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The Industrial Revolution in General Equilibrium

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This paper has been prepared for and presented at the Conference Nicholas Crafts @70 held at the University of Warwick, 15 and 16 March. I appreciate helpful comments from participants.

The Industrial Revolution in General Equilibrium

Nick Crafts and I share most our cited paper. Independently in the late seventies (in Nick's case) and the early eighties, we each published reassessments of aspects of the quantitative evidence on British economics growth in the Industrial Revolution that showed slower growth than earlier assessments had indicated. We discussed our work during my sabbatical leave in Oxford in 1982. Our ideas coincided closely and proved complementary. In particular, we both thought in general equilibrium terms and felt that a GE framework was necessary to understand the transformation of the British economy in the late eighteenth and early nineteenth century. In the early nineties, after our work had set off reaction, much apparently critical, we decided that collaboration would be the most effective to present our ideas. The result was "Output Growth and the British Industrial Revolution: a Restatement of the Crafts-Harley View" in the *Economic History Review* in 1992 Crafts and Harley, 1992) and a series of articles over the following decades (Crafts and Harley, 1995; 2004; Harley 2002; Harley and Crafts, 2000).

Our reinterpretation of the quantitative evidence (Fig. 1), despite some initial criticism, has been incorporated (with some improvements) into the consensus view of the industrial revolution (Broadberry et al 2015). It is now generally accepted that income in mid-eighteenth century Britain was considerably higher than had been implied in earlier research. Consequently, current analysis of Britain's emergence into modern economic growth sees a more drawn out process than was presented in traditional views of the Industrial Revolution. In recent years, much of the most important research on Britain's emergence has concentrated on the early modern economy.

In this paper, I want to concentrate on Nick's and my shared view that a general equilibrium/ trade theory perspective is appropriate to understand what was going on between 1750 and 1850 and how this period fit into the emergence of modern economic growth over the long run. Nick and I both started from general equilibrium issues. Nick explored the connection between income growth and per capita agricultural growth (Crafts, 1976; 1985). I was motivated by a desire to understand the demand side of industrial growth (Harley, 1982). We continued to think in general equilibrium terms but this part of our vision has not received the attention that our output estimates have. We largely presented our general equilibrium views in papers that explored computational general equilibrium models of the British economy in an international context. (I was fortunate to have been a colleague of John Whalley and particularly Tom Rutherford, who developed a user-friendly program that I was able to use). These models were benchmarked to input-output relationships for the economy in 1830 (Table 1). Analysis using these models provides quantitative indication of the importance of the impact of various underlying changes in technology and factor supplies. This quantitative method, although indispensable in accounting for multiple sectors and for providing quantitative estimate, does not easily yield intuitive understanding of the economic forces at work. In this paper, I use fairly simple geometric general equilibrium models to provide more intuitive insight even though these conceptional, or teaching, models cannot accurately indicate the quantitative importance of the processes that they represent. In what follows a series of basic diagrams illustrate the general equilibrium processes inherent in Britain's development – both the emergence of modern economic growth and the Industrial Revolution of the late eighteenth and early nineteenth centuries – more intuitively than more complex numerical models alone can do. In this way, they help to focus the narrative on key themes.

As a starting point, it is appropriate to observe that economic growth, industrialization and the classical Industrial Revolution are often discussed as though they were synonyms. This is simplistic and inappropriate. The common confounding of modern economic growth, industrialization and the Industrial Revolution, sees modern economic growth as the product of industrial technology and the growth of the manufacturing sector. In fact, however, there were various connections between growth and industrialization, not all of which reflect causation or economic growth. Thinking in general equilibrium terms using basic diagrammatic tools helps sort out these different relationships.

Figure 2 presents, in diagrammatic form, the common view of the Industrial Revolution – that improved industrial technology lead to industrialization and economic growth. Here, the pre-industrial economy is represented with a production possibility frontier (PPF the solid red line) which delimits the combinations of manufacturing and agricultural goods the economy's resource base and technology can provide. If the economy is allocating resources efficiently and is confined to consuming its own production, market processes will lead to production that maximize the 'utility' (depicted by the family of black indifference curves from the origin). The diagram is presented in per caput form since is the unit appropriate for the 'utility' or welfare measures. The efficient economy will produce the combination of the two goods at point A on the diagram. A market economy generates this allocation through a system of equilibrium prices. The exchange possibilities these prices present are represented by the downward sloping straight line.

In this view of the Industrial Revolution, agriculture is seen as rendered stagnant by constraints of hierarchical relationships of feudal and peasant society. This pre-industrial society is rent asunder by forces of capitalism and innovation in new industrial sectors of the economy.

Thus Industrial Revolution improvement is seen as confined to manufacturing technology while agriculture technology remains stagnant. This shift the production possibility frontier outward, as shown in the broken red line above the original PPF. Since the technological improvement is confined to manufacturing and absent in agriculture, the PPF will not move where it meets the Agriculture axis and all resources are devoted to agricultural output. Technology has an increasing impact as manufactured goods make up an increasing share of output. If the economy is not trading, a new equilibrium will be found at some point like B (indifference curve not drawn to avoid clutter). Here the relative price of manufactured goods will have fallen relative to the price of agricultural goods. If, however, the economy can trade with the rest of the world at the relative price that prevailed before technological improvement in manufacturing particular to this country occurred, there are additional benefits. At these prices, it will pay to shift more resources out of agriculture. The economy will produce at C and trade manufactured goods for agricultural goods at world prices. Consumption (real income) will be at D, higher than at A and also than B.

This view of modern economic growth appears at least implicitly in various places in the economic history literature. It is most explicit in some of Joel Mokyr's work. He used this model centrally his 1976 book *Industrialization in the Low Countries* (Mokyr 1976) where its assumptions may be appropriate for the Belgium case he considers. He has also applied it to the British Industrial Revolution, most explicitly in his 1976 "Growing-up and the Industrial Revolution in Europe." The general view is also apparent elsewhere in his more recent work, including his 1999 editor's introduction to *The British Industrial Revolution: an Economic Perspective* (Mokyr, 1999). He sees the period from the innovations of the 1760s until the 1830s as a period of disequilibrium as the improved manufacturing technology is gradually employed.

Application of new technology required specific physical capital to expand. Mokyr feels capital market failed to finance this expansion and thus capital had to be built up from retained profits. This internal accumulation took protracted time. I would argue, however, that despite its popularity direct application of this model to Britain's growth seriously distorts the historical process. We will see, however, that similar general equilibrium models with modified assumption provide a range of insights into more complex interactions between manufacturing and economic growth in Britain..

Figure 3 provides a relevant starting point of discussion using these models to explore the interaction between economic activity and population growth. This figure can, perhaps, be labelled "pre-modern economy in a single picture." In pre-modern economies, population size was the primary driver of the level of economic welfare and strongly influence economic structure. Figure 3 illustrates population growth in a land-constrained economy facing sharply diminishing returns to increasing labour on the land. On a per-worker basis, population growth reduces land available, and consequently agricultural output, but does not effect manufacturing productivity (assumed not dependent on land). This shifts the per caput PPF inward along the agricultural axis from the solid red PPF to dashed PPF. In the absence of trading opportunities, output would shift optimally to a point B with lower consumption per caput and higher relative agricultural prices. This would also probably result in a lower degree of industrialization. The diagram, however, has serious shortcomings in this case. A more complete general equilibrium representation generates changes in factor prices with land rent rising relative to wages. This shifts the income distribution in favour of wealthy landowners whose consumption patterns were less concentrated on agricultural production. Consequently, manufacturing output might increase.

This representation more or less corresponds to major historical periods. The High

Middle Ages of the late thirteenth and early fourteenth century experienced high population pressure. The roughly halving of population by the Black Death in the fourteenth century and the persistence of low population in the fifteenth were a case of released population demands and an outward shift of the per caput production possibilities. The resumption of European population growth after 1500 saw resumption of population pressure. For England, the pause in population growth between 1650 and 1750 saw a renewed period of relaxation of the agricultural restraint.

