Emerging Market Winners and Losers in Manufacturing

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Executive summary

What effect will new manufacturing technologies like 3-dimensional (3D) printing have on emerging markets? In preparing this brief, we have found that emerging markets like India will probably see a net positive effect. China will almost certainly lose out during the next wave of manufacturing. It is likely that upper-income, OECD countries – particularly Germany, the U.S., and Japan – will continue producing high-value goods. Because these economies have a strong skilled labor and service-based orientation, they will be able to respond quickly to additive manufacturing. Additive manufacturing, meaning, printing products, will disrupt the old, low-wage, supply-chain-driven approach to cost competition and economic development. Roughly one third of all manufacturing subsectors will undergo radical change as a result of additive manufacturing.

Several implications for the future derive from new manufacturing. It will probably destroy more production than it creates. Printing centers will bring manufacturing to the third world in large amounts. OECD manufacturers (and their peers in emerging markets) will rely primarily on service workers. Manufacturers should adopt small, flexible organizational structures. They should hire good IP lawyers, but they should not expect them to make very much headway. Finally, individuals and companies looking to take advantage of new manufacturing should invest in the petrol and plastics industries.

Introduction

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It is likely that upper-income, OECD countries – particularly Germany, the U.S., and Japan – will continue producing high-value goods. Because these economies have a strong skilled labor and service-based orientation, they will be able to respond quickly to additive manufacturing. Additive manufacturing, meaning printing products, will disrupt the old, low-wage, supply-chain-driven approach to cost competition and economic development. Roughly one third of all manufacturing subsectors will undergo radical change as a result of additive manufacturing.

Several implications for the future derive from new manufacturing. It will probably destroy more production than it creates. Printing centers will bring manufacturing to the third world in large amounts. OECD manufacturers (and their peers in emerging markets) will function as service providers. Manufacturers should adopt small, flexible organizational structures. They should hire good IP lawyers, but they should not expect very much from them. Finally, individuals and companies looking to take advantage of new manufacturing should invest in the petrol and plastics industries.

Industrialization trends

Industrialized Countries

In most developed, industrialized countries, manufacturing (as a percent of GDP) reached its peak in around the 2000s. Figure 1 shows the percentage of GDP of manufacturing exports in selected upper-income and developed economies. Many of these countries, including Australia, Canada, Finland, France, Ireland, and the U.S., reached their peak around the year 2000. In the case of Canada, manufacturing exports as a share of GDP increased from roughly 13% of GDP in 1990 to about 24% by 2005. In Germany's case, manufacturing output as a percentage of GDP remained relative stable, increasing from 21% in 1990 to about 30% by 2005. Ireland represents an extreme case, with manufacturing having started out at a high 35% of GDP in 1990. By 2000, its manufacturing exports consisted of about 68% of GDP. In other cases (Japan and South Korea), manufacturing exports continued to grow as a percentage of GDP until the end of the 2000s. Japanese manufactured exports increased from 9% of GDP in 1990 to about 13% by 2010. In the case of South Korea, manufacturing exports increased steadily over the period – reaching 41% by decade's end.

While manufacturing exports have decreased as a percentage of GDP in many upper-income countries, employment has shrunk. Figure 2 illustrates the annual percentage change in employment in the manufacturing sectors of selected OECD and upper-income countries. The U.S. and the U.K. have lost the most employment in manufacturing with losses of 25% and 30% of the manufacturing sector headcount since 2000.

In general, developed markets have lost out to emerging markets in export-led manufacturing. We now turn to the developing markets.

Emerging Markets

Manufacturing has grown steadily as a percentage of GDP in a number of emerging markets. Figure 3 lists the annual growth rates in manufacturing in a number of emerging markets. In Latin America, for example, manufacturing as a percentage of GDP has remained at less than 10% with the exception of Mexico. Mexico, reflecting its proximity to the U.S., its free trade agreement with the U.S. and its comparatively lower wages, has comparatively specialized in manufacturing. Throughout the later part

Figure 1: Percent of Manufacturing Exports to GDP

	1990	1995	2000	2005	2010
Australia	3%	4%	5%	4%	3%
Austria	22%	21%	28%	33%	32%
Belgium			63%	70%	64%
Canada	13%	20%	24%	18%	12%
Finland	16%	25%	32%	28%	22%
France	13%	15%	20%	17%	16%
Germany	21%	18%	24%	30%	30%
Ireland	35%	47%	68%	46%	46%
Japan	9%	8%	9%	12%	13%
South Korea	24%	24%	29%	31%	41%
United Kingdom	14%	17%	15%	12%	12%
United States	5%	6%	6%	6%	6%

