the expected signs except for the estimated parameters, β_{x4} of the low-technology provinces model.

The likelihood ratio (LR) test statistic for the null hypothesis that the group-specific frontiers are identical is 106.44. The LR test statistic follows a chi-square distribution with 39 degrees of freedom. The null hypothesis was rejected with a p-value less than 0.001. This result implies that the group-specific frontiers are not the same. Therefore, the metafrontier function described in section 2.3 needs to be estimated. Table 2 also presents the estimated coefficients of the stochastic metafrontier function. All first-order coefficients have the expected signs and can also be interpreted as shadow shares. The estimates of the input elasticities under the stochastic metafrontier function model are 0.0413, 0.2446, 0.4341, 0.0530, 0.0690 and 0.5285 for capital, labor, fertilizer, pesticide, plastic and irrigation, respectively. The sum of the input elasticities provides information about scale economies and is 1.3705, indicating that the technology exhibits moderately increasing returns to scale at the sample mean. The first order coefficients of the time trend variable provide estimates of the average annual rate in TC. The stochastic metafrontier function model suggest that the technology is improving at a rate of 2.71 % per annum,

Table 2: Estimated parameters of stochastic group-specific frontier and metafrontier models

Parameters ^a	Stochastic frontier						Metafrontier ^b	
	Advanced-technology provinces		Low-technology provinces		All provinces			
β_0	2.6686	(0.0465)	2.5797	(0.0537)	2.5495	(0.0433)	2.6293	(0.0150)
β_{x1}	0.0420	(0.0317)	0.0184	(0.0289)	0.0439	(0.0164)	0.0413	(0.0085)
β_{x2}	0.3646	(0.0614)	0.3304	(0.1202)	0.2947	(0.0356)	0.2446	(0.0060)
β_{x3}	0.2906	(0.0727)	0.5293	(0.1149)	0.3859	(0.0552)	0.4341	(0.0167)
β_{x4}	0.0051	(0.0519)	-0.0140	(0.0658)	0.0358	(0.0312)	0.0530	(0.0113)
β_{x5}	0.0678	(0.0392)	0.0255	(0.0309)	0.0203	(0.0177)	0.0690	(0.0064)
β_{x6}	0.5520	(0.1193)	0.8039	(0.2364)	0.4799	(0.0748)	0.5285	(0.0310)
β_t	0.0421	(0.0059)	0.0207	(0.0078)	0.0365	(0.0033)	0.0271	(0.0010)
β_{x11}	0.0211	(0.0355)	-0.0295	(0.0267)	-0.0067	(0.0204)	-0.0027	(0.0110)
β_{x12}	-0.2059	(0.0510)	0.0128	(0.0575)	-0.0776	(0.0274)	-0.1603	(0.0126)
β_{x13}	0.1199	(0.0520)	-0.0125	(0.0660)	0.0672	(0.0398)	0.0946	(0.0250)

β_{x14}	0.0374	(0.0442)	-0.0420	(0.0339)	-0.0314	(0.0228)	0.0230	(0.0123)
β_{x15}	0.0408	(0.0359)	0.0009	(0.0218)	0.0176	(0.0159)	0.0825	(0.0116)
β_{x16}	-0.1707	(0.0775)	0.1570	(0.1130)	-0.0315	(0.0663)	-0.2160	(0.0231)
β_{x22}	0.3070	(0.1112)	-0.2944	(0.2748)	0.1332	(0.0685)	0.0839	(0.0289)
β_{x23}	-0.0850	(0.1230)	0.1517	(0.3298)	-0.1045	(0.0962)	-0.1217	(0.0589)
β_{x24}	-0.1129	(0.0713)	0.0083	(0.1219)	-0.0074	(0.0420)	0.0834	(0.0308)
β_{x25}	-0.0272	(0.0570)	0.0230	(0.0633)	-0.0007	(0.0282)	0.0424	(0.0130)
β_{x26}	0.7263	(0.1500)	-0.5272	(0.4302)	0.6944	(0.1135)	0.5261	(0.0411)
β_{x33}	-0.1962	(0.2384)	-0.0540	(0.5815)	0.2132	(0.1840)	0.5670	(0.1326)
β_{x34}	0.1590	(0.0900)	0.0428	(0.1775)	-0.0047	(0.0648)	-0.2128	(0.0448)
β_{x35}	0.1951	(0.1022)	-0.1470	(0.1087)	-0.0728	(0.0577)	-0.1915	(0.0198)
β_{x36}	-0.4919	(0.2330)	1.0752	(0.6946)	-0.3362	(0.1899)	-0.3234	(0.0722)
β_{x44}	-0.0311	(0.0210)	-0.1430	(0.1051)	-0.0005	(0.0192)	0.0379	(0.0107)
β_{x45}	-0.0691	(0.0408)	0.0990	(0.0506)	0.0330	(0.0258)	0.0380	(0.0131)
β_{x46}	-0.0037	(0.1043)	0.1337	(0.3230)	-0.0659	(0.0922)	-0.0456	(0.0623)
β_{x55}	-0.1638	(0.0637)	-0.0084	(0.0264)	0.0120	(0.0194)	0.0029	(0.0064)
β_{x56}	0.0586	(0.0959)	-0.3459	(0.1728)	-0.1349	(0.0819)	-0.0458	(0.0607)
β_{x66}	0.4344	(0.5484)	-2.6276	(0.9912)	1.1428	(0.4167)	0.3150	(0.1620)
β_{x1t}	-0.0213	(0.0048)	0.0039	(0.0055)	-0.0050	(0.0027)	-0.0212	(0.0014)
β_{x2t}	0.0324	(0.0085)	-0.0061	(0.0149)	0.0164	(0.0047)	0.0007	(0.0028)
β_{x3t}	-0.0369	(0.0103)	0.0174	(0.0164)	-0.0185	(0.0071)	-0.0024	(0.0023)
β_{x4t}	0.0115	(0.0058)	-0.0033	(0.0100)	0.0074	(0.0038)	0.0109	(0.0031)
β_{x5t}	0.0093	(0.0047)	0.0005	(0.0065)	-0.0003	(0.0033)	0.0087	(0.0022)
β_{x6t}	0.0501	(0.0122)	-0.0318	(0.0369)	0.0546	(0.0106)	0.0448	(0.0057)
β_{tt}	0.0004	(0.0011)	0.0006	(0.0019)	0.0016	(0.0008)	0.0004	(0.0005)
σ^2	0.0146	(0.0019)	0.0122	(0.0016)	0.3107	(0.4543)		
γ	0.7200	(0.0633)	0.6612	(0.0568)	0.9830	(0.0249)		
η	-0.0075	(0.0120)	0.0136	(0.0089)	-0.0082	(0.0056)		
Log-likelihood	256.1712		235.9472		438.8973			

Note: Numbers in parentheses are standard errors.

^a Subscripts on β_x coefficients refer to inputs: 1 = capital; 2 = labor; 3 = fertilizer; 4 = pesticide; 5 = plastic and 6 = irrigation.

^b Standard deviations of the metafrontier estimates are calculated using parametric bootstrapping as presented in BATTESE, RAO and O'DONNELL (2004).

Table 3 provides annual average production elasticities of inputs – capital, labor, fertilizer, pesticide, plastic and irrigation – for the year 1991-2005. The production elasticity for capital decreases over the period 1991-2005 by 7.42 % per annum. The production elasticity for labor increases during 1991-1993 and decreases during 1994-2005 leading to a decrease by 2.40 % per annum. The production elasticity for fertilizer decreases over the period 1991-2002 and increases during the period 2003-2005 leading to an increase by 0.44 % per annum. The production elasticities for pesticide and plastic increase throughout the period by 12.79 % and 7.84 % per

anuum, respectively. The production elasticity for irrigation increases during 1991-2002 and decreases during 2003-2005 leading to an increase by 2.11 % per annum. The results indicate that the annual rates of increase of production elasticities for fertilizer, pesticide, plastic and irrigation are greater than the rates of decrease for capital and labor. The results also show that labor and fertilizer still make important contributions to output, and thus improving the quality of farmers and applying modern physical inputs is also crucial to TFP growth.

Table 3: Annual average production elasticities for different inputs, 1991-2005

Year	Capital	Labor	Fertilizer	Pesticide	Plastic	Irrigation
1991-1993	0.081	0.297	0.434	0.029	0.053	0.471
1994-1996	0.075	0.306	0.426	0.032	0.054	0.489
1997-1999	0.054	0.299	0.412	0.053	0.071	0.537
2000-2002	0.036	0.278	0.399	0.076	0.072	0.650
2003-2005	0.029	0.215	0.453	0.101	0.114	0.589
1991-2005	0.041	0.245	0.434	0.053	0.069	0.529

4.2 Discussions of decomposition technical efficiency under metafrontier

Table 4 provides average TE scores relative to the stochastic group-specific frontier and metafrontier technologies as well as TGR scores for each group of provinces during 1991-2005. Moreover, Table A1 in Appendix reports TE scores relative to the stochastic group-specific frontier and metafrontier technologies as well as TGR score for all 28 provinces over the period 1991 to 2005. TE scores relative to the group-specific technology for the advanced-technology provinces range from 0.688 by Hebei to 0.978 by Guangdong with an average of 0.806. TE scores relative to the group-specific technology for the advanced-technology provinces were decreasing over time. Based on the metafrontier technology as a reference, TE scores for the advanced-technology provinces range from 0.661 by Hebei to 0.940 by Guangdong with an average of 0.764. The average TE score implies that the advanced-technology provinces in this study were, on average, producing 80.6 % of the outputs that could be potentially produced from the given inputs by using their own technologies as a reference and 76.4 % using the metafrontier technology as a reference. The estimates of TGR for the advanced-technology province range from 0.847 by Shanghai to 0.980 by Helongjian with an average of 0.948. This result implies that the possible outputs for the advanced-technology provinces based on their groups-specific technology is, on average, 94.8 % of that represented by the metafrontier technology. Hebei and Tianjin are the two lowest ranked TE scores relative to both group-specific and metafrontier technologies whereas Guangdong and Liaoning are the two highest ranked TE scores relative to both technologies. The ranking of the TE scores from other provinces is not much different relative to both technologies except for Shanghai. Shanghai is the third highest ranked TE score relative to its group-specific technology while it is the fifth lowest ranked TE scores relative to the metafrontier technology.

Turning to the low-technology provinces, TE score relative to their own technology range from 0.581 by Ningxia to 0.979 by Sichuan with an average of 0.732. TE scores relative to the group-specific technology for the low-technology provinces were increasing over time. Based on the metafrontier technology as a reference, TE scores for the low-technology provinces range from 0.443 by Ningxia to 0.842 by Inner-Mongolia with an average of 0.644. The average TE score implies that the low-technology provinces in this study, on average, could be potentially produced 27 % more outputs from the given inputs by using their own technologies as a reference

and 36 % more outputs using the metafrontier technology as a reference. The estimates of TGR for the low-technology provinces range from 0.764 by Ningxia to 0.975 by Gansu with an average of 0.882. This result implies that the possible outputs for the low-technology provinces based on their group-specific technology is, on average, 88.2 % of that represented by the metafrontier technology. Ningxia and Anhui are the two lowest ranked TE scores relative to the group-specific technology while Ningxia is still the lowest ranked TE scores relative to the metafrontier technology and Anhui is the fourth lowest ranked TE scores relative to the metafrontier technology. Sichuan and Inner-Mongolia are the two highest ranked TE scores relative to both technologies. The ranking of the TE scores from other provinces is quite different relative to both technologies.

The empirical findings show that the advanced-technology provinces had average province TE higher than the low-technology provinces. The advanced-technology provinces generally led in terms of TGR and had smaller variation of TGR than the low-technology provinces. The comparatively low TE scores in the low-technology provinces imply that the low-technology provinces were operating far from the metafrontier. The fluctuation of TE measured with respect to the metafrontier function indicates it is possible that Chinese agricultural TFP growth can be improved through the improvement of TE.