A slightly modified similar model (Figure 4) can illustrate industrialization in a small region trading within a larger economy. If population pressure is local and relative prices in the larger economy with which it trades do not shift, the region can do better than point B by exploiting trading opportunities. In an efficient and flexible market economy that is able to shift resources towards manufacturing (population pressure on land has not reduced productivity) and trade manufactured goods for food will increase welfare. New equilibrium occurs with production at point C. The economy has industrialized. Manufactured goods are exported to purchase agricultural goods. Consumption occurs at point D. This scenario of population pressure induced industrialization describes much of proto-industrialization with putting-out industries that occurred in early modern Europe. Certainly, the small-scale manufacturing of toys and trinkets in the Black Forest and Switzerland fit this case. Similarly, the early concentration on maritime activities and manufacturing in Holland reflected an adaption to poor agricultural resources of this type. In Britain, the shift of textile production to low-wage northern areas from traditional regions in the south of England in the eighteenth century involved, at least in part, such a dynamic. We might consider this industrialization from immiserization; not industrialization causing growth. Of course, this adjustment required responsiveness of factor allocation to relative prices and access to trading opportunities.

Industrialization need not be the source of economic growth but can, instead, be the result of economic growth. It is a commonplace of consumer economics (Engel's Law) that at low levels of income, food is a necessity and manufactured goods, luxuries. Consequently, as incomes increase (with relative prices unchanged), the proportion of income devoted to manufactured goods increases. This is represented in diagrammatically in the left panel of Figure 5. The spacing of the indifference curves indicate that as income increases a proportional increase in food consumption provides a smaller increase in utility than does a similar increase in manufactured goods consumption; a larger proportional increase in food production than of manufactured goods is necessary to produce a given increase in consumer utility. The right panel illustrates that industrialization occurs with productivity in agriculture and manufacturing increase in equal proportions. At a high level of generalization this could be thought of as "the modern economy in a single picture."

Research on the British economy before the Industrial Revolution now convincingly demonstrates that Britain had achieved relatively high levels of income by the mid-eighteenth century. Broadberry et al estimate that real GDP per head grew by about sixty percent between 1650 and 1750. The increase in income was accompanied by impressive levels of industrialization. The Cambridge Group for the History of Population and Social Structure estimates that around 1600 about two-thirds of the male labour force in England was engaged in agriculture and about a fifth was engaged in manufacturing. By the mid-eighteenth century, before the Industrial Revolution, employment in agriculture had fallen to about forty percent of the male population and manufacturing employment had doubled to about the same proportion of the workforce. The exact contributions of increased productivity in various sectors to the increase in income have not yet been reliably calculated. It is, nonetheless, apparent that a

remarkable increase in agricultural productivity, initiating in the Low Countries but spreading to England by the seventeenth century, played a major, and perhaps dominant, role, in the growth of incomes. Between 1600 and 1750, English population increased by some forty percent while the male labour force in agriculture declined by about ten percent. These changes could only have occurred with major increase in agricultural productivity. The nature of this increase in agricultural productivity are increasingly becoming well-documented (Allen and Overton). Industrialization occurring as a response to the relative income elasticity of demand for manufacturing was the dominant force in this early industrialization (Wrigley, 2016). Demand elasticities of this sort, rather than unbalanced technology, appear to be the major driving force in historical industrialization. In the twentieth century, similar forces drove the shift of the economy towards services. Unusual episodes of technological change and responses to changing international trading opportunities, of course, also influenced economic structure, but the income elasticity of demand provided the underlying dynamics for most of modern changes in economic structure.

Export of manufactured goods long influenced the structure of the British economy. By the mid eighteenth century Britain was already an important trading nation exchanging a wide range of manufactured goods for primary product imports. In 1640, Britain's exports already consisted almost entirely of manufactured goods. These were almost all woollen textiles sold to continental Europe. In return, as Ralph Davis (1954, 150) noted, "[i]mports [were], in the main, of those textile products from North-west Europe which have always been complained of as unnecessary, frivolous and worthless; of luxury foodstuffs such as wine and fruits from Spain, Portugal and the Mediterranean; and of raw materials for the textile industries from the Mediterranean, and for the metallurgical, building and shipbuilding industries from the northern

countries." By the mid-eighteenth century the pattern had changed significantly. Exports remained manufactured goods and woollen textiles remained the largest category but they had been joined by a wide range of other manufactured goods. Britain had also become a major entrepôt for goods from the Far East and the New World. New World discoveries drove these developments to a remarkable extent. New World bullion, at least as much as the eastward voyages of discovery, drove the expansion of European Asiatic trade in which Britain played an increasing role in the seventeenth and eighteenth centuries. Sugar cultivation on slave plantations in the West Indies created a new mass consumption import. Fish from the Grand and Georges Banks and tobacco from the Chesapeake also became trading staples for English merchants. The staple colonies of the West Indies and the southern North American mainland were joined by the northern mainland colonies and population grew rapidly in all. Population growth in the mainland colonies stimulated most of the eighteenth century expansion of British non-woollen manufacturing exports, which went overwhelmingly to North American markets. The Americans took nearly two-thirds of these new manufactured exports – nearly three times the amount sold in Europe. The mainland colonists financed these imports with the staple trades in the south, and in the northern mainland colonies, by providing shipping and commercial services to the British Atlantic Empire.

Within the context of the trade diagrams I am exploring here, the New World resources, settlement to exploit them and the intra-Imperial trade should be seen as an outward shift in the rest of the world's offer curve facing Britain. The result was an improvement in Britain's terms of trade arising from cheaper (and new) imports and rising demand for manufactured exports. Figure 6 illustrates the opportunities for trade from discovery and imperial expansion further increasing British industrialization in the eighteenth century.

The general evolution of the British economy from the eighteenth into the twenty-first century followed the path of broadly-based technological improvement that became apparent in the eighteenth century with the structure of the economy shifting primarily in response to the income elasticity of demand. This overall path was, however, deflected by exceptional episodes of technological change and changing conditions of international trade. Of course the textile innovations of the Industrial Revolution in the late seventeenth century shifted the British production possibility curve in the manner illustrated in Figure 2. With lowered cost of production, resources were drawn to textiles and exports increased. However, the expansion of foreign sales were not driven directly by improved technology facing unchanged international prices but by sharply lower prices. Figure 2 assumes that the country in question's increased production was too small to shift the international and domestic price of the good where productivity advance occurred. This was, of course, not the case with the revolution in British textile production. The price of cotton cloth fell rapidly in the decades following the invention of the water-frame. By the late 1820s, the relative price of a standard piece of calico printing cloth had fallen to about a fifth of its price in the early 1780s. Prices of British exports relative to imports continued to fall until mid-century. Overall, Albert Imlah' s calculations of British barter terms of trade show a decline of nearly half 1800 to 1850. Britain's productivity advance causes a fall in the price of its export good. The country became more industrialized as increasing quantities of textiles were produced for both domestic consumption and for export. However, it is not widely realized that the effect on real national income (as indicated by the utility function of the representative consumer) was more ambiguous.

Figure 7 modifies Figure 2 in two important ways that reflect the reality of the Industrial Revolution. First, the country was a substantial exporter of manufactured goods before the

productivity advance. Second, the productivity advance, increased production and competition among firms within Britain substantially lowered the international terms of trade for the manufactured good. The pre-Industrial Revolution economy is represented by the solid red PPF with production at point A and consumption after trade at point B. Technological change in manufacturing moved the PPF as in Figure 2 to the dashed red line. If as in Figure 2, terms of trade had not changed (i.e., the black dashed price line) production would have moved strongly towards manufacturing, there would have been very substantial trade of manufactured goods for agricultural goods and a large increase in real income (represented by the dotted indifference curve). However, in the Industrial Revolution, the increase in British textile production was large relative to existing world demand. Sale of the increased output required a sharp fall in the relative price of textiles. Thus the price line pivots clockwise; equilibrium production occurs at point C; and textiles are traded for agricultural goods to result in consumption at point D. In this representation, industrialization has increased considerably but much less than would have occurred if relative prices had not shifted. Real income increases somewhat but much less than if trade could have continued at old relative prices. Looking at the diagram (blue relative price line in Figure 5a) it is evident that it is even feasible that the technical advance in the textile export industry could have left the representative consumer worse off than before (immiserizing growth) (Crafts 1985, 148-51). This outcome is possible because Britain was a substantial exporter of textiles prior to the textile inventions and one effect of the inventions was to lower the foreign goods that these exports could command.