Source: World Bank (2013). * bold shows when reached peak of the 2000s, Mexico's manufacturing output has hovered at around 20% of GDP. These data are significant given Mexico's relatively large GDP. In 2011, Mexico's GDP equaled $1.6 trillion, far higher than Argentina's GDP of $445 billion (although Mexico's GDP was less than Brazil's $2.5 trillion). Mexico's large maquiladoras (firms that produce in Mexico with the express intention of exporting to the U.S.) make up a significant part of this output.

Data on manufacturing in East Asia reveal a deliberate focus on developing manufacturing sectors across the region. Malaysia has the largest (and most variable) manufacturing sector. More than half of all of Malaysia's output in 2011 consisted of manufactured goods (largely auto and electronic goods destined for markets abroad). Cambodia, Thailand, and Vietnam followed closely behind (with manufacturing sectors representing more than 40% of output). China's manufacturing sectors (one of the largest in the world) came in at only about one-quarter of GDP, reflecting the size of the Chinese economy. The two large economies of India and Indonesia have manufacturing sectors that make up less than 10% of their GDP, suggesting a comparative advantage that lies outside the realm of producing goods.

The strengthening of emerging economies in Central and Eastern Europe reveals that Russia has lost its manufacturing potential in the longer term. Hungarian manufacturers produced over 60% of the country's output in 2011. Polish manufacturers consistently produce about one quarter of the country's output. Russian manufacturers, in contrast, produce only about 5% of GDP. This stems in part from the size and complexity of the Russian economy. However, as we will argue later, it also partly stems from the size and structure of the Russian manufacturers themselves.

With the exception of Turkey, emerging markets in the Middle East have not managed to transform their hydro-carbon-based economies into manufacturing ones. Egypt and Saudi Arabia, two of the larger economies in the region, have manufacturing sectors hovering at about 5% of GDP. Turkey has managed to increase its share of manufacturing to about 10% of GDP. In the case of Turkey, much of this manufacturing

Figure 2: Annual Changes in Manufacturing Sector Employment in Developed Markets

	2000	2001	2002	2003	2004	2005	2006	2007	2008
Australia	5%	-3%	2%	-1%	0%	-1%	-1%	2%	1%
Austria				-2%	-6%	2%	5%	-2%	-4%
Canada	3%	-1%	3%	0%	1%	-4%	-4%	-4%	-4%
Canada	5%	-3%	-2%	-1%	-2%	-2%	-1%	-3%	-5%
Finland	1%	2%	-2%	-4%	-2%	1%	1%	1%	-2%
Finland	3%	1%	-2%	-1%	-3%	-1%	-1%	0%	0%
France					-1%	-1%	-1%	-1%	-2%
Germany	0%	1%	-1%	-3%	-1%	-1%	2%	3%	0%
Ireland	0%	3%	-6%	1%	-2%	-2%	-2%	0%	-4%
Italy	0%	0%	1%	1%	-1%	0%	0%	1%	-1%
Japan					-2%	-1%	2%	1%	-2%
United Kingdom	-3%	-3%	-4%	-4%	-7%	0%	-1%	0%	-5%
United States	0%	-5%	-7%	-5%	-1%	-1%	0%	-2%	-3%

Source: ILO (2012).

output stems from maquiladora-type relationships with countries like the Netherlands and Germany. As we shall see later, part of this success is a result of the presence of the many relatively small, flexible manufacturers in Turkey.

Few manufacturers of significant size operate in Sub-Saharan Africa. South Africa houses most of the region's large manufacturers and produces about 10% of the country's GDP. Nigeria, one of the few emerging markets in the region, has not been able to produce more than 5% of GDP in manufactured goods.