Table 4: TE Scores by the group-specific and metafrontier technologies and TGR for each group, 1991-2005

Year	Advanced-technology provinces			Low-technology provinces		
	TE ^k	TGR	TE [*]	TE ^k	TGR	TE [*]
1991	0.815 (0.075)	0.911 (0.055)	0.744 (0.096)	0.710 (0.142)	0.904 (0.113)	0.636 (0.115)
1992	0.814 (0.076)	0.916 (0.042)	0.746 (0.078)	0.714 (0.140)	0.907 (0.076)	0.645 (0.119)
1993	0.813 (0.076)	0.957 (0.042)	0.778 (0.078)	0.717 (0.139)	0.904 (0.073)	0.646 (0.126)
1994	0.811 (0.077)	0.966 (0.029)	0.784 (0.083)	0.720 (0.138)	0.909 (0.071)	0.653 (0.126)
1995	0.810 (0.077)	0.977 (0.022)	0.791 (0.079)	0.723 (0.136)	0.901 (0.066)	0.649 (0.116)
1996	0.809 (0.078)	0.979 (0.014)	0.792 (0.077)	0.726 (0.135)	0.899 (0.067)	0.651 (0.123)
1997	0.808 (0.078)	0.973 (0.036)	0.785 (0.077)	0.729 (0.133)	0.885 (0.072)	0.643 (0.113)
1998	0.806 (0.079)	0.946 (0.088)	0.761 (0.092)	0.732 (0.132)	0.871 (0.089)	0.636 (0.117)
1999	0.805 (0.079)	0.959 (0.055)	0.771 (0.084)	0.735 (0.131)	0.869 (0.098)	0.637 (0.122)
2000	0.804 (0.080)	0.963 (0.055)	0.773 (0.083)	0.738 (0.129)	0.817 (0.140)	0.599 (0.131)
2001	0.802 (0.080)	0.956 (0.053)	0.766 (0.074)	0.741 (0.128)	0.886 (0.079)	0.655 (0.123)
2002	0.801 (0.081)	0.936 (0.066)	0.749 (0.086)	0.743 (0.127)	0.881 (0.076)	0.656 (0.129)
2003	0.800 (0.081)	0.940 (0.064)	0.751 (0.089)	0.746 (0.125)	0.869 (0.087)	0.648 (0.124)
2004	0.799 (0.082)	0.925 (0.075)	0.739 (0.101)	0.749 (0.124)	0.869 (0.090)	0.650 (0.120)
2005	0.797 (0.082)	0.919 (0.080)	0.732 (0.102)	0.752 (0.123)	0.868 (0.098)	0.652 (0.124)
1991-2005	0.806 (0.076)	0.948 (0.058)	0.764 (0.086)	0.732 (0.128)	0.883 (0.089)	0.644 (0.119)

4.3 Discussions of TFP decomposition

Table 5 presents weighted growth rate of TFP decomposition by the group of the provinces during 1991-2005. TFP growth by all provinces increases by 62.45 % over the sample period with a weighted average of about 3.234 % per annum. TEC is nearly negligible; it decreases by 0.43 % over the sample period (average of about 0.029 % per annum). SEC is less important; it increases by 1.46 % over the sample period (average of 0.097 % per annum). Overall, TC explains most of the TFP growth. It increases by 60.79 % with a weighted average of 3.166 % per annum. The major findings show that TFP change in China agriculture over the study period was mainly driven by technological progress. These aggregate figures dissimulate the diversity of effects across the two groups of provinces, although TC changes are dominant in both of two groups.

The advance-technology provinces show TFP growth of 65.6 % over the sample period (average of about 3.362 % per annum). TC increases by 66.3 % (average of about 3.391 % per annum) and the technical progress with the highest rate occurred during 2000-2002. TEC increases by 0.57 % with a weighted average incline of about 0.038 % per annum even though it indicates a decline after the period 1997. SEC decreases by 0.99 % with a weighted average decrease of about 0.066 % per annum although the entire decline is due to the negative SEC during 1997-2005. TC explains most of the TFP growth throughout the period. There is an impressive technical progress during 2000-2002. TEC is a major contribution to TFP growth together with TC during 1991-1996 and 2000-2005. However, TEC is negligible relative to TC and SEC during 1997-1999. SEC is negligible relative to TC and SEC throughout the period.

The low-technology provinces countries experience a TFP increase of 58.92 % over the sample period (average of about 3.088 % per annum). TC and SEC increase by 54.26 % (average of about 2.890 % per annum) and 4.57 % (average of about 0.298 % per annum). There is a major deteriorate in SEC during 2000-2002. TEC slightly decreases by 1.48 % over the sample period with a weighted average decline of about 0.099 % per annum. TC explained most of the TFP growth for the entire period. There is an impressive technical progress during 2000-2002. TEC is negligible relative to TC and SEC throughout the period except the period of 1997-1999. SEC is a major contribution to TFP growth together with TC during 2000-2002.

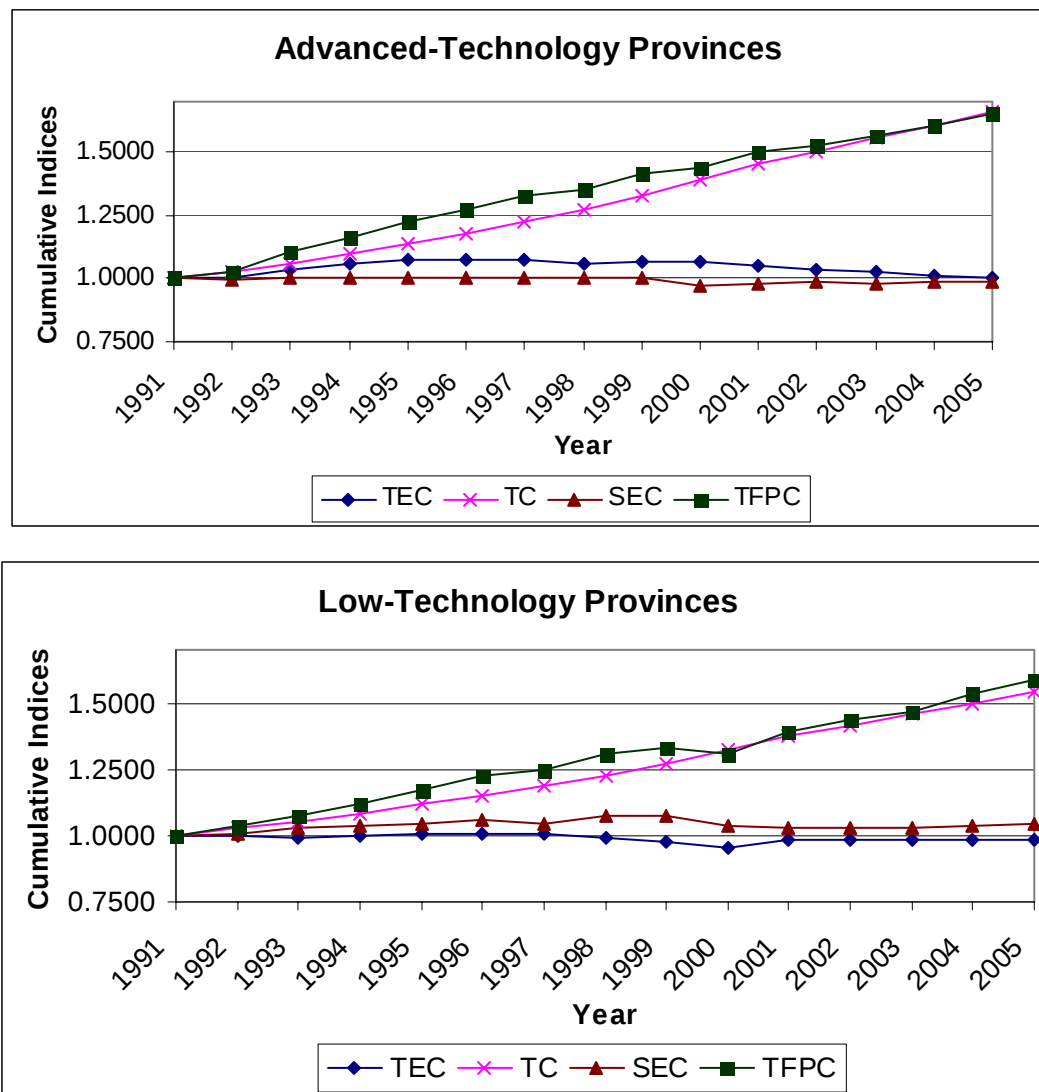
Table 5: Weighted annual growth rates of decomposed TFPC by provinces group (%)

<i>Period</i>	<i>TEC</i>	<i>TC</i>	<i>SEC</i>	<i>TFPC</i>
<i>Advanced-technology provinces</i>				
1991-1993	1.267	1.938	0.158	3.363
1994-1996	1.100	3.612	0.003	4.714
1997-1999	-0.283	3.829	-0.032	3.514
2000-2002	-1.056	4.238	-0.667	2.515
2003-2005	-0.840	3.338	0.206	2.703
1991-2005	0.038	3.391	-0.066	3.362
<i>Low-technology provinces</i>				
1991-1993	-0.335	1.730	0.958	2.354
1994-1996	0.512	2.957	0.901	4.371
1997-1999	-0.853	3.215	0.463	2.825
2000-2002	0.219	3.671	-1.419	2.471
2003-2005	-0.041	2.875	0.587	3.420
1991-2005	-0.099	2.890	0.298	3.088
<i>All provinces</i>				
1991-1993	0.529	1.842	0.525	2.897
1994-1996	0.838	3.320	0.403	4.561
1997-1999	-0.537	3.555	0.184	3.202
2000-2002	-0.493	3.983	-1.005	2.484
2003-2005	-0.480	3.132	0.377	3.028
1991-2005	-0.029	3.166	0.097	3.234

Figure 4 contains a set of the cumulative index plots of the TFP growth and its associated components by the group of the advanced- and low-technology provinces over the entire 1991-2005 period. The plot of the advanced-technology provinces shows that there was TFP progress over time and mainly driven by TC. The advanced-technology provinces showed a decline in TFP growth during 1991-1993 and 2000-2005 which was resulted from a decline in TEC. There was a significant increase in TEC in 1993 and a major decrease in SEC in 2000. The plot of the advanced-technology provinces shows that TFP change was closely driven by TC throughout the period. The TFP and TC changes were steadily improved while TEC and SEC was steadily stable leading to an increase of TFP growth for the entire periods. Overall, TC explains most of the TFP growth. However, the TEC was attributed to TFP growth more than the SEC throughout the period.

The plot of the low-technology provinces shows that TFP change was closely driven by TC. TFPC change was steadily improved throughout the period except in 2000. A decrease in TEC led to a decrease in TFPC in 2000. TC change was steadily improved throughout the period. TEC was steadily stable and showed a small decrease during 1999-2000. SEC was steadily stable and showed an increase during 1993-1999. Overall, TC explains most of the TFP growth and the SEC was attributed to TFP growth more than the TEC throughout the period.

Figure 4: Cumulative indices of TEC, TC, SEC and TFPC by groups of the provinces, 1991 to 2005



The proportional growth of the average TEC, TC and SEC components constituting the average TFP growth for all provinces in each group over the time period of 1992 to 2002 are also reported in Table A1 in Appendix. All provinces can be divided into different categories according to their TFP growth and what sources are attributed to their TFP growth. All advanced-technology provinces except Helongjiang indicated TPF progress over the time period. TFP regress for Helongjiang was driven by a decline of TC and SEC. Hebei is the only province which TFP progress was driven by an increase in TEC, TC and SEC. TFP progress for Beijing, Zhejiang, Fujian and Guangdong was driven by an increase in TEC and TC with a decrease in SEC. TFP progress for Tianjin, Shanghai, Jiangsu, Hubei was mainly attributed by technical progress with a decline in TEC and SEC. Liaoning, Jilin, Shandong and Xijiang showed an increase in TC and SEC but a decrease in TEC attributing to their TFP progress.