Because Britain became the dominant supplier of textile, the level of British output affected world prices, This implies that the Corn Laws, as Deirdre McCloskey noted in 1980, somewhat complicated this picture because in this situation issues of optimum tariff apply. By

restricting imports the Corn Laws also restricted exports through the balance of payments mechanism. Since Britain's exports were concentrated in the new industries in which new technology had made British producers the dominant – and sometimes nearly sole – supplier world-wide, restriction of British exports restricted international supply enough that international prices rose relative to what they would have been in the absence of the Corn Laws. Consequently, Britain may have benefited from Corn Laws as a means of exploiting the international dominance (monopoly) of its new industries. The repeal of the Corn Laws may have been an act of "Magnanimous Albion" that increased the textile supply to the rest of the world and reduced the price of the British manufactured goods to their benefit. This effect is not, however, guaranteed. Britain still exported a considerable quantity of goods in which it was not the dominant supplier and the fall of exports from the restrictions of the Corn Laws probably fell mainly on potential exports of these goods, largely negating a favourable shift in the terms of trade.[i]

Narratives of the Industrial Revolution often note that Britain practically "monopolized" global production of textiles and iron that the new technologies transformed in the last quarter of the eighteenth century. These narratives at least imply that the concentration of these industries in Britain and the vast exports of their products contributed significantly to the growth of the well-being of British consumers. However, putting aside the optimal tariff issues just discussed, when the price changes in internationally traded goods is considered it becomes apparent that the gains to British consumers from the concentration of textile production and textile exports in Britain were likely very modest. The analysis here can be illustrated by Figure 8 where both Britain and its trading partner, "the rest of the world," are represented. The picture has been drawn with textiles on the y-axis. Value added in textile production never constituted more than about fifteen percent of British national income but dominated exports and particularly the technologically-induced growth of new exports. Because of this, the figure is truncated to only the lower right-hand portion of the total production possibility frontier (as indicated by the break on the x-axis and on the PPF). Initially, it is assumed (somewhat historically) that both Britain and the rest of the world faced the same production possibility curve and had similar tastes. Consequently, no trade occurred (this can be relaxed at the cost of some complication). The Industrial Revolution is represented as an outward shift in the British production possibility frontier along the textile axis without a similar shift elsewhere. Consequently, production of textiles became concentrated in Britain, textile production elsewhere was effectively abandoned (except when protected) and British firms exported textiles to the rest of the world.

The production possibility frontiers have been drawn as effectively straight lines in this region since textiles lacked returns to scale, textile production used no important scarce resources

and the sector made up a relatively small portion of the economy. Thus we are accepting the classical economists' characterization that while there were increasing costs to expanding agriculture, manufacturing faced constant costs. In this situation, the technological advance in textiles without trade increases the welfare of the representative British consumer by allowing her to move to a new consumption point on a higher indifference curve by purchasing textiles at a lower price. Trade with rest of the world will expand as a result of lower textile costs and prices in Britain and textile production elsewhere will be abandoned. Thus Britain increases its level of industrialization and textile jobs in the rest of the world disappear. However, the diagram illustrates that the welfare gains from the rest of the world abandoning textile production in favour of importing low-cost British producers accrue entirely to consumers in the rest of the world. The British consumer's consumption is unaffected. Of course, there may have been some scarce resources employed in the expansion of British textile production. Increased textile production undoubtedly contributed to the relative increase in male wages in the north of England relative to wages in the south in the late eighteenth and early nineteenth century. The increase in male wages may, however, been more than compensated by the loss of income to the large numbers of women who had spun previous to the mechanization of spinning. (Humphries and Schneider, 2019).

All these general equilibrium sketches illuminate aspects of the economics of the Industrial Revolution. Probably the most significant contribution of the revised growth figures that we proposed was the insight that eighteenth century Britain was richer and more industrialized than previous estimates had implied. That industrialization had been driven primarily by balanced and persistent technological improvements throughout the economy. In this Smithian growth process, improvements occurred in agriculture, transportation and industry.

This is not the place to enumerate these advances. Clearly, however, they included the adoption of coal in heating for buildings and in industrial processes, mixed farming, improved roads and shipping. Here we see industrialization driven by consumption income elasticities as illustrated in Figure 5.

Trade also drove industrialization and this trade induced industrialization predated the Industrial Revolution. In the first instance this involved the growth of textile exports to continental Europe from Tudor times. This was reinforced by opportunities arising from the Age of Discovery. The development of the silver mines in the Americas proved a major driving force in expansion of trade to Asia with Britain obtaining specie by selling textiles to Spain and tapping into Low Country trading patterns within the Spanish Empire. Industrial production increased in response to the triangle trade in slaves and sugar. Ultimately, more importantly, the rapidly growing mainland colonies inserted themselves into the growing Atlantic economy proved a most important engine of British industrialization and North Americas became the major customers for increasingly diversified manufacturing exports (Harley 2015). Thus we had the forces illustrated in Figure 6 at work.

The two generations spanning the turn eighteenth century into the nineteenth – the conventional Industrial Revolution – saw rapid change. Of course, the technological advances in textiles and in metal production occupy a central place in the narrative but other forces, less obvious, were importantly at play. Most importantly, unprecedentedly rapid population growth affected both the rate of overall economic growth and economic structure. To understand fully what was happening, it is also crucial to appreciate how increasing industrial productivity changed world prices. Figure 9 illustrates the various forces at work during the Industrial Revolution within the framework I have been discussing. First, of course, the increase in

productivity in the famous industries of the Industrial Revolution shifted the production possibility curve up along the manufacturing axis (it is perhaps best to think of this as tradeable manufacturing) as in Figure 2. Equally importance, however, was the two and a quarter-fold increase in population between 1770 and 1840. The population increase, although partially offset by impressive increases in agricultural productivity, shifted the per capita production possibility curve inward along the agricultural axis as in Figure 3. Finally, technological change in the manufacturing industries in the competitive environment of late eighteenth century Britain caused rapid increase in the output of textiles and a concomitant fall in their prices. The major decline in British terms of trade was an important part of the ongoing change. Even between 1815 and 1840, long after the initial technological breakthroughs and initial sharp price declines, the price of cotton textiles, whose output and exports increased more than fivefold, declined by about a half relative to imported goods. This sharp deterioration of the terms of trade dramatically pivoted the trading possibility line as in Figure 7. Furthermore, British cotton textile exports effectively displaced production elsewhere. Expansion of cotton production with the new technology occurred at approximately constant cost (although, of course, continuing technical advance lowered costs over time) in Britain. Consequently, the welfare contribution of expanded production and trade of cotton textiles in Britain approximated the situation in Figure 8. There are clear welfare gains from increased domestic consumption of cotton textiles. Similarly, foreign consumers experienced similar gain. While exports sharply increased the size of the British industry, exports had little welfare benefits to British consumers. In fact, the price declines were sufficiently sharp that the newly expanded exports earned insufficient to finance the increased food imports driven by rising population. Consequently, even British industries that had not been transformed by the new technology expanded their exports (Crafts and Harley,

2000).

The simple general equilibrium diagrams discussed here greatly aid intuitive understanding of the general equilibrium factors that belong in narratives of the nature and impact of underlying changes on the British economy before and during the Industrial Revolution. Diagrams, however, are poor indicators of quantitative effects since they are drawn to highlight the nature of the process and do not reflect the quantitative importance of the sector and changes involved. In addition, they are limited to the two dimensions of the page. These problems are at least partially overcome by numerical representation in a computational general equilibrium framework of the sort that Nick and I implemented in several places.

The first, and perhaps most important contribution, of this numerical representation involves the calculation of a base benchmark of accounts for the economy. In our case, we adopted an 1840 representation of the British economy as our base. We chose this benchmark because we felt that 1840 was the earliest date at which statistical material was abundant and reliable enough to work with. The benchmark social accounting matrix we worked with is presented in Table 1. The table shows the level of detail we were able to achieve, the sizes of various industries and the flows of income and demand.

The benchmark social accounting matrix brings appropriate scale to the representation of the economy and allows us to begin to estimate magnitudes of changes arising from various changes. A benchmark is not enough, however, to permit useful general equilibrium simulations. For this we need indications of the structures of production technologies and consumer preferences. These can be approximated by substitution elasticities with which it is possible to calculate comparative statics relative to the benchmark. Most production elasticities we used were set at 1. These were chosen because factor share of income were generally roughly stable

over the period. This was not appropriate for agriculture where the share of income that accrued to landlords during the period increased as population put pressure on British farming. Consequently, we adopted a lower elasticity of substitution in agriculture production. However, these elasticities were chosen without serious statistical estimation. We did, however, establish that results were not very sensitive to plausible alternative elasticities. We spent more time calibrating demand elasticities but still these are not statistical estimates. We chose a strategy of nested functions as shown in Figure 10. At the highest level, elasticities of substitution between broad consumption categories were relatively low (0.5). The substitutability between components within broad consumption categories increased as the goods enumerated were increasingly homogeneous. For example, we considered domestic and imported temperate agricultural goods as perfect substitutes. Imported and domestic cotton goods were substitutable with an elasticity of 5. The elasticities are presented in Figure 10.