The goal of policymakers and industrialists in countries with emerging markets has not been simply to maximize the value of manufactured goods produced in these countries. Figure 4 displays the results of strategies pursued by major manufacturing exporters in

Figure 3: Annual Growth Rates of Manufacturing as a Percent of GDP in Selected Emerging Markets

	2007	2008	2009	2010
Latin America				
Argentina	7%	7%	6%	6%
Brazil	6%	5%	4%	3%
Chile	5%	6%	4%	4%
Colombia	6%	5%	4%	3%
Mexico	19%	20%	20%	22%
East Asia				
Cambodia	46%	40%	46%	48%
China	32%	29%	23%	25%
India	8%	9%	8%	8%
Indonesia	11%	10%	9%	8%
Malaysia	67%	49%	57%	56%
Pakistan	11%	10%	8%	9%
Philippines	29%	24%	20%	22%
Thailand	47%	47%	43%	46%
Vietnam	37%	38%	35%	42%
Central and Eastern Europe				
Hungary	57%	56%	54%	61%
Poland	26%	26%	25%	26%
Russia	5%	5%	4%	4%
Middle East and North Africa				
Egypt	2%	6%	6%	5%
Turkey	14%	15%	13%	12%
Saudi Arabia	5%	4%	4%	6%
Sub-Saharan Africa				
Nigeria	1%	2%	1%	3%
South Africa	11%	14%	9%	10%

Source: World Bank (2012).

Figure 4: Types of Manufactured Goods Exported f

ECONOMY	PRODUCT	ARGENTINA		CHINA		IND
		change	ave	change	ave	change
Argentina	Total manufact			17%		10%
	Low skills			11%	11%	6%
	Medium skill			13%	25%	7%
	High skill			14%	35%	9%
Brazil	Total manufact	21%		21%		13%
	Low skills	10%	3%	13%	10%	8%
	Medium skill	20%	68%	16%	26%	9%
	High skill	15%	21%	17%	40%	11%
China	Total manufact	10%				15%
	Low skills	6%	15%			9%
	Medium skill	6%	6%			10%
	High skill	7%	25%			13%
Germany	Total manufact	11%		29%		19%
	Low skills	4%	1%	19%	12%	11%
	Medium skill	10%	58%	20%	19%	12%
	High skill	8%	21%	24%	39%	13%
India	Total manufact	8%		22%		
	Low skills	5%	19%	13%	9%	
	Medium skill	6%	22%	16%	23%	
	High skill	5%	20%	19%	52%	
Japan	Total manufact	7%		35%		14%
	Low skills	4%	7%	20%	6%	10%
	Medium skill	4%	9%	24%	19%	9%
	High skill	6%	70%	27%	30%	11%
Malaysia	Total manufact	8%		22%		14%
	Low skills	6%	39%	14%	10%	10%
	Medium skill	5%	17%	16%	20%	9%
	High skill	4%	6%	19%	47%	11%
Mexico	Total manufact	13%		21%		12%
	Low skills	7%	7%	11%	7%	8%
	Medium skill	11%	55%	15%	24%	8%
	High skill	10%	28%	17%	43%	9%
Russia	Total manufact	5%		23%		14%
	Low skills	4%	43%	12%	7%	7%
	Medium skill	3%	17%	14%	14%	8%
	High skill	4%	33%	15%	17%	11%
Turkey	Total manufact	6%		19%		14%
	Low skills	4%	12%	12%	13%	9%
	Medium skill	4%	13%	14%	26%	9%
	High skill	5%	57%	15%	31%	11%