Similarly, all low-technology provinces except Inner-Mongolia indicated TPF progress over the time period. TFP regress for Inner-Mongolia was driven by a decline of TEC and TC. TFP progress for all provinces except Qinghai and Ningxia was mainly driven by technical progress. Shanxi, Henan, Guizhou, Yunnan, Shaanxi, Gansu showed an increase in TEC, TC and SEC attributing to their TFP progress. TFP progress for Anhui and Guangxi Guangdong was driven by an increase in TC and SEC but a decrease in TEC. TFP progress for Jiangxi, Hunan and Sichuan was mainly attributed by technical progress with a decline in TEC and SEC.

The results of TFP growth decomposition by selected provinces are discussed here. The provinces are selected as a representation to explain agricultural productivity for each group of provinces. We select four provinces – two provinces with highest output shares and two provinces with lowest output shares – from each group. Two provinces with the highest output shares for the advanced-technology provinces are Shandong and Jiangsu, respectively, and two provinces with the lowest output shares are Shanghai and Tianjin, respectively. For the low-technology provinces, two provinces with the highest output shares are Sichuan and Henan, respectively, and two provinces with the lowest output shares are Qinghai and Ningxia, respectively.

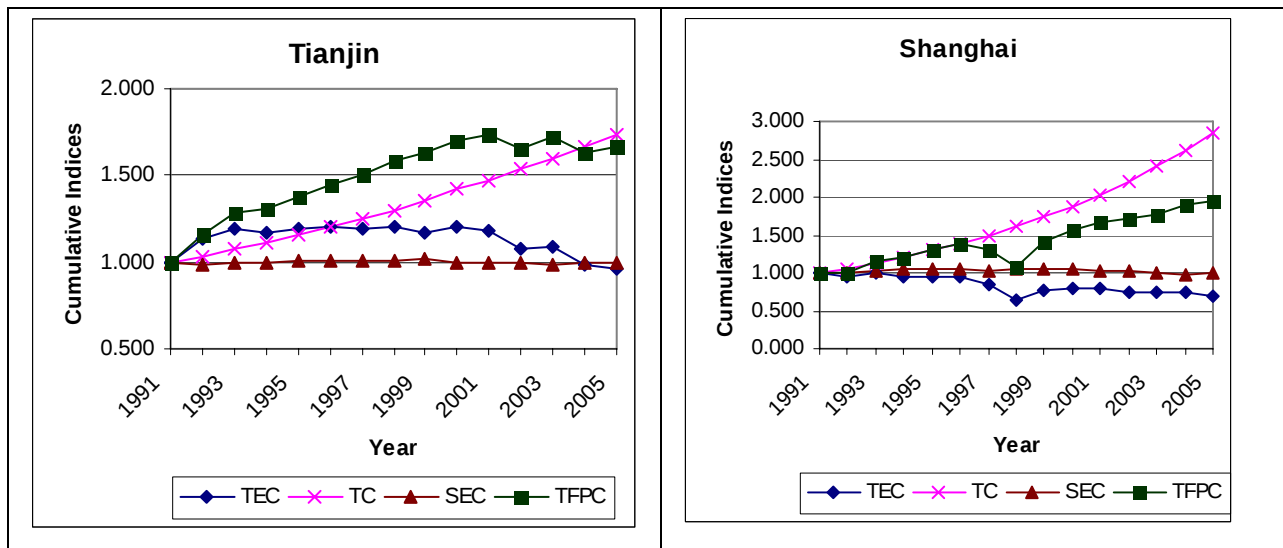
The unweighted TFP growth and its associated components over the sample period for each province are reported in Table A1 in Appendix. The unweighted TFP growth for the advanced-technology provinces over the sample period was 3.585 percent by Shandong, 3.327 percent by Jiangsu, 4.484 percent by Shanghai and 3.384 percent by Tianjin. Shandong showed its agricultural productivity progress driven by TC and SEC whereas Jiangsu, Shanghai and Tianjin showed their productivity progress mainly driven by technology progress with a decline in the TEC and SEC effects.

Figure 5 contains a set of the cumulative index plots of the TFP growth and its associated components by Tianjin, Shanghai, Jiangsu and Shandong over the entire 1991-2005 period. Tianjin showed agricultural productivity progress throughout the period except in 2002 and 2004. TEC was a major contribution to TFP progress during 1991-1996 whereas TC was a major contribution to TFP progress during 1997-2005. A decrease in TEC led to TFP regress in 2002 and 2004. TC was steadily improved throughout the period while SEC was steadily stable. Shanghai exhibited agricultural productivity progress over the sample period except in 1999 due to a decline of TEC in this period. TC was steadily improved throughout the period while SEC was steadily stable. Jiangsu and Shandong showed that TFP change was closely driven by TC throughout the period. The TFP and TC changes were steadily improved while TEC and SEC was steadily stable leading to an increase of TFP growth for the entire periods. Overall, TC explains most of the TFP growth. However, the TEC was attributed to TFP growth more than the SEC during 1991-2001.

Turning to the TFP growth decomposition for the low-technology provinces, the unweighted TFP growth over the sample period reported in Table A1 in Appendix was 3.774 percent by Sichuan, 3.054 percent by Henan, 1.980 percent by Qinghai and 1.523 percent by Ningxia. The high output share provinces such as Sichuan and Henan showed that technical progress led to their agricultural productivity progress. The low output share provinces such as Qinghai and Ningxia showed technical regress over time and an increase in TEC and SEC was led to their agricultural productivity progress.

Figure 6 contains a set of the cumulative index plots of the TFP growth and its associated components by Henan, Sichuan, Qinghai and Ningxia over the entire 1991-2005 period. Henan exhibited agricultural productivity progress over the sample period. All TEC, TC and SEC effects were major contributions to its TFP progress during 1991-1999 and 2003-2005. During 2000-2002, TEC was declining and TC and SEC were major contributions to its TFP progress during these periods. Sichuan showed that TFP change was closely driven by TC throughout the period. The TFP and TC changes were steadily improved while TEC and SEC was steadily stable leading to an increase of TFP growth for the entire periods. Qinghai showed agricultural productivity progress during 1991-1999 and a significant TFP regress in 2000 following with TFP regress during 2002-2005. TEC was a major contribution to TFP growth throughout the period. TC changes were steadily decreased for the entire periods. SEC was steadily stable throughout the period except a significant increase in 2000. Ningxia showed agricultural productivity progress throughout the period except in 1998, 2000 and 2002-2003. A decrease in TEC resulted in TFP regress. SEC was major contributions to its TFP progress for the entire periods. TC changes were steadily decreased for the entire periods.

Figure 5: Cumulative indices of TEC, TC, SEC and TFPC by the advanced-technology groups, 1991 to 2005



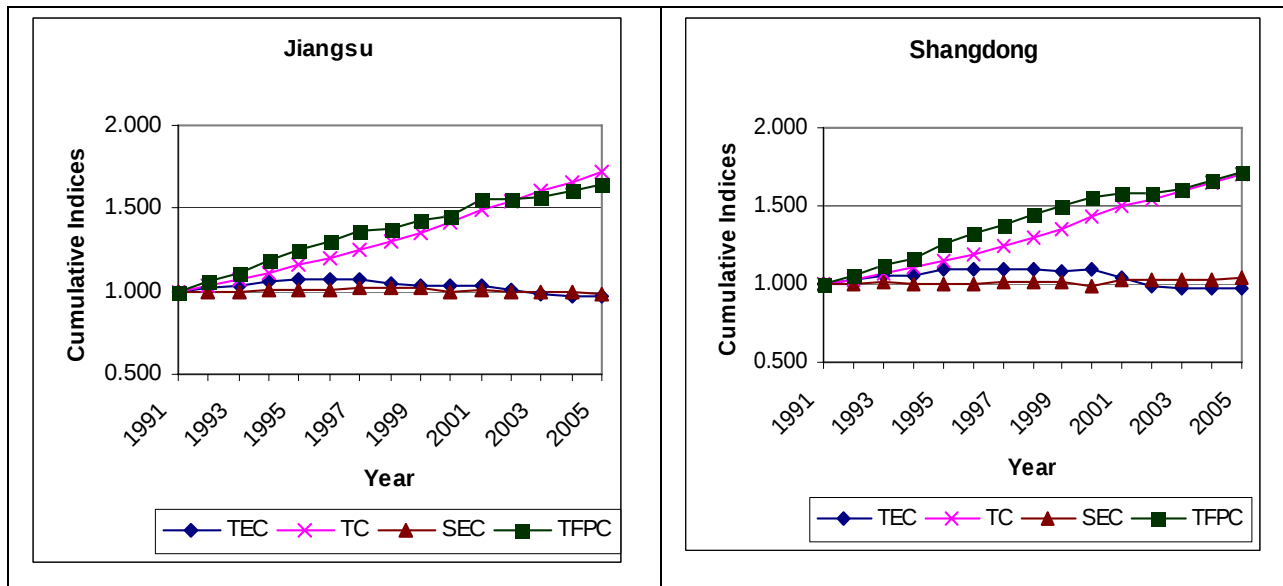
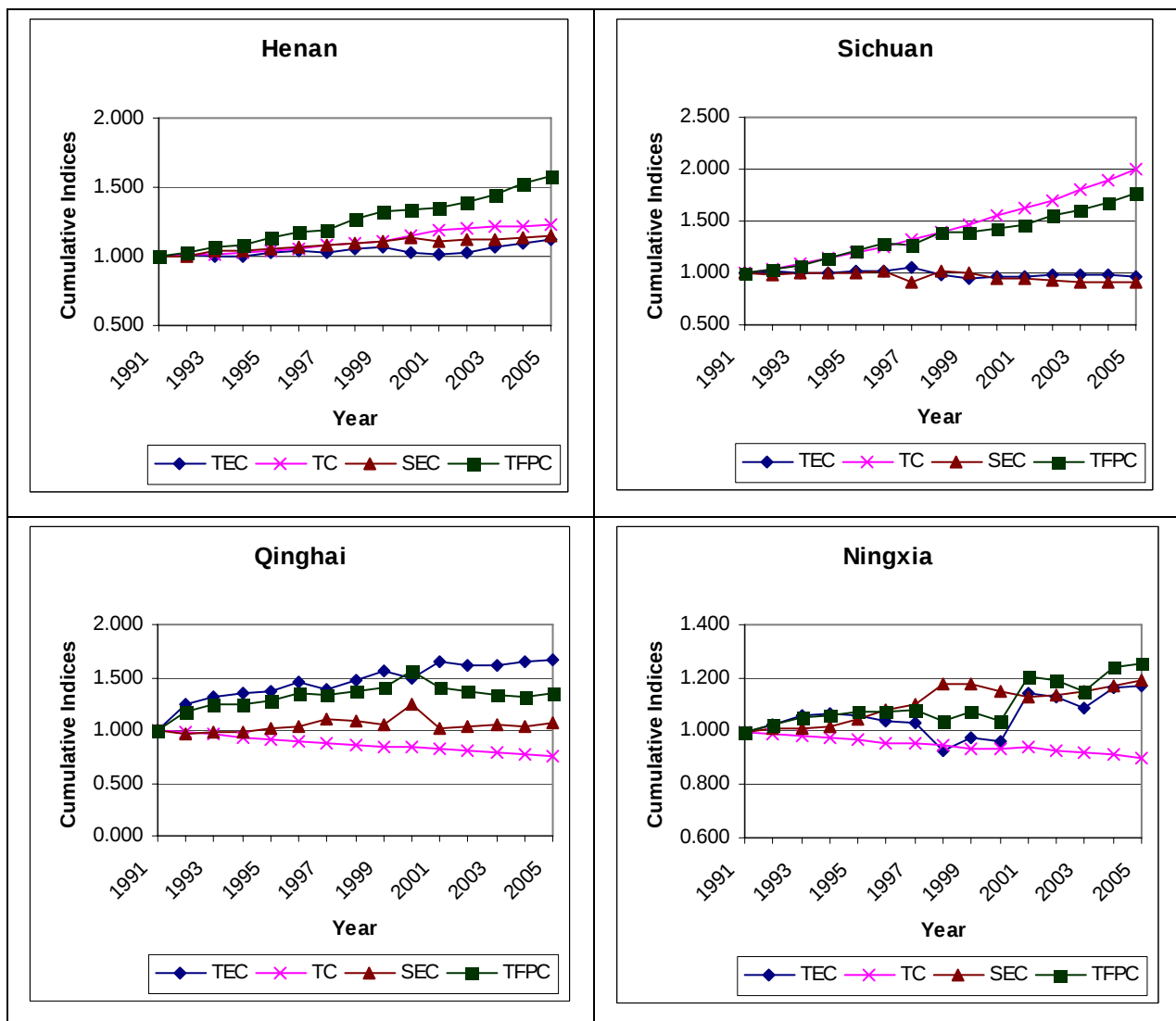