Finally, examination of the impact of the changes in technology required a quantification of the important technological changes of the period. This was done by estimating changing input output coefficients in various industries between 1840 and 1770. Our choices are presented in Table 2.

The value of the CGE framework, in addition to its attachment to actual accounting data for the economy and its ability to consider multidimensional representation of the economy, lies in the fact that numerical results can be investigated for sensitivity to various assumptions. The results of our computational general equilibrium exercises were revealing and we are fairly confident in them. They highlight the importance of factor markets that adjusted to keep marginal products largely in line across the sectors of the economy; the importance of population increase in the changing economic structure acting through international trade; the importance of

paying attention to the changing prices that accompanied technological change and increasing output. Our results, although not, of course, firmly evidence-based provide valuable insight into what we feel were the key forces in Britain's precocious industrialization.

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i Research on the United States antebellum economy where raw cotton made up a large proportion of exports and where U S supply dominated world consumption has also tended to assume that optimal tariff arguments would be relevant. My own research using CGE modelling, however, indicates that this is an inappropriate conclusion (Harley, 1992). I think it likely that similar results hold for Industrial Revolution Britain.

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Tables and Figures

Table 1: Accounting matrix for 1840 benchmark for CGE

BRITAIN	Good (+ production, - purchase):										Factor		
Sector:	Cotton textiles	Other textiles	Metals	Other traded	Non-traded	Agricul-ture	Services	Int'l services	Tropical Raw mat.	Tropical	Labour	Capital	Rent
Cotton textiles	10.3				-2.3				-2.7		-2.1	-3.2	
Other textiles		12.7				-3.4			-0.9		-3.4	-5.0	
Metal			4.2	-0.4							-1.5	-2.3	
Other traded				8.7							-5.2	-3.5	
Non-traded					8.7						-5.2	-3.5	
Agriculture						22.1					-8.8	-4.4	-8.8
Service							41.8				-25.1	-16.7	
Int'l Services								1.2			-0.7	-0.5	
Imports	0.1	0.2	0.2	0.4		7.1			3.6	4.5			
Total final	10.4	12.9	4.4	8.7	6.4	25.8	41.8	1.2	0.0	3.0	-52.1	-39.1	-8.8
Consumption	4.2	10.1	2.9	5.8	6.4	25.8	41.8	0.0	0.0	3.0	-52.1	-39.1	-8.8
Exports	6.2	2.8	1.5	2.9				1.2					
REST OF WORLD													
Sector:													
Cotton textiles	3.4				-0.8				-0.9		-0.7	-1.0	
Other textiles		17.4				-4.7			-1.2		-4.6	-6.9	
Metal			3.7	-0.4							-1.3	-2.0	
Other traded				12.9							-7.7	-5.1	
Non-traded					15.8						-9.5	-6.3	
Agriculture						297.0					-118.8	-59.4	-118.8
Service							214.2				-128.5	-85.7	
Tropical Ag.									22.0		-8.8	-4.4	-8.8
Iimports	6.2	2.8	1.5	2.9				1.2					
Total final	9.6	20.2	5.2	15.4	15.0	292.3	214.2	1.2	19.9		-279.9	-170.9	-127.6
Consumption	9.5	20.0	5.0	15.0	15.0	285.2	214.2	1.2	13.3		-279.9	-170.9	-127.6
Exports	0.1	0.2	0.2	0.4		7.1			3.6	3.0			

Table 2: Model factor inputs 1840 and 1770.

Appendix Table 3: Model Factor inputs 1840 and 1770												
	Britain						Rest of World					
	1840			1770			1840			1770		
	Lab	Cap	Land	Lab	Cap	Land	Lab	Cap	Land	Lab	Cap	Land
Agriculture (Crafts)	0.4	0.2	0.4	0.7	0.35	0.7	0.4	0.2	0.4	0.4	0.2	0.4
Agriculture (Allen)	0.4	0.2	0.4	0.6	0.3	0.6	0.4	0.2	0.4	0.4	0.2	0.4
Cotton Textiles	0.21	0.31		2.40	3.60		0.21	0.31		0.96	1.44	
Other Textiles	0.26	0.40		0.80	1.20		0.26	0.40		0.80	1.20	
Metal Products	0.36	0.54		0.68	1.36		0.36	0.54		0.56	0.84	