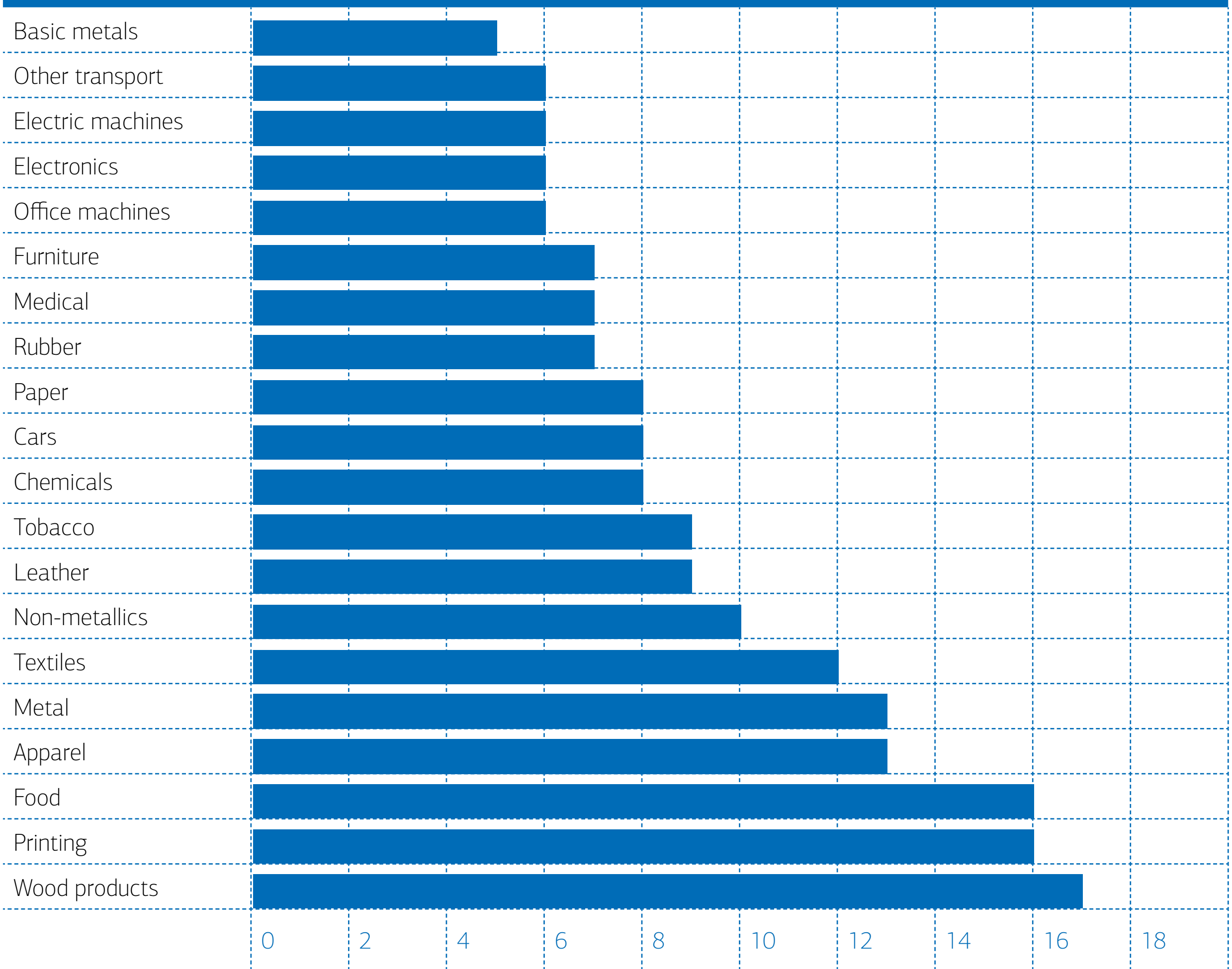
from Selected Emerging Markets to Other Markets

DIA	MALAYSIA		RUSSIA		TURKEY	
ave	change	ave	change	ave	change	ave
	9%		8%		8%	
11%	4%	4%	4%	4%	4%	12%
18%	6%	14%	4%	12%	6%	45%
45%	8%	59%	8%	81%	4%	10%
	12%		13%		9%	
10%	6%	4%	9%	17%	6%	20%
16%	7%	11%	6%	3%	8%	45%
48%	11%	62%	12%	79%	5%	6%
	22%		19%		10%	
14%	10%	3%	13%	28%	8%	38%
11%	14%	13%	12%	15%	6%	18%
49%	20%	77%	16%	47%	7%	20%
	19%		17%		22%	
7%	9%	4%	15%	50%	12%	6%
16%	12%	14%	12%	16%	17%	29%
21%	18%	74%	13%	21%	12%	6%
	16%		17%		9%	
	8%	1%	12%	28%	6%	20%
	10%	10%	11%	14%	7%	31%
	15%	77%	14%	34%	7%	25%
	24%		11%		9%	
20%	10%	2%	10%	70%	4%	4%
13%	15%	12%	4%	1%	6%	26%
25%	22%	69%	7%	14%	5%	8%
			11%		7%	
27%			7%	39%	4%	17%
12%			6%	6%	6%	36%
35%			9%	48%	4%	18%
	15%		10%		8%	
14%	5%	1%	6%	16%	5%	15%
20%	11%	23%	6%	9%	7%	54%
35%	14%	67%	10%	74%	4%	7%
	9%				16%	
14%	4%	6%			8%	6%
10%	6%	12%			12%	28%
35%	8%	67%			10%	15%
	11%		16%			
13%	5%	4%	14%	55%		
17%	7%	13%	8%	4%		
30%	9%	48%	12%	29%		