Figure 6: Cumulative indices of TEC, TC, SEC and TFPC by the low-technology groups, 1991 to 2005



5 CONCLUSIONS

With nearly one quarter of the potential agricultural resources and one-fifth of the world's population, China has the potential to supply a substantial share of the expected growth in food demand forecast for the first half of this century. This study utilizes a parametric meta-frontier function approach presented in BATTESE et al. (2002, 2004) to measure and decompose Chinese agricultural TE and TFP growth in 28 provinces over the period from 1991-2005. The provinces are categorized into advanced- and low-technology provinces due to distinctive levels of economic development and production technologies. The metafrontier approach allows to investigate whether all producers in different regions have potential access to the same technology or they may choose to operate on a different part of their own technologies.

The empirical findings indicate that the weighted average TFP growth in the Chinese agriculture over the study period grew at 3.234 % per annum, which was driven primarily by a 3.166 % increase in TC. SEC exhibited a positive effect to TFP growth whereas TEC showed positive in early years, then negative starting in 1997. TC was a major contribution to TFP growth in both advanced- and low-technology provinces. SEC and TEC exhibited negative effects to TFP growth for the advance- and low-technology provinces, respectively. Most of the advanced-technology provinces exhibited higher TE than the low-technology provinces. The comparatively low TE scores in low-technology provinces were found to be related to the TE measured with respect to its own-group technology and the technology gap ratio. As researchers and policy makers discuss the "pros and cons" of China's WTO commitments in agriculture, the analysis in this study suggests that there may be benefits through the improvement of TE. The empirical results also show that labor and fertilizer still make important contributions to output, and thus improving the quality of farmers and applying modern physical inputs is also crucial to TFP growth.

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Appendix

Table A1: Average TE, TGR and the TFP decomposition by province

<i>Provinces</i>	<i>TE^k</i>	<i>TGR</i>	<i>TE[*]</i>	<i>TEC</i>	<i>TC</i>	<i>SEC</i>	<i>TFPC</i>
<i>Advanced-technology provinces</i>				(in percentage)			
Beijing	0.820	0.948	0.778	0.180	4.190	-0.173	4.197
Tianjin	0.740	0.938	0.694	-0.286	3.693	-0.024	3.384
Hebei	0.688	0.960	0.661	0.499	2.049	0.534	3.082
Liaoning	0.948	0.948	0.898	-0.239	3.076	0.143	2.979
Jilin	0.784	0.969	0.760	-0.392	0.705	0.325	0.638
Helongjiang	0.839	0.980	0.822	0.012	-0.410	-0.344	-0.741
Shanghai	0.840	0.847	0.712	-2.439	6.957	-0.034	4.484
Jiangsu	0.793	0.960	0.761	-0.221	3.636	-0.088	3.327
Zhejiang	0.742	0.958	0.710	0.909	4.974	-0.914	4.969
Fujian	0.771	0.943	0.728	0.708	5.556	-0.257	6.007
Shandong	0.797	0.951	0.758	-0.198	3.559	0.225	3.585
Hubei	0.742	0.950	0.705	-0.037	4.486	-0.067	4.382
Guangdong	0.978	0.962	0.940	0.613	4.662	-0.786	4.489
Xijiang	0.806	0.958	0.772	-0.715	2.788	0.359	2.431
Average	0.806	0.948	0.764	-0.115	3.566	-0.079	3.372
<i>Low-technology provinces</i>							
Shanxi	0.615	0.903	0.554	0.277	1.188	0.534	2.000
Inner-Mongolia	0.976	0.863	0.842	-1.092	-0.602	1.285	-0.408
Anhui	0.596	0.938	0.558	-0.306	2.435	0.446	2.575
Jiangxi	0.694	0.844	0.584	-1.698	6.440	-0.770	3.972
Henan	0.726	0.858	0.623	0.743	1.378	0.934	3.054
Hunan	0.699	0.789	0.551	-0.895	6.074	-0.724	4.455
Guangxi	0.720	0.934	0.672	-0.588	2.393	0.547	2.351
Sichuan	0.980	0.842	0.825	-0.184	4.642	-0.683	3.774
Guizhou	0.731	0.888	0.650	0.577	3.082	0.043	3.702
Yunnan	0.711	0.941	0.669	0.214	2.231	0.942	3.387
Shaanxi	0.649	0.966	0.627	0.549	0.668	1.160	2.378
Gansu	0.649	0.975	0.633	0.135	0.977	1.401	2.512
Qinghai	0.917	0.851	0.781	3.423	-1.893	0.449	1.980
Ningxia	0.581	0.764	0.443	1.048	-0.692	1.167	1.523
Average	0.732	0.883	0.644	0.157	2.023	0.481	2.661

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Development, Transition and Agricultural Productivity in Asia¹

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Abstract

This study utilizes a parametric output distance function approach to decompose total factor productivity (TFP) growth into its associated components. The most recent Food and Agricultural Organisation (FAO) data set of 27 Asian countries over the period from 1980-2004 is used. Our major finding indicates that Asian countries on average achieved TFP growth at nearly 2 percent per annum. However, there were large differences among the transition countries in terms of the magnitude and direction of TFP growth. Some transition countries such as China and Mongolia exhibited above average growth. Others, such as, Kyrgyzstan, Uzbekistan, Laos, and Vietnam did not do so well.

Keywords: Agriculture, Productivity, Transition countries, Asia

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Introduction

During the past two decades, Asia has experienced impressive growth in rice and wheat production after the Green Revolution was successfully introduced (Pingali and Heisey, 1999). The Green Revolution in Asia was achieved through the application of the high-yielding varieties of major cereals, chemical fertilizers, pesticides and the development of irrigation system. Increased input use, however, cannot guarantee a long-run sustainable growth rate of yields and output (Huang, Pray and Rozelle, 2002). Over time, cultivated land per capita has declined due to population growth, urbanization, industrialization in a set of rapidly developing Asian nations that were already characterized as relatively limited in terms of their land resources. The decline in arable area was exacerbated by a series of land degradation processes (Pingali et al., 1997). Moreover, rapid economic growth in many countries has enhanced the availability of off-farm employment and increased the opportunity cost of rural labor.

In fact, it is possible to paint a fairly pessimistic picture of Asian agriculture. As well-established in the literature, agricultural production depends critically on the factors that contribute to the improved TFP beyond the quantity of resources, including labor, land and fertilizer. Pingali et al. (1997) show that the potential sources of inputs are mostly exhausted in many countries. Hence future agricultural growth in most countries will not rely on the mobilization inputs but will mainly depend on rising productivity, including the adoption of innovations, a more efficient use of inputs and an improved efficiency by the expansion of the scale of production. However, over the long run the record in the literature is not very encouraging. Indeed, in one of the most exhaustive studies of the productivity of Asian agriculture, Suhariyanto and Thirtle (2001) estimated that between 1965 and 1996 the annual growth rate of TFP was only 0.31 percent, although over their study period the rate was rising somewhat.

For several reasons in our analysis we seek to build on the previous literature and believe it is time to reevaluate TFP in Asia. The literature on the analysis of intercountry differences in agricultural efficiency and TFP growth has expanded significantly in the past two decades due to the availability of new panel data sets and the development of frontier analysis. One type of frontier analysis, Stochastic Frontier Analysis (SFA) which is a parametric approach, allows the analyst to not only calculate TFP, but also decompose changes in TFP into three components: technical change, changes in technical efficiency and scale economy changes.² Previous attempts to examine TFP across a wide number of Asian countries (e.g., Suhariyanto and Thirtle, 2001) used an index approach. Details on the SFA technique are described later in the paper and in Coelli et al (2005).

In our paper, we also pay particular attention to the former Socialist countries that are currently in transition—for example, countries like China and Mongolia in East Asia; Laos, Myanmar and Vietnam in Southeast Asia; and the nations of Central Asia. It is important when trying to sketch a picture of all of Asia that transition countries be included for several reasons. In the past because of data problems (both absence of data and differences in the nature of data between Socialist and non-Socialist countries) many

² Another type of frontier analysis is called non-parametric or known as Data Envelopment Analysis (DEA) model.

analyses of the economy just ignored most of these countries (e.g., Young, 1995; Otsuka, Chuma and Hayami, 1992; Pingali et al., 1997). Yet these countries account for almost half of the regions population and more than half of the land area. In Suhuriyanto and Thirtle (2001), although China and some East and Southeast Asia nations were included, those in Central Asia were not.

Including the transition countries also is important since without them it is difficult to predict what is happening for overall Asia since predicting the direction of TFP change is difficult for transition countries. On the one hand they generally have a long history of investment into pro-technology R&D and, in some cases, may be somewhat behind the rest of the world in terms of level of new technology adoption. As a result of this, it might be expected that there is relative great potential for expanding TFP by improving the technological base of some of the nations and this in turn would suggest that there could be above average shifts in TFP. However, at the same time, these countries are, by definition, in transition. As a result it is possible that in some cases this means that the set of institutions that are needed in agriculture to produce and extend new technologies are weak or deteriorating enough (because they are in transition and there has not been an equilibrium attached) that there has been a fall in technical efficiency. Indeed, in a recent book that examines the impact of the economic reforms on agricultural production in transition countries found that the effect differed widely across countries and over time within countries (Swinnen and Rozelle, 2006). Moreover, given the timing of the analysis in Suhuriyanto and Thirtle (2001), which was conducted in the years soon after the beginning of the reforms (which did examine the cases of China and Vietnam, but not Central Asia), it is possible that it was difficult to understand the real situation in transition countries since there was still a lot of disequilibrium in the 1970s, 1980s and early 1990s in many transition countries). As a result, making an assessment with data through the mid-2000s may be able to reveal what is happening (and what will be happening) to transition countries.

Finally, increased availability of data on enough variables on enough countries for sufficient years makes it possible to use the new methods to rigorously analyze differences in productivity for a large number of nations over time and update the analysis to a more recent time period. In the past, a number of papers looked at the effect of market-orient reforms on agricultural performance (e.g., Lerman, 2000; Macours and Swinnen, 2002; and Lissitsa, Rungsuriyawiboon and Parkhomenko, 2007). But limited data kept the authors from looking at a broad range of countries and only allowed them to use partial measures of productivity. Swinnen and Rozelle (2006) is one of the only cross regional papers that examines intercountry comparisons (including transition nations) of agricultural TFP. In their work, however, they admit that the coverage of their work is spotty and their use of different productivity measures in different countries does not facilitate comparisons. In our paper, we examine 27 countries for 25 years. The size of this sample allows us to examine TFP for almost all major nations in Asia over time.