Fig 1: British GDP per capita,1700-1870

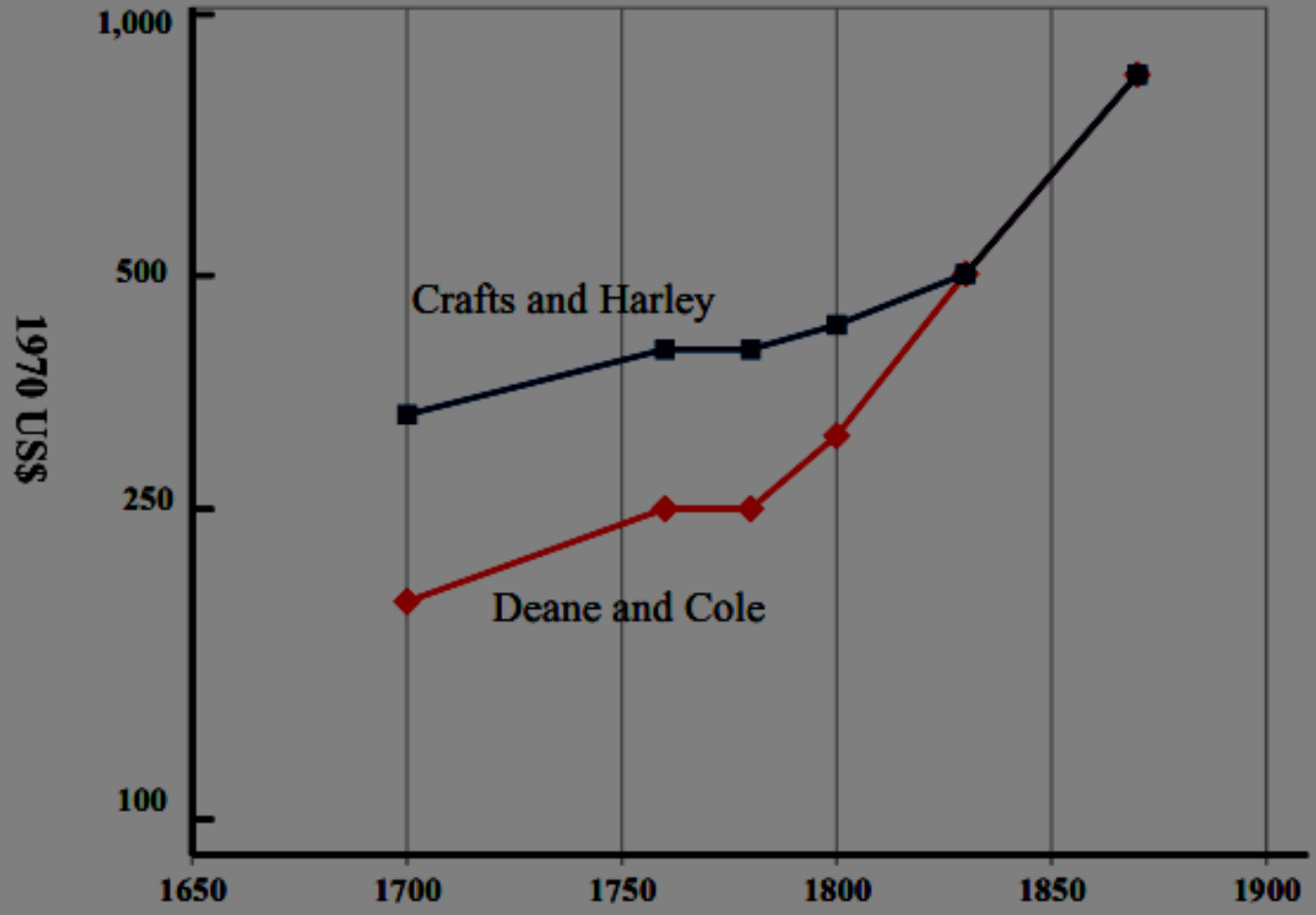

Fig 2: Industrialization & growth: manufacturing technology & trade

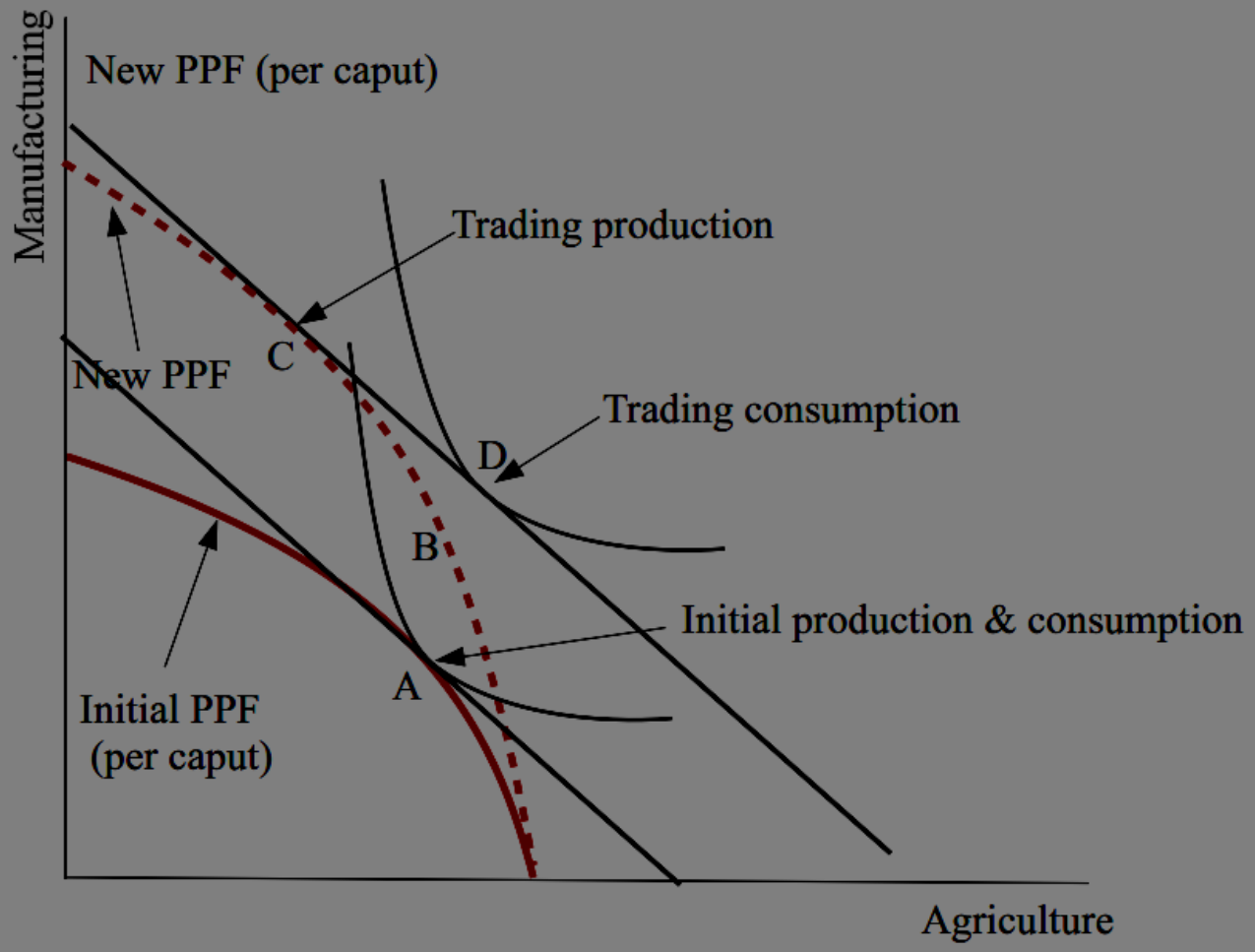

Fig 3: Economic History before Modern Growth in one graph