Figure 4: Types of Manufactured Goods Exported f

ECONOMY	PRODUCT	ARGENTINA change	ARGENTINA ave	CHINA change	CHINA ave	IND change
UK	Total manufact	8%		26%		19%
	Low skills	5%	9%	17%	11%	12%
	Medium skill	6%	19%	19%	20%	13%
	High skill	7%	49%	20%	31%	12%
USA	Total manufact	15%		40%		24%
	Low skills	11%	19%	24%	9%	15%
	Medium skill	10%	18%	28%	18%	15%
	High skill	12%	32%	32%	34%	17%
World	Total manufact	26%		55%		34%
	Low skills	16%	11%	35%	11%	23%
	Medium skill	22%	43%	39%	19%	23%
	High skill	20%	30%	44%	35%	25%

Figure 5: Growth in Value Added of Selected Manufactured Goods in Emerging Markets



Source: UNIDO (2009) as reported in Hepburn (2011).

rom Selected Emerging Markets to Other Markets

DIA	MALAYSIA		RUSSIA		TURKEY	
ave	change	ave	change	ave	change	ave
	18%		13%		19%	
10%	8%	2%	11%	40%	11%	8%
16%	13%	26%	7%	6%	14%	27%
15%	15%	47%	11%	40%	12%	11%
	27%		18%		19%	
12%	11%	1%	15%	39%	12%	15%
12%	17%	13%	10%	8%	13%	20%
20%	25%	71%	15%	43%	12%	12%
	39%		32%		33%	
14%	19%	4%	26%	39%	22%	16%
16%	26%	14%	22%	18%	25%	28%
23%	36%	69%	25%	32%	21%	11%

the 2000s in various emerging markets. During the 2000s, Argentina increased its worldwide, manufactured exports by about 25% and increased its exports of manufactured goods to Brazil by about 20%. In contrast, it increased its exports to East Asian countries by 10% or less. Manufacturers who produced goods requiring low-skill laborers represented the largest proportion of exports to Malaysian and Russian markets. Medium-skill-level manufactures represented the largest proportion of exports to Brazil and Germany. High-skill-level manufactures exported the largest proportion of goods to Japan, Turkey, the U.K., and the U.S.

Trends in selected emerging markets tell us that manufacturers in these countries pursued different strategies in different markets. Argentina grew most quickly in medium-skill manufactured exports (with a 22% annual increase from 2000 to 2010). These medium-skill exports comprised more than low- or high-skill exports, accounting for 43% of manufacturing export. China, in contrast, grew most quickly over the decade in high-skill exports (with a 44% per annum growth rate). These high-skill exports comprised the highest proportion of exports in manufactured goods (representing roughly 35% of total manufacturing exports). India grew by almost the same amount (about 25% per year) with growth spread over different types of manufacturing (low-, medium-, and high-skill manufacturers). The proportion of high-skill manufacturers exceeded other types by only about 7 percentage points). Malaysia's exporters grew their markets the most in high-skill goods (with a growth rate of about 35% worldwide and with high-skill exports comprising almost 70% of exports across all types of skills). Russia, in contrast, grew its low-skill markets the most at a rate of 26%, comprising about 40% of all exports in manufactured goods. Finally, Turkey focused on medium-skill goods with growth rates of about 25%, about 30% of which was in manufactured exports.

These data point to several features of manufacturing (and manufacturers) in the 2000s. First, manufacturers in various emerging markets sought niche markets where they could effectively compete. Argentine and Turkish manufacturers selling their goods in Mexico focused on medium-skill manufactured goods. Russian, Chinese, Malaysian, and Indian companies focused on selling high-skill-level goods in Mexico. If Russian firms tried to sell high-skill-level goods in Mexico, they focused on low skill goods in Turkey. Second, we can deduce from these data that different types of manufacturing companies sold different types of goods in these various markets. Organizational structure generally follows strategy. In general, low-skill manufactured goods can be produced by machines and assembly lines and are more capital-intensive. Higher-skill manufacturers tend to require larger numbers of well-paid staff. If emerging market manufacturing firms fail to adopt the right organizational size (in terms of capital employed and staffing), low returns on capital and labor can hurt their competitiveness.