To fill these gaps, the main purpose of the paper is to understand the state of productivity improvements in Asia the world's most populated region. To meet this overall goal we have three specific objectives. First, we seek to measure TFP growth in Asia for the years between 1980 and 2004. Second, we will decompose TFP growth into

three of the sources of productivity growth: technical change, changes in technical efficiency and shifts in scale economies. The technical change component is further decomposed to uncover evidence of how input and output intensities shift in response to the adoption of innovations. Finally, because of the importance transition countries, we are going to pay particular attention to their trends and the contribution to overall Asian TFP growth.

The reminder of the paper is organized as follows. The next section presents the methodology used to construct the TFP growth and its decomposition. The following section discusses the data set and the definitions of the variables used in this study. The empirical results are presented and discussed in the next section and the final section concludes and summarizes.

Model Specification

Decomposition of a TFP Growth

TFP growth is theoretically defined as the difference between the growth rate of total output and the growth rate of total inputs. For example, if agricultural output grew by 2.20 percent and total inputs grew by 1.05 percent between 2004 and 2005, then TFP would grow by 1.15 percent during the years between 2004 and 2005. TFP growth in agriculture is important as it is one source for increasing food production, keeping agricultural prices low and raising incomes of farmers.

TFP growth, however, is not always easy to track or to predict since there are many different factors that affect its growth. To help understand the forces that affect the growth of TFP in a given economy, conceptually it is possible to decompose TFP into three part—technical change (TC); changes in technical efficiency (TEC) and changes in scale economies (SEC). The TC-related effect results when the “frontier of production” shifts and there is more output for a given set of inputs, given that producers are already producing efficiently. The TEC-related effect (when it is positive) explains the “catching-up” part of the TFP growth. In other words, TEC occurs when output rises while inputs are constant, given a specific production frontier, because the producer is using the inputs more efficiently. Finally, the SEC-related effect represents the effect of adjusting the optimal farm size to the TFP growth. Understanding which of these components are driving overall TFP growth is important because they provide useful information to policy makers that want to design suitable policies to maintain or achieve greater rates of TFP growth.

A Generalized MPI Change Decomposition and a Parametric Framework

In the literature, TFP growth can be measured by using a productivity index. The most commonly used TFP index is the Malinquist Productivity Index (MPI) presented in Caves, Christensen, and Diewert (1982) and Färe et al. (1994). The MPI has gained more interest in practice because it allows one to identify the various components of TFP growth (specifically, TC, TEC and SEC), which (as discussed above) are often of particular interest to policy makers. The MPI can be empirically calculated using the DEA or SFA technique. Both techniques involve the estimation of a production technology. Färe et al. (1994) initially presented a non-parametric DEA approach to

measure the change in the MPI between two time periods. The MPI is defined using an output distance function.³ By imposing an assumption of Constant Returns to Scale (CRS) on the production technology, the MPI change can be decomposed into TEC and TC.

Since it is of interest to understand which factors of production are contributing to production (and finding the technologies that enhance those factors), the MPI has another important characteristic. Specifically, Färe et al. (1997) extended the measure of the change in the MPI and is able to show that the TC component can be decomposed into two components: input- and output-biased TC and non-neutral TC. This decomposition allows one to investigate how the inputs and outputs are reallocated when there is TC. With the availability of new panel data sets and the development of a non-parametric DEA technique, a number of papers decomposing MPI change appeared. However, Färe et al. (1994) raised a fundamental criticism of the decomposition of MPI change using DEA. Fare's work demonstrated that it may not provide an accurate measure of TFP growth because the DEA-based measure ignores shifts in scale economies (SE). Subsequently, Orea (2002) proposed a parametric counterpart of the output-orientated MPI change and produced a way to take shifts in SE into account. Using this new methodology, SEC is considered as an additional component of the TFP growth.

Using Distance Functions to Measure and Decompose TFP Growth

To implement the methods in the literature, one must first introduce the approach of empirical estimation. In our paper, we measure the TFP growth (and decompose the MPI) using an output distance function. The output distance function is defined as a rescaling of the length of an output vector with the production frontier as a reference.

The first step in explaining our approach is to consider a multi-input, multi-output production technology where the i -th producer ($i=1,...,I$) at time period t ($t=1,...,T$) uses a non-negative $K \times 1$ input vector $X_{it} \in R_+^K$ to produce a non-negative $M \times 1$ output vector $Y_{it} \in R_+^M$. The set of all technologically feasible input-output combinations at time period t satisfying the standard properties discussed in Färe and Primont (1995) is $S_t = \{(X, Y) : X \text{ can produce } Y\}$.

The output distance function for the period t is defined as

$$D_t^o(X_t, Y_t) = \inf \{ \theta : (X_t, Y_t / \theta) \in S_t \}, \quad (1)$$

where the superscript o refers to an output orientation of the distance function. The output distance function is non-decreasing, linearly homogenous and convex in Y , and non-increasing and quasi-convex in X . $D_t^o(X_t, Y_t) \leq 1$ if and only if $(X_t, Y_t) \in S_t$. Moreover, $D_t^o(X_t, Y_t)$ is equal to Farrell's the output-orientated TE measured at time t , that is $0 \leq TE_t^o(X_t, Y) \equiv D_t^o(X_t, Y) \leq 1$.

Orea (2002) employs a parametric technique and applies Diewert's (1976) Quadratic Identity Lemma to derive a generalized MPI change decomposition. The

³ It can also be extended using an input distance function.

logarithmic form of a generalized output-oriented MPI change index between periods t and $t+1$ can be written as

$$\begin{aligned}
m_{t,t+1}^{o,v} &= \left(\frac{d_{t+1}^{o,v}}{d_t^{o,v}} \right) - \frac{1}{2} \left[\frac{\partial d_{t+1}^{o,v}(\cdot)}{\partial t} + \frac{\partial d_t^{o,v}(\cdot)}{\partial t} \right] \\
&+ \frac{1}{2} \left[\sum_{k=1}^K \left(-\sum_{k=1}^K e_{kt+1} - 1 \right) \cdot s_{kt+1} + \left(-\sum_{k=1}^K e_{kt} - 1 \right) \cdot s_{kt} \right] \left(\frac{x_{kt+1}}{x_{kt}} \right), \\
&= \ln TEC^{o,v} + \ln TC^{o,v} + \ln SEC^{o,v},
\end{aligned} \tag{2}$$

where the superscript v refers to a measure that is calculated from the distance function corresponding to VRS technology; m^o is the logarithm of the MPI change index between periods t and $t+1$; $d_t^{o,v}$ is the logarithm of output distance term which is equivalent to the logarithm of output-orientated measure of Farrell TE in period t ; $d_t^{o,v}(\cdot)$ is the logarithm of the output distance function; x_{kt} is the logarithm of the k^{th} input in period t ; $e_{kt} = \partial d_t^{o,v}(\cdot) / \partial x_{kt}$ is the distance elasticity for the k^{th} input in period t , and $s_{kt} = e_{kt} / \sum_{k=1}^K e_{kt}$ is the distance elasticity share for the k^{th} input in period t . In our paper $\ln TEC^{o,v}$ represents the logarithmic form of TEC, $\ln TC^{o,v}$ represents the logarithmic form of TC, and $\ln SCE^{o,v}$ represents the logarithmic form of SEC. Equation (2) is expressed in terms of proportional rates of growth instead of a product of indices.

Estimating the Distance Function

The components of the generalized MPI change can be measured by estimating the output distance function. To estimate the parameters of an output distance function, however, we must first specify a functional form. The output distance function taking the log-quadratic translog functional form can be defined as

$$\begin{aligned}
d_{it}^{o,v}(\cdot) &= \beta_0 + \sum_{m=1}^M \beta_{y_m} y_{mit} + \frac{1}{2} \sum_{m=1}^M \sum_{n=1}^M \beta_{y_m y_n} y_{mit} y_{nit} + \sum_{k=1}^K \beta_{x_k} x_{kit} + \frac{1}{2} \sum_{k=1}^K \sum_{l=1}^K \beta_{x_k x_l} x_{kit} x_{lit} \\
&+ \sum_{k=1}^K \sum_{m=1}^M \beta_{x_k y_m} x_{kit} y_{mit} + \beta_t t + \frac{1}{2} \beta_{tt} t^2 + \sum_{k=1}^K \beta_{x_k t} x_{kit} t + \sum_{m=1}^M \beta_{y_m t} y_{mit} t,
\end{aligned} \tag{3}$$

Where the β s are unknown parameters to be estimated. Young's theorem requires that the symmetry restriction is imposed so that $\beta_{x_k x_l} = \beta_{x_l x_k}$.

Linear homogeneity in outputs requires the following restrictions:

$$\sum_{m=1}^M \beta_{y_m} = 1, \quad \sum_{n=1}^M \beta_{y_m y_n} = 0 \quad (m=1, \dots, M), \quad \sum_{m=1}^M \beta_{x_k y_m} = 0 \quad (k=1, \dots, K) \quad \text{and} \quad \sum_{m=1}^M \beta_{y_m t} = 0. \tag{4}$$

Imposing the linear homogeneity in outputs yields the estimating form of the output distance function, in which the distance term, $d_{it}^{o,v}(\cdot)$, can be viewed as an error term as follows:⁴

$$\begin{aligned}
 -y_{Mit} = & \beta_0 + \sum_{m=1}^{M-1} \beta_{y_m} y_{mit}^* + \frac{1}{2} \sum_{m=1}^{M-1} \sum_{n=1}^{M-1} \beta_{y_m y_n} y_{mit}^* y_{nit}^* + \sum_{k=1}^K \beta_{x_k} x_{kit} + \frac{1}{2} \sum_{k=1}^K \sum_{l=1}^K \beta_{x_k x_l} x_{kit} x_{lit} \\
 & + \sum_{k=1}^K \sum_{m=1}^{M-1} \beta_{x_k y_m} x_{kit} y_{mit}^* + \beta_z t + \frac{1}{2} \beta_{tt} t^2 + \sum_{k=1}^K \beta_{x_k t} x_{kit} t + \sum_{m=1}^{M-1} \beta_{y_m t} y_{mit}^* t - d_{it}^{o,v},
 \end{aligned} \tag{5}$$

where $y_{mit}^* = (y_{mit} - y_{Mit})$. By replacing the distance term, $-d_{it}^{o,v}$, with a composed error term, $v_{it} - u_{it}$, equation (5) can be estimated as a standard stochastic frontier function where v_{it} s are a two-sided random-noise component assumed to be i.i.d. $N(0, \sigma_v^2)$ and u_{it} s are a non-negative technical inefficiency component assumed to be a half normal distribution, $N^+(0, \sigma_u^2)$. The two terms, v_{it} and u_{it} , are error terms that are assumed to be distributed independently of each other, and of the regressors.

Data

The empirical analysis in this study focuses on agricultural production of 27 Asian countries. The primary source of data is obtained from the website of the FAO of the United Nations (UN). Specifically, the agricultural statistics were acquired from the AGROSTAT system, which is supported by the Statistics Division of the FAO. The data used to measure agricultural performance contain the measurements of agricultural output and input quantities. In this study, the production technology is presented by two output variables (i.e., crop output and livestock output) and five input variables (i.e. land, tractor power, labor, fertilizer and livestock).

Output Variables

In this study, the output series are derived by aggregating detailed output quantity data on 127 agricultural commodities (115 cropping commodities and 12 livestock commodities). The construction of the output data series used two basic steps. First, the Geary-Khamis method was used to construct output aggregates from the output quantity data. To do so, we used average international prices (expressed in US dollars) for the base period 1999 to 2001.⁵ Second, the aggregate output values during the base period were used to generate an aggregate output series from 1992-2002 using the FAO production indices for crops and livestock separately.⁶

⁴ Homogeneity can be imposed by estimating the model with $M-1$ output variables normalized by the M^{th} output variable.