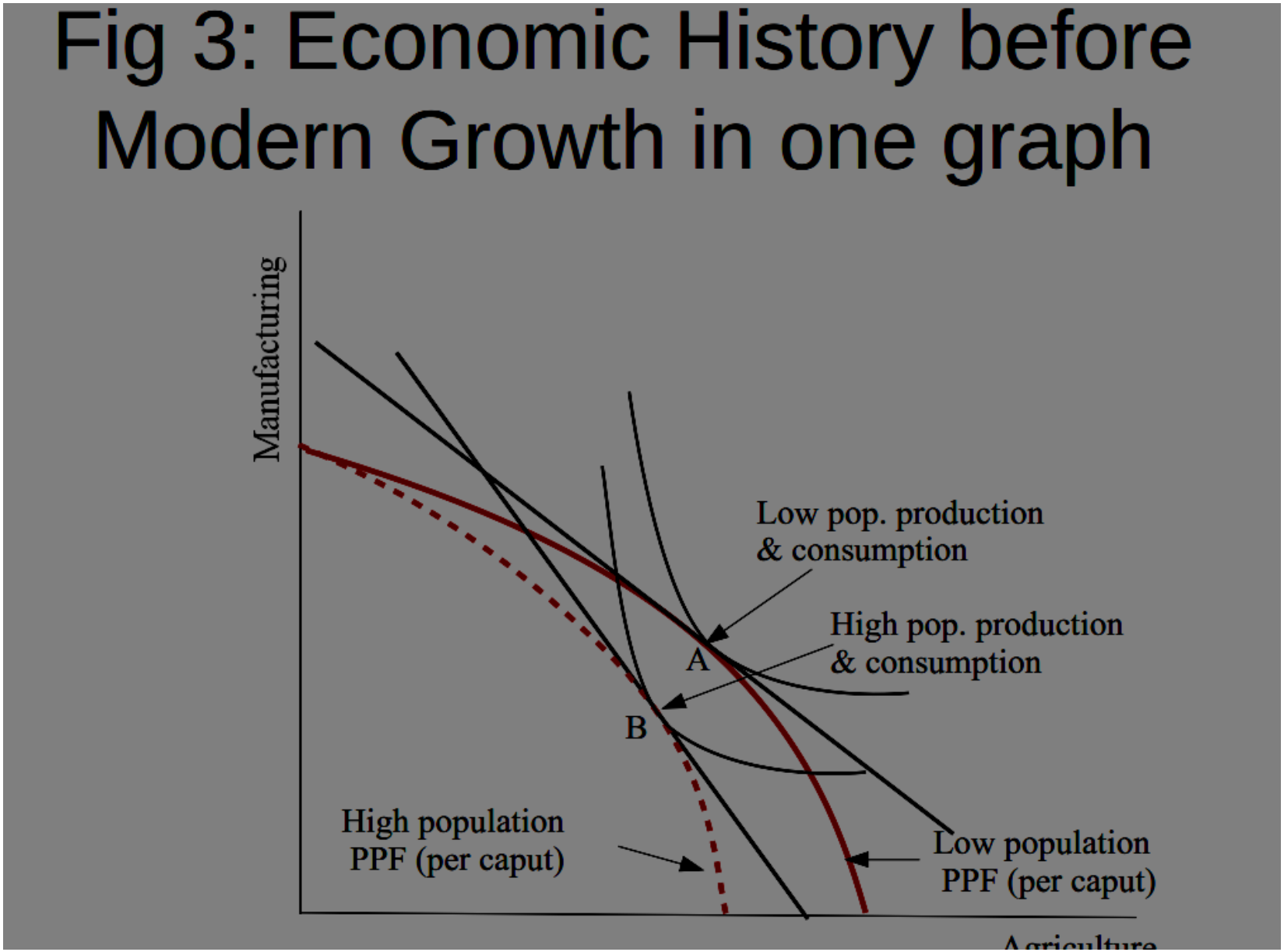

Fig 4: Regional Industrialization: population growth & trade

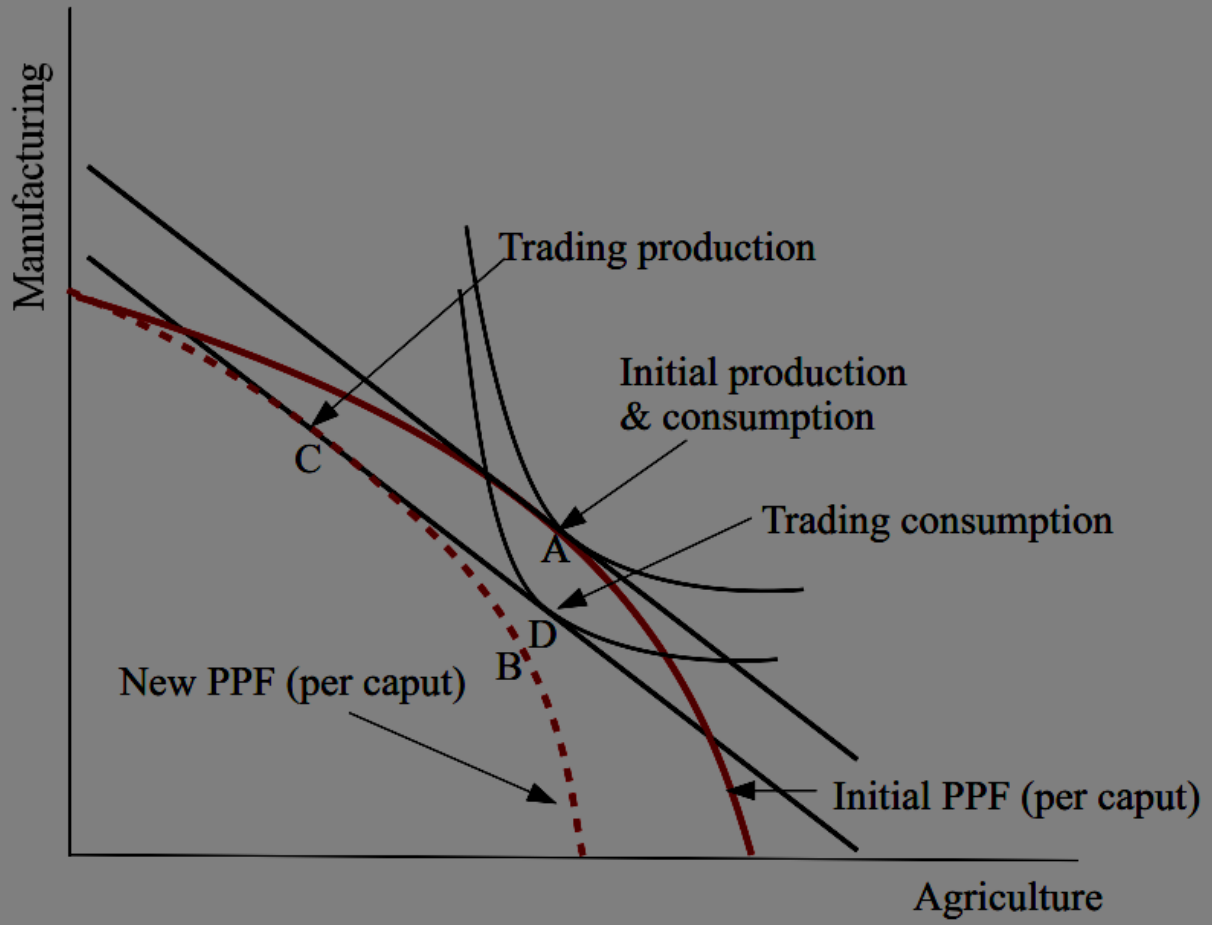

Fig 5: Modern Economic Growth: Engel's law & Industrialization

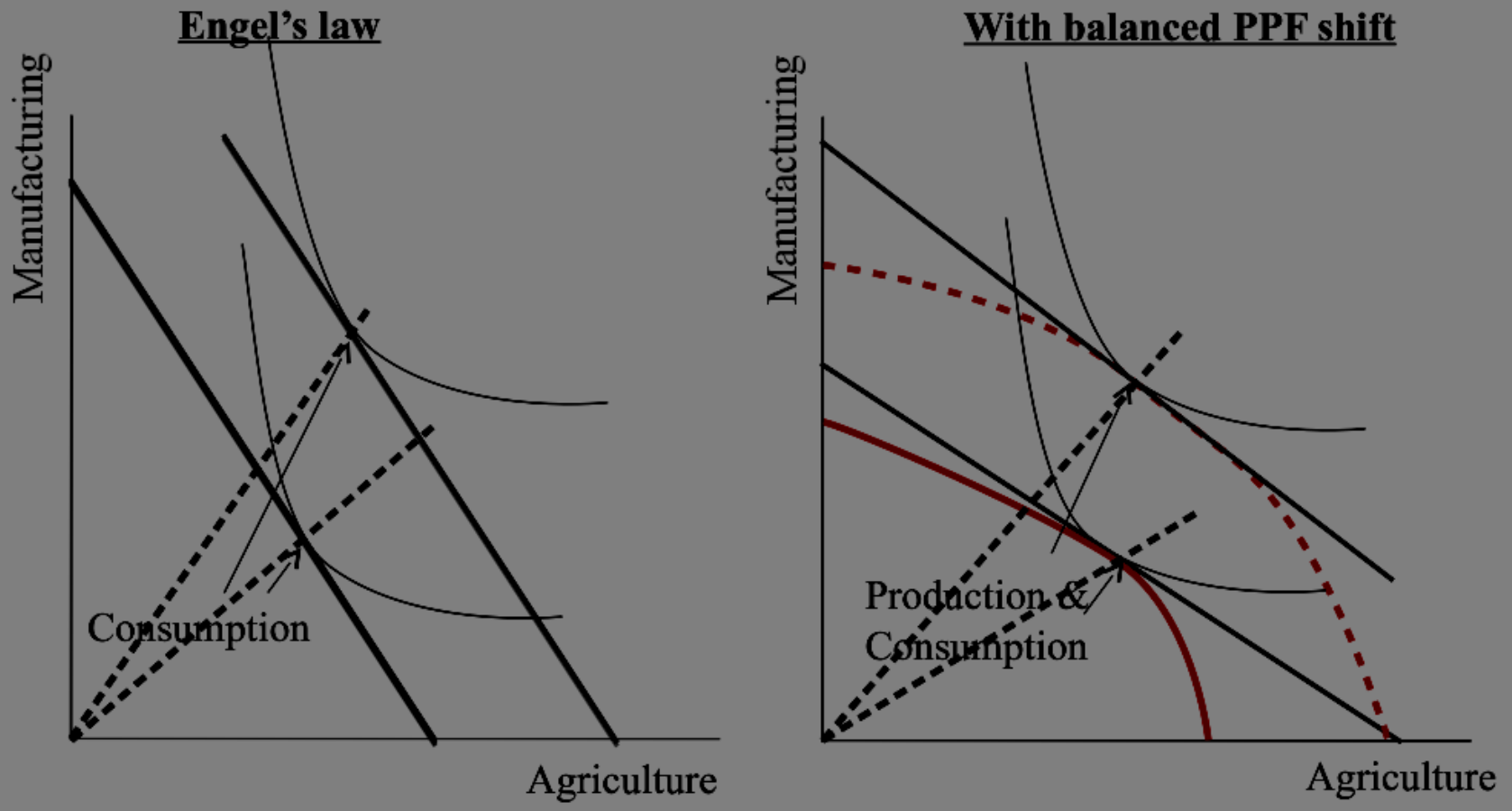