⁵ Detailed information on how international average prices are constructed can be found in Rao (1993)

⁶ See the FAO STAT (FAO, 2004) for details regarding the construction of production index numbers

Input Variables

Given limitations on the number of input variables that could be used in the analysis (due to lack of data on other variables on the FAO website), only five input variables are used in our study. Our input variables are defined as follows:

Land input variable represents arable land in each country in each year. Arable land includes both land under permanent crops as well as the area under permanent pasture. The variable is measured in hectares.

Tractor input variable represents the total number of wheeled- and crawler tractors that are used in agriculture. We exclude garden tractors.

Labor variable refers to the number of economically active people in agriculture. It is best thought of as a measure of the number of laborers in the agricultural sector.

Fertilizer input variable sums up, in nutrient-equivalent terms, the commercial use of nitrogen, potassium and phosphate fertilizers. The variable is expressed in thousands of metric tons. The fertilizer input variable is defined by following the approaches of other studies on inter-country comparison of agricultural productivity (Hayami and Ruttan, 1970; Fulginiti and Perrin, 1997).

Livestock input variable is the sheep-equivalent of the six categories of animals used in constructing this variable. The six categories considered are buffaloes, cattle, pigs, sheep, goats and poultry. The total number of each category of these animals is converted into sheep equivalents using a standard conversion factor: 8.0 for buffalos and cattle; 1.00 for sheep, goats and pigs; 0.1 for poultry (Hayami and Ruttan, 1970).

Panel data on 27 Asian countries over the time period of 1980 through 2004 are used in the empirical analysis. These countries account for more than 46 percent of global agricultural outputs and 56 percent of world's population. The countries account for 94 percent of the population of Asia. Only a small number of nations (e.g., Bahrain; Brunei; Bhutan; Cyprus; Jordan; Kuwait; Lebanon; Maldives; Oman; Qatar; Singapore) are excluded due to the absence of data.

Countries selected for analysis are categorized into six regions: Central Asia (CA), Eastern Asia (EA), Southern Asia (SA), Southeast Asia (SEA), Western Asia (WA) and China (CN).⁷ In recognition of its size and due to differences in its accounting practices over time, China is treated as a region by itself.⁸ A list of the countries in each region is summarized in Table 1.

Table 1: Classification of Selected Countries

Region	Country	Region	Country
<i>Central Asia (CA)</i>	Kazakhstan (KAZ) Kyrgyzstan (KGZ) Tajikistan (TKM) Turkmenistan (TJK) Usbekistan (UZB)	<i>Southeast Asia (SEA)</i>	Cambodia (KHM) Indonesia (IDN) Laos (LAO) Malaysia (MYS) Myanmar (MMR) Philippines (PHL) Thailand (THA)
<i>Eastern Asia</i>	Japan (JPN)		

⁷ The regional groupings are based on their geographical used in UN Statistics Division.

⁸ According to the UN definition, China is located within the EA region.

(EA)	Republic of Korea (PRK) Mongolia (MNG)		Vietnam (VNM)
Southern Asia (SA)	Bangladesh (BGD) India (IND) Islamic Rep of Iran (IRN) Nepal (NPL) Pakistan (PAK) Sri Lanka (LKA)	Western Asia (WA)	Iraq (IRQ) Israel (ISR) Saudi Arabia (SAU) Syrian Arab Republic (SYR)
		China (CN)	China (CHN)

Descriptive statistics of the variables summarized by each region is presented in Table 2. China shows that it produces the highest share of agricultural output values for both crop and livestock commodities.⁹ China also accounts for the highest share of agricultural land, labor and fertilizer use. The EA region exhibits the highest share of tractors whereas the SA region shows the highest share of livestock input.¹⁰

Table 2: Descriptive Statistics of Variables, 1980-2004

Variable	Units	Region						
		CA *	EA	SEA	SA	WA	CN	All
Outputs								
- Crops	×10 ⁶ US \$	1793 (1446)	4465 (3496)	7267 (6423)	19020 (30127)	4517 (6221)	165817 (44930)	14794 (35694)
- Livestock	×10 ⁶ US \$	1282 (1072)	3711 (3369)	1389 (1099)	7926 (11919)	1660 (1844)	62344 (33658)	5616 (14707)
Inputs								
- Land	×10 ³ ha	57.31 (78.46)	44.13 (57.43)	13.17 (12.24)	47.33 (63.19)	40.11 (53.12)	518.41 (36.23)	54.29 (107.67)
- Tractors	×10 ³	76.46 (64.03)	674.65 (903.59)	36.13 (53.64)	284.01 (514.45)	175.78 (292.12)	825.24 (92.53)	231.25 (476.38)
- Labor	×10 ³	1.29 (0.90)	2.72 (2.01)	15.33 (13.67)	52.42 (85.03)	3.28 (5.08)	480.97 (35.18)	36.96 (101.00)
- Fertilizer	×10 ⁶ ton3	206 (350)	871 (734)	775 (840)	2785 (4626)	557 (630)	28418 (9009)	2237 (6096)
- Livestock	×10 ⁶	32.86 (26.61)	38.53 (10.89)	60.45 (41.32)	537.65 (850.03)	42.07 (56.95)	1439.04 (272)	217.18 (525.27)

* Data for each country in this region are only available during the time period of 1992 to 2004.

Notes: Means are calculated. Standard deviations are presented in parentheses

⁹ Agricultural output values for crops account for 43.78% by CN, 30.13% by SA, 15.3% by SEA, 5.96% by WA, 3.54% by EA and 1.23% by CA, and agricultural output values for livestock account for 43.36% by CN, 33.08% by SA, 7.74% by EA, 7.73% by SEA, 5.77% by WA and 2.32% by CA.

¹⁰ Agricultural land accounts for 37.30% by CN, 20.43% by SA, 14.43% by WA, 10.72% by CA, 9.53% by EA and 7.58% by SEA. Agricultural labor accounts for 50.84% by CN, 33.25% by SA, 12.97% by SEA, 1.73% by WA, 0.86% by EA and 0.35% by CA. Fertilizer used in agriculture accounts for 49.63% by CN, 29.18% by SA, 10.83% by SEA, 4.86% by WA, 4.56% by EA and 0.93% by CA. Tractor used in agriculture accounts for 34.19% by EA, 28.79% by SA, 14.85% by WA, 13.94% by CN, 4.88% by SEA and 3.36% by CA. Livestock used in agriculture accounts for 58.02% by SA, 25.88% by CN, 8.70% by SEA, 3.78% by WA, 2.08% by EA and 1.54% by CA.

Results

The panel data on 27 Asian countries during the time period from 1980 to 2004 were used to estimate the translog output distance function under the VRS model from equation (5) and the CRS model from equation (6). The variables used in the model estimation were each transformed by dividing by their respective geometric means.¹¹ The maximum likelihood parameter estimates are listed in Table 3.

In general, the estimation performed well. All first-order coefficients from both models have the expected signs, implying that the output distance functions are increasing in outputs and decreasing in inputs at the sample mean.¹² The estimates of the distance elasticities with respect to outputs estimated by the VRS model are 0.490 and 0.510 for crops and livestock. The output elasticities estimated by the CRS model are fairly consistent, 0.436 for crops and 0.564 for livestock. The estimates of the distance elasticities with respect to inputs estimated by the VRS model are -0.099, -0.184, -0.192, -0.224 and -0.334 for land, tractors, labor, fertilizer, and livestock, respectively. The point estimate of the sum of the input elasticities from the VRS model is -1.033, indicating that the technology exhibits small to moderately increasing returns to scale at the sample mean. When the CRS model is used, the estimates of the input elasticities are -0.064, -0.202, -0.136, -0.342 and -0.255 for land, tractors, labor, fertilizer, and livestock, respectively, and by definition add to -1.

According to the results of our two models, we find some evidence that there are moderate economies of scale in Asian agriculture. Our hypothesis test that the CRS to scale model accurately captures the nature of the economies of scale in cropping and livestock production was conducted using a likelihood ratio (LR) test. The LR test is rejected at the 90 percent level implying the economies of scale may be marginally significant. Because of this result, in the rest of the analysis the parameter estimates of the VRS model are used to calculate the components of the MPI change decomposition.¹³

Table 3: Estimated Parameters of the Output Distance Model

Parameter ^a	VRS Model		CRS Model	
	Estimates	<i>t</i> -Statistic	Estimates	<i>t</i> -Statistic
β_0	0.277	8.781	0.532	9.438
β_{y1}	0.490	20.114	0.436	15.200
β_{y1y1}	0.331	5.253	0.340	5.524

¹¹ This transformation does not alter the performance measures obtained, but does allow one to interpret the estimated first-order parameters as elasticities, evaluated at the sample means.

¹² Tests of the regularity conditions are checked at each data point in all 615 observations. We find the convexity condition and the monotonicity constraints on outputs are satisfied at all observations in the output distance function for both models. The monotonicity constraints in inputs are violated at 9, 3, 6, 5, and 10% of all observations in the case of land, tractors, labor, fertilizer and livestock inputs, respectively, for the VRS model. In the CRS model, the monotonicity constraints in the corresponding inputs are violated at 11, 5, 12, 3, and 10% of all observations.

¹³ Investigating how the inputs and outputs are reallocated attributed to TC requires the CRS assumption. Hence, the estimates from the CRS model are used to calculate the components of the TC decomposition.

β_{x1}	-0.099	-7.126	-0.064	-4.128
β_{x2}	-0.184	-15.228	-0.202	-14.205
β_{x3}	-0.192	-8.222	-0.136	-5.153
β_{x4}	-0.224	-16.310	-0.342	-28.582
β_{x5}	-0.334	-11.067		
β_{x1x1}	-0.101	-7.517	-0.098	-6.898
β_{x2x2}	0.033	3.321	0.027	2.272
β_{x3x3}	0.151	2.455	0.220	3.775
β_{x4x4}	-0.022	-3.161	-0.027	-3.405
β_{x5x5}	-0.228	-2.034		
β_{x1x2}	0.043	5.147	-0.006	-0.726
β_{x1x3}	-0.103	-4.426	-0.086	-3.816
β_{x1x4}	0.048	5.470	0.075	7.118
β_{x1x5}	0.035	1.179		
β_{x2x3}	0.195	8.454	0.348	14.712
β_{x2x4}	-0.060	-7.818	-0.095	-10.992
β_{x2x5}	-0.128	-4.866		
β_{x3x4}	-0.214	-10.331	-0.231	-10.274
β_{x3x5}	-0.008	-0.103		
β_{x4x5}	0.296	12.564		
β_{x1y1}	-0.051	-2.115	-0.051	-2.351
β_{x2y1}	-0.093	-4.688	-0.169	-7.606
β_{x3y1}	-0.182	-3.831	-0.311	-6.767
β_{x4y1}	0.189	10.061	0.216	10.204
β_{x5y1}	0.114	2.067		
β_t	-0.008	-6.887	-0.006	-4.240
β_{tt}	-0.001	-2.590	-0.002	-4.654
β_{x1t}	-0.008	-6.996	-0.009	-7.168
β_{x2t}	0.003	3.128	0.002	1.534
β_{x3t}	0.002	0.808	-0.007	-2.748
β_{x4t}	0.001	1.036	0.007	5.569
β_{x5t}	-0.006	-2.564		
β_{y1t}	-0.001	-0.410	-0.002	-0.758
σ^2	0.062	8.042	0.072	4.819
γ	0.788	11.257	0.581	3.091
Likelihood				
Value	215.501		81.959	

^a Subscripts on β_x coefficients refer to inputs: 1 = land; 2 = tractors; 3 = fertilizer; 4 = labor; 5 = livestock input and subscripts on β_y coefficients refer to outputs: 1 = crops; 2 = livestock output

Perhaps the most general and important finding in our paper is that over the entire time period of our analysis (1980 to 2004), the annual growth rate of TFP across all of Asia (the 27 countries in our study) was positive and nearly 2 percent (1.902 percent—Table 4, section A, row 6, column 6). A growth rate of 2 percent is typically considered as a sign that agriculture is healthy in terms of its improvement in productivity. It is

higher than the rate of growth of the population of Asia during 1990s (around 1.5 percent—Asia Development Bank, 2001). Most developed countries that are considered to have well performing agricultural economies (e.g., the United States, Germany, Australia) have consistently posted TFP growth rates of more than 1.5 percent (Bureau, Färe and Grosskopf, 1995).

The importance of examining productivity shifts over the past decade are important since this fairly robust rate of TFP growth for Asia the entire study period to a large extent are driven by rises in TFP during the past 10 years (Table 4, Section A, column 6). Between 1980 and 1995, TFP growth average only a bit over 1 percent (rising from 0.343 percent in the 1980-85 period to 1.775 (1.857) percent during the 1984-90 (1990-95) period. These numbers are remarkably consistent with those of Suhariyanto and Thirtle (2001) that found the growth of TFP in Asia before 1996 was around 1 percent. After 1995, the rate of growth of TFP accelerates, rising by 2.023 percent in 1995-2000 and by nearly 4 percent in 2000-04.

The findings of the decomposition analysis demonstrate convincingly that the relatively high overall rate of TFP growth and its recovery over the past two decades has relied, in general, on technological change (TC—Table 4, Section A, column 4). In fact, through the entire period (except after 2000), the rate of TC exceeds TFP growth. Between 1980 and 2004, the adoption of new varieties of crops, the extension of new breeds of livestock and other breakthroughs have pushed up the production frontier by 2.321 percent annually. During the past decade TC has grown by nearly 3 percent annually (2.847 percent between 1995 and 2000; and 3.245 percent between 2000 and 2004). While in this paper it is beyond the scope of our analysis to identify the exact sources of TC, according to work by Evensen and Golin (2003), David and Otsuka (1994), and Pingali et al. (1997), the second generation of the Green Revolution appears to be succeeding in keeping the rate of TC high.

Table 4: Weighted Average Growth Rates of the TE Scores and MPI Change for Each Region over the Time Period of 1980 to 2004 (in %)

Region	Period	TEC	TC	SEC	TFP Growth
A) All	1980-1985	-0.598	1.422	-0.481	0.343
	1985-1990	0.371	1.897	-0.494	1.775
	1990-1995	-0.218	2.376	-0.300	1.857
	1995-2000	-0.885	2.847	0.061	2.023
	2000-2004	0.835	3.245	-0.165	3.916
	1980-2004	-0.138	2.321	-0.280	1.902
B) SA	1980-1985	-0.613	1.833	-0.179	1.041
	1985-1990	-0.235	2.154	-0.145	1.774
	1990-1995	-0.121	2.479	-0.085	2.273
	1995-2000	-0.104	2.819	0.019	2.734
	2000-2004	0.285	3.128	0.103	3.516
	1980-2004	-0.176	2.456	-0.064	2.216
C) SEA	1980-1985	0.041	0.199	-0.032	0.208
	1985-1990	1.159	0.607	0.047	1.813

	1990-1995	-0.100	0.872	-0.223	0.549
	1995-2000	0.101	1.105	-0.132	1.074
	2000-2004	0.248	1.472	0.123	1.843
	1980-2004	0.292	0.825	-0.050	1.066
D) WA	1980-1985	0.405	-0.854	0.374	-0.076
	1985-1990	-0.689	-0.295	-0.022	-1.005
	1990-1995	-0.401	0.201	-0.155	-0.355
	1995-2000	-0.705	0.578	-0.077	-0.203
	2000-2004	-0.674	0.949	-0.484	-0.208
	1980-2004	-0.402	0.081	-0.056	-0.376
E) EA	1980-1985	-0.280	-2.083	-3.386	-5.749
	1985-1990	0.163	-1.721	-1.059	-2.617
	1990-1995	0.103	-1.328	-1.016	-2.241
	1995-2000	-0.581	-0.914	-0.032	-1.528
	2000-2004	1.532	-0.607	-2.689	-1.763
	1980-2004	0.131	-1.361	-1.592	-2.822
F) EA+CN	1980-1985	-0.810	1.598	-0.865	-0.077
	1985-1990	0.613	2.189	-0.911	1.892
	1990-1995	-0.381	2.838	-0.475	1.982
	1995-2000	-1.613	3.420	0.186	1.993
	2000-2004	1.430	3.877	-0.388	4.919
	1980-2004	-0.218	2.739	-0.495	2.026
G) CA	1992-1995	1.360	1.612	-0.177	2.795
	1995-2000	-0.623	1.808	-1.083	0.103
	2000-2004	-0.502	2.350	-0.041	1.806
	1992-2004	-0.087	1.940	-0.509	1.344

Rates of TC that exceeded TFP growth, in fact, were needed to keep TFP growing at a healthy rate since our decomposition analysis shows that during the study period TFP has been pulled down due to declining technical efficiency (TEC—Table 4, Section A, column 3). According to our results, TFP growth between 1980 and 2004 would have been 0.138 percent high had efficiency levels not fallen. Over time there has been less of a consistent change in TEC. In the most recent period (2000 to 2004), somewhat surprisingly (given the continued rise in off farm employment—which might be one factor is behind falling efficiencies), TEC rose by 0.835 percent. When combined with TC, it is clear now why TFP growth was so high in the 2000 to 2004.

TFP growth rate during the study period would have been even higher had changes in scale economies (SEC) not deteriorated (Table 4, Section A, column 5). Between 1980 and 2004, the contribution of scale economies to TFP growth was negative (-0.280 percent). In other words, TFP growth would have been 0.280 percent higher had not efficiencies due to economies of scale fallen. The result, with the exception of the 1995 to 2000 period (perhaps associated with the Asian Crisis), most likely was reflecting the continued tendency for farm sizes in Asia to decline (Kuhnen, 1996).

In summary, then, for Asia as a region as a whole, productivity growth is relatively robust and rising. This is good news for those concerned about keeping balance in Asia and world food markets, especially given the secular declining trends in

cultivated land, labor and water (Pingali, 2001). If Asia's food output is going to help contribute to world supplies, productivity is going to need to continue since it is likely that resources will continue to flow out of the sector as development in many of the region's countries continues. The importance of agricultural R&D is clear from our findings as TC accounts for all of the growth in TFP. One implication of the results is that if the factors that are contributing to the falls in TEC and SEC can be reversed, it is possible that TFP could grow even faster.

Sources of TFP Growth in Asia's Major Regions and the Importance of Transition Nations

If we examine TFP growth during the study period in the regions of Asia that have been the focus of most studies in the past it is clear that the aggregate story of TFP growth would be somewhat different than when looking at the region as a whole (as we did in the previous section). The record of the major regions from *traditional Asia* can be seen in Sections B, C, D and E in Table 4. In the table, the results of our TFP analysis are given for each of the study's subperiods as well as the findings of the decomposition analysis.

Interestingly, the patterns of TFP growth in South Asia (SA) parallel those of the rest of Asia (Table 4, Section B). The annual growth rate of TFP is around 2 percent (2.216 percent) and it is rising over time. In addition, the rate of TC exceeds that of TFP growth in all periods, except the period after 2000, meaning that TC in SA, as in Asia as a whole, is responsible for all of the growth. This high rate of TC in SA is needed since the TEC and SEC components are negative (also like that in Asia as a whole). It is clear from these results that the increasingly robust performance of SA is at least one driver of the results found in Asia more generally.

The healthy performance in SA is not matched by the other regions (Table 4, Sections C, D and E). The growth rate of TFP in Southeast Asia (SEA) is only around 1 percent, about half that of Asia as a whole. This rate in SEA, however, is at least positive; those in Western Asia (WA) and Eastern Asia (EA) are negative. Especially in the case of EA, between 1980 and 2004, on average, TFP has fallen by 2.822 percent annually. In the case of all three of these regions, SEC has detracted from productivity (especially in EA where land tenure laws and agricultural support policies discourage farm consolidation). Technological change, although contributing to TFP growth slightly in SEA and WA, drags down TFP growth in EA. Finally, while TEC is negative in WA, it is slightly positive in SEA and EA.

It is clear that the story of Asia, had it relied on these four regions (SA, SEA, WA and EA) alone, would not have been such an encouraging story. In fact, if we had only included the countries in these regions (the nations that were mostly studied in the past), the estimated rate of TFP growth would have been much lower. Although not reported in the table, the rate of increase in TFP from the four regions between 1980 and 2004 was 1.543 percent. The importance of SA in the record of Asia as a whole is shown by computing the rate of TFP growth with only SEA, WA and EA (0.664 percent). Such low growth rates would be the source of concern for those that worry that Asia is not able to contribute significantly to world food production. If both TFP and input levels are falling, food output in the region would also necessarily fall.

The performance of Asia's productivity growth, however, is greatly enhanced by including the former Socialist countries in East and Central Asia (Table 4, Sections F and G). In fact, the record of China—coupled with its size—shows that it (like SA) also is one of the driving forces behind the rebound of Asian productivity. In fact, the rate of growth of TFP for China for most of the entire period and the rate of growth in the most recent period are nothing short of remarkable. Between 1985 and 2000, there was no five year period in which China's TFP growth fell below 2 percent annually. Between 2000 and 2004 TFP grew at a rate above 5 percent. While extremely high, in fact, these rates are most consistent with those estimated by Jin et al. (2007) which shows (with a completely different set of data) that TFP rates of cropping and livestock are high by international standards and growing over time.

The performance of China's productivity, like that of SA and Asia as whole, are driven by TC—and hurt by TEC and SEC (Table 4, Section F). Indeed, during the entire study period TC rose by 3.209 percent annually. As shown in Jin et al. (2002) most of this growth can be accounted for by investments into R&D. The analysis of China's agricultural economy over the entire reform period, described in Huang, Otsuka and Rozelle (2007), is able to explain why it is that TEC and SEC falls. Problems with the extension system, disequilibrium from rapid change and the relatively rigid tenure system (as well as pure demographics) have kept farms in China relatively small and inefficient.

While not as spectacular as China, the record of CA nonetheless is a positive one (Table 4, Section G). During the entire period (1992 to 2004 for CA—due to absence of data in earlier periods) the growth rate of TFP reached 1.344 percent. Between 2000 and 2005 TFP rose by a rate of 1.806 percent almost as fast as Asia as a whole for the study period. This area, which is sometimes thought to be an underperformer (Swinnen and Rozelle, 2006), in fact, has not performed that poorly in terms of TFP growth. Like Asia as a whole (and China), shifts in TC are fully responsible for the growth in TFP. TEC and SEC (especially) detracted from TFP growth.

Examining Transition Countries in More Detail

When breaking down the transition countries in more detail, it actually is possible to see that overall they have contributed a lot to the growth of Asia's TFP during the study period (Table 5, Section A). When taking all countries in aggregate, it is clear to see that the record of them is an important part of the Asian experience. Overall TFP growth was 2.419 percent for the whole study period and rising over time. Most of the growth was due to TC, and TEC and SEC were negative. These trends suggest that the former Socialist nations and the leaders of their Transition governments may have been able to maintain TFP growth mostly through their investments into agricultural R&D or other initiatives to promote technology. At the same time, transition, even a decade or two or after the end of transition may be dragging down TFP growth due to continued disequilibrium (which is inherent in many transition phenomenon).