Fig 6:
New World: improved terms of trade

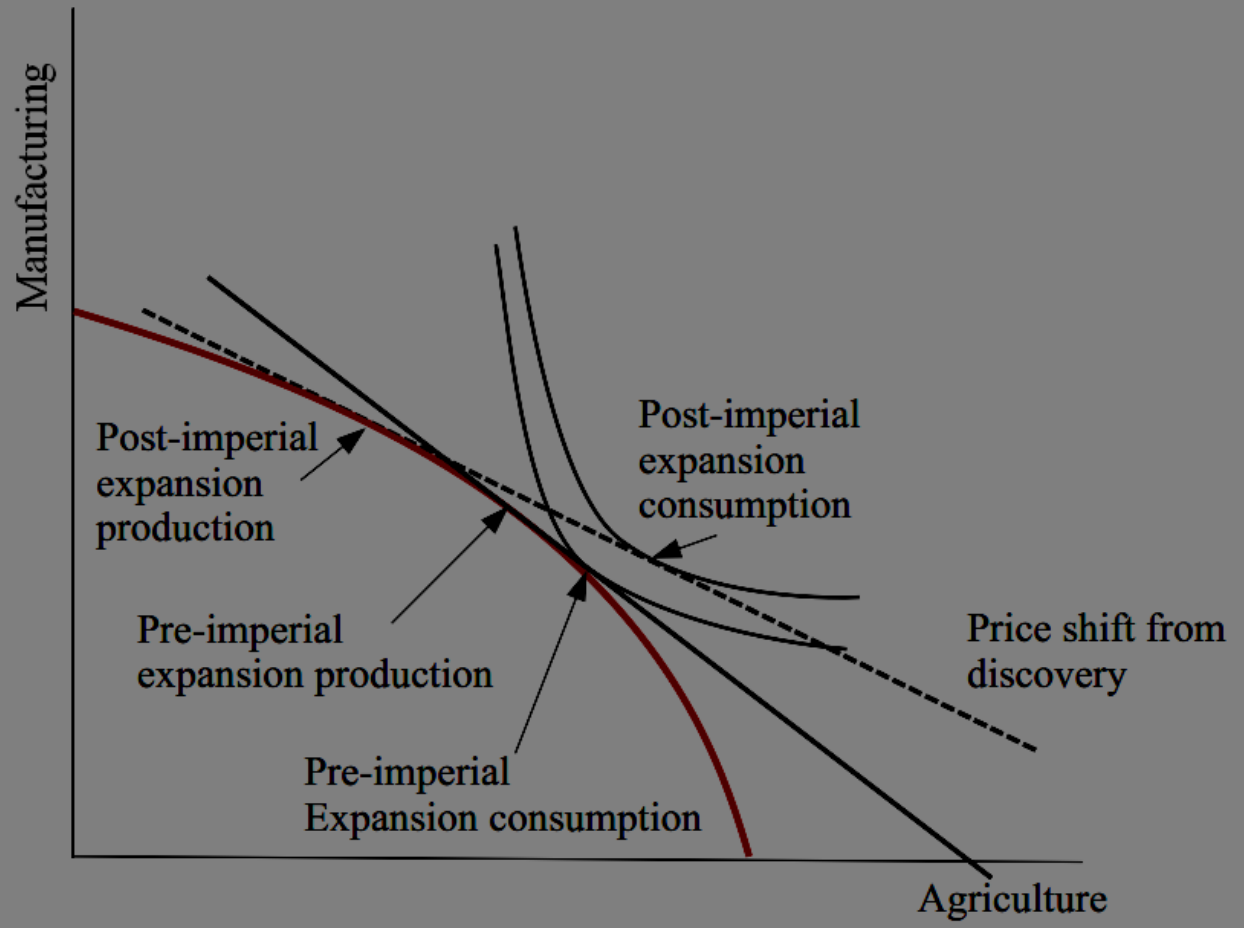

Fig 7: Productivity advance & deterioration of terms of trade

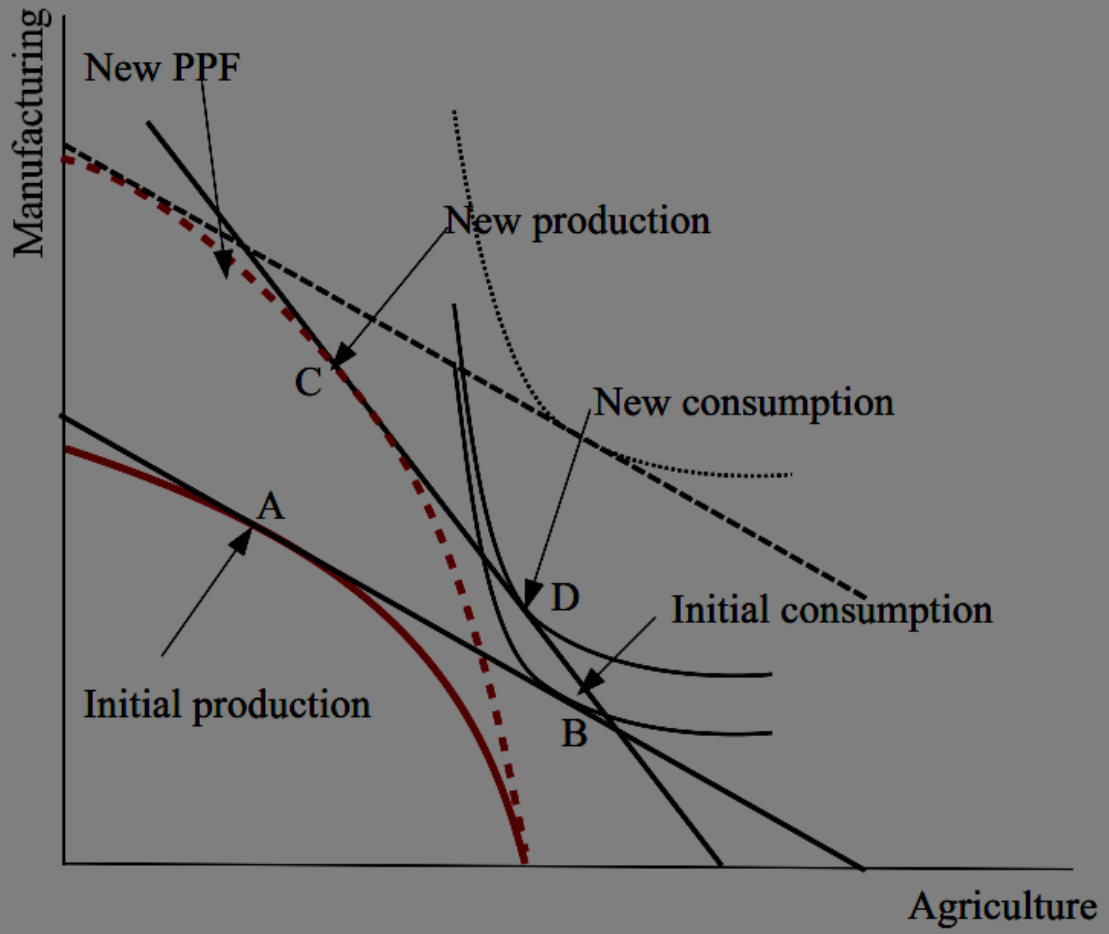

Fig 7a: Productivity advance deterioration of terms of trade