Table 5: Weighted Average Growth Rates of the TE Scores and MPI Change Decomposition by Transition Countries after the Start of Their Market Reform (in %)

Transition Country	Periods	TEC	TC	SEC	TFP Growth
A) All	1980-1985	-0.737	2.015	-0.438	0.840
	1985-1990	0.622	2.568	-0.818	2.372
	1990-1995	-0.304	3.058	-0.411	2.344
	1995-2000	-1.552	3.520	0.097	2.065
	2000-2004	1.252	3.916	-0.179	4.989
	1980-2004	-0.202	2.978	-0.357	2.419
B) China	1980-1985	-0.895	2.205	-0.440	0.871
	1985-1990	0.679	2.751	-0.883	2.547
	1990-1995	-0.437	3.302	-0.409	2.456
	1995-2000	-1.696	3.791	0.202	2.297
	2000-2004	1.435	4.191	-0.237	5.388
	1980-2004	-0.250	3.209	-0.358	2.600
C) Mongolia	1991-1995	-1.365	3.456	1.777	3.868
	1995-2000	-3.401	4.105	3.102	3.806
	2000-2004	6.232	4.489	-7.315	3.406
	1991-2004	0.078	3.983	-0.347	3.714
D) Vietnam	1986-1990	-1.301	-0.346	-0.143	-1.790
	1990-1995	1.797	-0.101	-1.112	0.583
	1995-2000	0.358	0.153	-1.452	-0.941
	2000-2004	-1.364	0.616	-0.100	-0.848
	1986-2004	-0.062	0.052	-0.734	-0.744
E) Laos	1986-1990	-0.267	-0.032	0.950	0.651
	1990-1995	0.043	0.438	0.935	1.417
	1995-2000	-5.314	0.805	-0.218	-4.728
	2000-2004	0.653	1.059	0.500	2.212
	1986-2004	-1.320	0.542	0.544	-0.234
F) Myanmar	1989-1992	0.275	1.085	-0.153	1.207
	1992-1996	-1.577	1.472	-0.026	-0.131
	1996-2000	-0.372	1.848	0.442	1.917
	2000-2004	1.705	2.410	1.917	6.033
	1989-2004	0.008	1.704	0.545	2.256
G) Kazakhstan	1992-1996	2.977	2.990	-1.297	4.669
	1996-2000	-2.746	3.412	-3.423	-2.757
	2000-2004	0.444	3.833	-0.346	3.932
	1980-2004	0.225	3.412	-1.689	1.948
H) Kyrgyzstan	1992-1996	-0.007	0.247	-0.124	0.117
	1996-2000	-1.621	0.477	0.109	-1.034
	2000-2004	0.969	1.036	-3.045	-1.040
	1980-2004	-0.219	0.587	-1.020	-0.653
I) Tajikistan	1992-1996	0.290	-0.139	-1.469	-1.318
	1996-2000	-1.764	0.323	-0.705	-2.146
	2000-2004	3.027	0.512	2.978	6.518

	1980-2004	0.517	0.232	0.268	1.018
J) Turkmenistan	1992-1996	0.556	1.063	0.150	1.768
	1996-2000	-1.497	1.469	0.110	0.082
	2000-2004	1.149	2.055	1.801	5.004
	1980-2004	0.069	1.529	0.687	2.285
K) Uzbekistan	1992-1996	0.098	0.830	0.278	1.206
	1996-2000	-0.250	1.173	0.094	1.017
	2000-2004	-2.698	1.642	-0.006	-1.062
	1980-2004	-0.950	1.215	0.122	0.387

Because of the danger that the China's record (Table 5, Section B) dominates the findings when aggregating the region as a whole, we also can examine the other 9 transition economies. When doing so we find that there are sharp differences among them. Excluding China, in the case of 5 of them (Mongolia—section C; Myanmar—section F; Kazakhstan—section G; Tajikistan—section I; and Turkmenistan—section J), there was positive TFP growth above 1 percent. In fact, four of them had rates of growth that were more (or close) to 2 percent annually. Interestingly, in all cases in which the transition nation's experienced positive TFP growth, the rate of growth of TC was positive. In all of these countries, TEC was also positive. Therefore, the negative disequilibrium effect found for China may not have been due to transition, but rather a function of its extremely fast growth rates. All of the countries with positive TFP growth which also had a positive contribution of TEC during the 2000-2004 period, actually experienced negative TEC in an earlier period. What these results suggest is that the disequilibrium of transition which detracted from growth in earlier period was a temporary phenomenon and now growth from TEC is positive.

There were, however, four nations (Vietnam—Section D; Laos—Section E; Kyrgyzstan—Section H; Uzbekistan—Section K) that had either negative or small positive TFP growth rates (Table 5). It is difficult—and beyond the scope of this paper—to determine why some of these countries had TFP growth rates of rose while those of others did not. Swinnen and Rozelle (2006) state that in no large part differences in the performance of the transition countries, in general (including those inside and outside of Asia) are due to differences in pricing, land rights and marketing policies. If this were the case in our sample, it would then lead to the further question about why it is that different countries adopted different policy regimes. Such questions need to be answered in further research.

Conclusions

With nearly half of the potential agricultural resources, Asia has the potential to supply an increase in world food demand. More than half of the population in Asia is living in the rural area where agricultural products are the main source of food supply and income of rural households. It has been recognized that during the past two decades, many countries in this continent have undergone a transformation from the CPE to a market-oriented economy. Understanding the magnitude and direction of TFP growth as well as

what sources attributing to TFP growth is important because they provide useful information to policy makers that want to design suitable policies to maintain or achieve greater rates of TFP growth in these countries.

To meet this purpose, this study employs a parametric output distance function approach to construct and decompose TFP growth into three of the sources of productivity growth: TC, TEC and SEC. This model is empirically implemented using the most recent FAO data set of 27 Asian countries over the period from 1980-2004. Our major finding indicates that Asian countries on average achieved TFP growth at nearly 2 percent per annum, which is typically considered as a sign that agriculture is healthy in terms of its improvement in productivity. The decomposition of TFP showed convincingly that the relatively high rate of TFP growth was mainly driven by technology improvement. TFP growth rate over the past two decades would have been even higher if TEC had not declined or SEC not deteriorated.

Focusing on the transition economies, there were large differences among the transition countries in terms of the magnitude and direction of TFP growth during the transition process. Market reforms have contributed to the progress achieved to date in most countries in CA, China, Mongolia and Myanmar. Transition countries such as China, Vietnam, Mongolia, Kazakhstan and Kyrgyzstan showed that the impact by adjusting the farm size under the current land allocation system and the thin land rental market did not guarantee the healthy economy through the scale of economy, but through the improvement of technology or the more efficient use of input factors.

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บทความสำหรับการเผยแพร่

วิกฤติด้านอาหารของโลกได้กลายเป็นประเด็นเชิงนโยบายที่สำคัญของรัฐบาลในหลายๆ ประเทศ เป็นที่แน่ชัดว่าในแต่ละภูมิภาคของโลกจำเป็นต้องเร่งทำการผลิตสินค้าเกษตรให้ได้อย่างเพียงพอเพื่อที่จะสามารถรองรับต่อความต้องการด้านอาหารที่เติบโตสูงขึ้น เอเชียเป็นทวีปที่มีขนาดใหญ่และมีประชากรมากที่สุดของโลก เอเชียจึงถือได้ว่าเป็นทวีปหนึ่งที่มีศักยภาพในการผลิตสินค้าทางการเกษตรที่จะเป็นส่วนแบ่งที่สำคัญของโลกเพื่อที่จะสามารถรองรับต่อการเติบโตทางด้านอุปสงค์อาหารที่เพิ่มขึ้นอย่างมากในศตวรรษนี้

ในระหว่างสองทศวรรษที่ผ่านมา เอเชียประสบผลสำเร็จอย่างมากในการผลิตสินค้าเกษตร หลังจากการปฏิวัติเขียวที่เริ่มต้นในช่วงปลายทศวรรษ 1960 ผลสำเร็จที่เกิดขึ้นสืบเนื่องมาจากการใช้เมล็ดพันธุ์พืชที่มีคุณภาพให้ผลผลิตสูง การใช้ปุ๋ยเคมีและสารกำจัดศัตรูพืชในกระบวนการผลิต รวมถึงการพัฒนาระบบชลประทาน การที่จะรักษาการเติบโตทางการผลิตด้านการเกษตรให้มีความยั่งยืนได้นั้นจะไม่สามารถให้ความสำคัญในเรื่องการเติบโตของปัจจัยการผลิตได้เพียงอย่างเดียว แต่จะต้องคำนึงถึงการเพิ่มผลผลิตทางการเกษตรด้วย การเติบโตผลผลิตทางการเกษตรจะเกิดขึ้นได้เป็นผลเนื่องมาจากความก้าวหน้าของเทคโนโลยีสมัยใหม่ การใช้ทรัพยากรในกระบวนการผลิตอย่างมีประสิทธิภาพ รวมถึงการเลือกใช้นาของการผลิตให้เป็นไปอย่างเหมาะสมและมีประสิทธิภาพ ดังนั้น การศึกษาเพื่อวัดการเติบโตผลผลิตทางการเกษตร รวมถึงองค์ประกอบต่างๆ ที่ส่งเสริมให้เกิดการเติบโตผลผลิตขึ้นในการผลิตภาคการเกษตรของทวีปเอเชียจึงเป็นหัวข้อที่นักวิจัยให้ความสำคัญ เนื่องจากค่าการเติบโตผลผลิตที่วัดได้จะเป็นข้อมูลที่มีประโยชน์แก่ผู้กำหนดนโยบายในการนำไปใช้เพื่อวางแผนเชิงนโยบายที่เหมาะสมในการส่งเสริมให้เกิดการเพิ่มผลผลิตภาคการเกษตรของภูมิภาคนี้ต่อไป

เพื่อให้เข้าใจถึงผลการดำเนินการทางการเกษตรของประเทศต่างๆ ในทวีปเอเชีย งานวิจัยนี้ได้ศึกษาเพื่อวัดและเปรียบเทียบค่าการเติบโตผลผลิตปัจจัยการผลิตรวมทางการเกษตรของประเทศต่างๆ ในทวีปเอเชีย โดยอาศัยฐานข้อมูลการผลิตทางการเกษตรของประเทศต่างๆ ในทวีปเอเชีย จำนวน 27 ประเทศขององค์กรอาหารและการเกษตรของสหประชาชาติ ระหว่างปี ค.ศ. 1980-2004 ผลการศึกษาแสดงให้เห็นว่า ค่าเฉลี่ยการเติบโตผลผลิตปัจจัยการผลิตรวมทางการเกษตรในทวีปเอเชีย มีค่าเท่ากับ 2 เปอร์เซ็นต์ต่อปี ระหว่างปี ค.ศ. 1980-2004 ปัจจัยหลักที่ส่งผลต่อการเติบโตผลผลิตทางการเกษตร คือ การเปลี่ยนแปลงเทคโนโลยี นั้นแสดงว่า ประเทศต่างๆ ได้มีการนำเอาเทคโนโลยีใหม่ๆ มาใช้ในกระบวนการผลิตเพื่อส่งเสริมให้เกิดการเติบโตผลผลิตทางการเกษตรขึ้นในภูมิภาค ผลการศึกษายังแสดงให้เห็นว่าค่าการเติบโตผลผลิตปัจจัยการผลิตรวมของประเทศต่างๆ ในภูมิภาคเอเชียมีความแตกต่างกันมาก ประเทศที่แสดงค่าการเติบโตผลผลิตปัจจัยการผลิตรวมทางการเกษตรอยู่ในเกณฑ์สูง ได้แก่ ประเทศจีน และมองโกเลีย ในขณะที่ประเทศคาซัคสถาน อุซเบกิสถาน ลาว และเวียดนาม แสดงค่าการเติบโตผลผลิตปัจจัยการผลิตรวมทางการเกษตรอยู่ในเกณฑ์ต่ำ