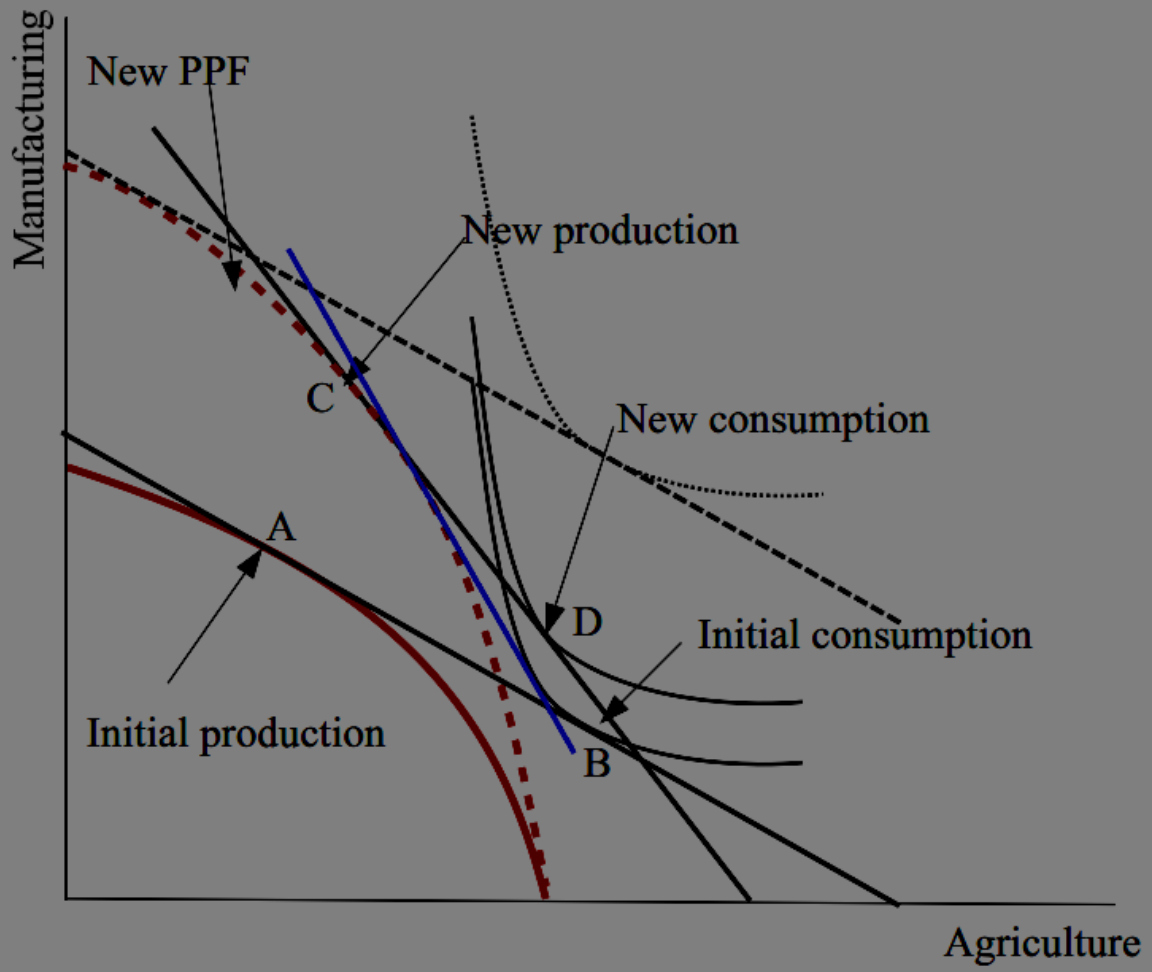

Fig 8: Ricardian trade & gains from IR exports

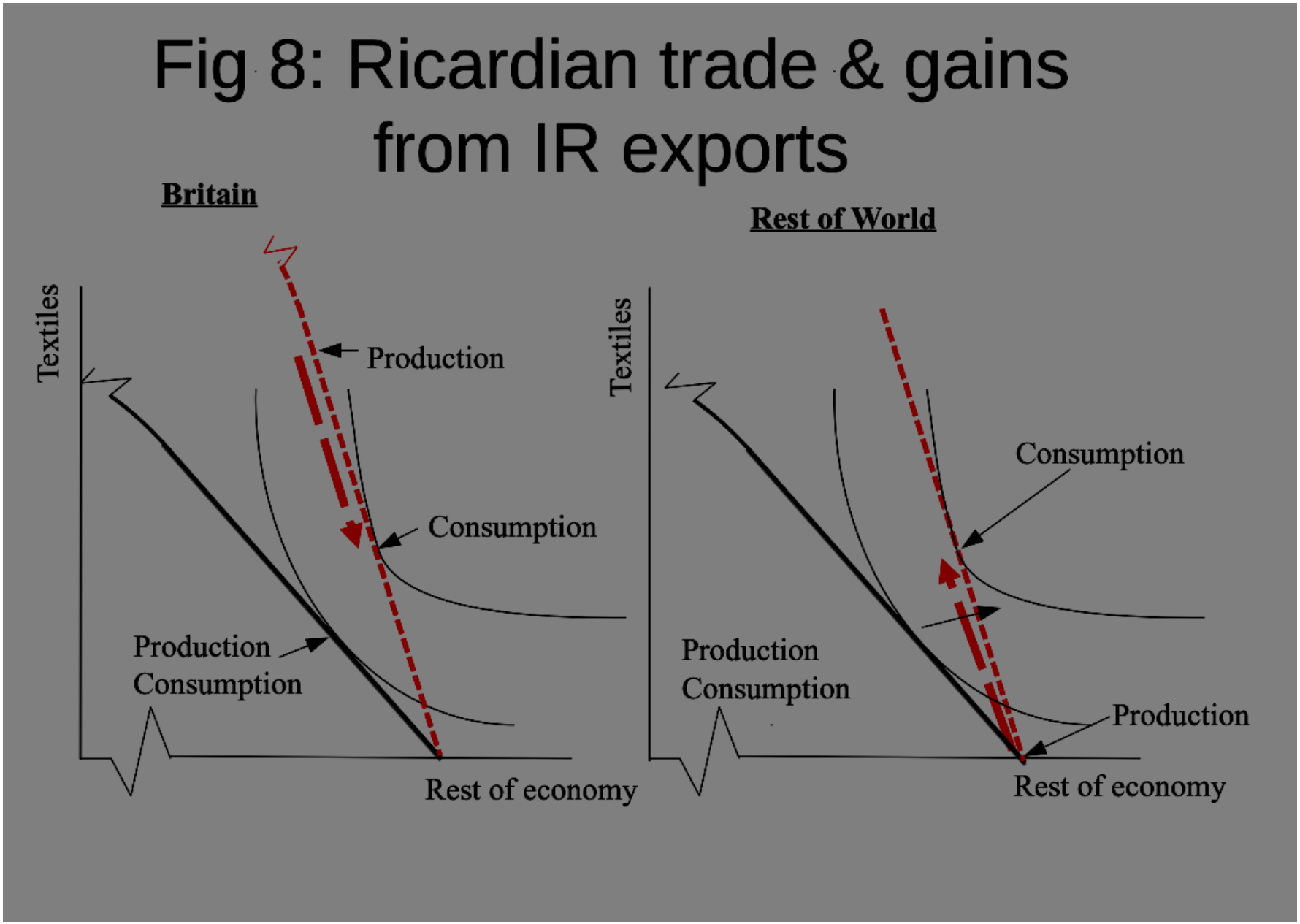

Fig 9: Industrial Revolution

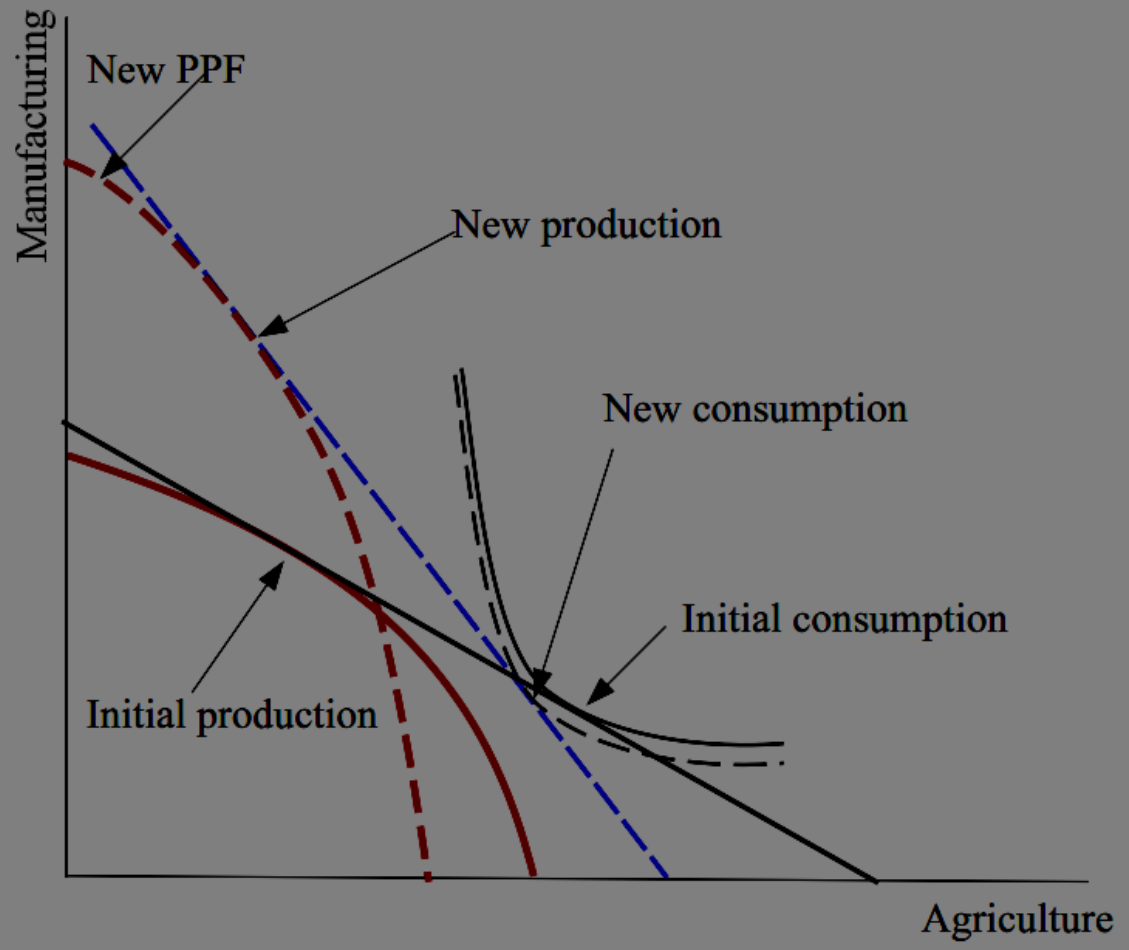

Figure 10: Consumer substitution elasticities for CGE