Manufacturing companies from various emerging markets compete in a range of product types. However, some product types seem more likely to fare well in the future than others. Figure 5 outlines the annual growth rates of the fastest-growing products in emerging markets. As shown, manufacturers specializing in wood products, printing, and food products have had a market-driven advantage in turning man-hours into profits. On the other hand, manufacturers involved in the production of basic metals have experienced much less market demand during the same period.

Strategic investments in related products and sectors can also improve a manufacturer's strategic position. Hausmann and co-authors refer to a country's "product space" as a grouping of products and industries that allows a country to obtain an advantage through manufacturing certain types of goods. For example, in 2008, Thailand's photo camera industry had built competencies that served developing control and peripheral hardware industries – as well as a burgeoning color TV industry. Thailand manufacturers' production of color TVs, in turn, supported the development of a range of silicon-based products. These linkages between sectors allowed Thailand's medium-skill manufacturers to develop products cheaply and gain export markets. As Hausmann and colleagues illustrated for a wide variety of countries, developing related industries and product lines can bolster manufacturers' revenue far more than simply concentrating on their own lines. Manufacturers prosper in the context of local eco-systems.

Measures of industrial diversity can help identify countries in a strong competitive position and those whose manufacturing CEOs need to invest in related product lines. Figure 6 provides an index of diversity that represents an anti-concentration measure of economic production in key emerging markets. More diverse economies receive higher scores in our index. We have compared these scores with Hausmann and colleagues' scores on the complexity of each national economy. In both scoring systems, developed economies like Germany and the U.S. scored relatively well. In our scoring system though, we designed our index to emphasize complexity, particularly in emerging

Figure 6: Two Measures of Economic Diversification in Selected Emerging Markets

Country	Index of diversity	Index of complexity
Emerging markets		
South Africa	2.31	0.109
India	2.13	0.23
Brazil	2.11	0.23
Turkey	1.98	0.419
Malaysia	1.97	0.76
Thailand	1.96	0.814
China	1.93	0.892
Russia	1.92	0.314
Indonesia	1.81	0.03
Argentina	1.80	0.079
Chile	1.40	0.35
Saudi Arabia	0.94	0.214
Mexico	0.01	1.15
Comparator countries		
Germany	1.98	2.01
USA	2.03	1.46

Source: Based on data by Hausmann et al. (2011).

markets. As shown, highly diversified economies like South Africa, India, Brazil, and Turkey have higher scores.

A lack of diversification and investment in related industries can pose significant problems for manufacturers. Figure 6 reveals a relative lack of diversity in Argentine industry. This lack has resulted in an inability to develop broad-based manufacturing competencies that give Argentine manufacturers a comparative advantage over rival firms in other countries. Among Argentina's top 20 products (as ranked by comparative advantage scores), only one manufacturing industry, bovine and equine leather products, made the top 20 list. Argentina's comparative advantages lie in the production of soybean oil, mate, oilcake, green groundnuts, and peanut oil. In contrast, 15 out of 20 of China's top product lines (also as ranked by comparative advantage) are manufactured goods. These include plastic ornaments, plaited products, umbrellas and canes, toys, and traveling rugs and blankets (among other products).

Manufacturers in various emerging markets sought niche markets where they could effectively compete

In many cases, the products that emerging market manufacturers export might not be the products for which they have a comparative advantage. Figure 7 shows the top five products for a range of countries as ranked by their revealed comparative advantage scores. For example, Argentina sent roughly $29 million in manufactured lime abroad in 2008 (the latest year for which we have data). In that same year, Argentine auto manufacturers sent $1.4 billion in trucks and vans abroad despite having a competitive advantage in truck manufacturing that was lower than that of lime product manufacturing. It would be useful to know why Argentine manufacturers produced more of something for which they had less of an advantage. The reason must depend in part on management decisions made by Argentine manufacturing companies themselves.

Individual manufacturers cannot always make lateral investments that help to diversify their entire production base. However, they can work through their local associations and chambers. To continue with the example of Argentina, channeling investments into related industries can be accomplished through organizations like the Chamber of Elastic Fabric Manufacturers, the Argentine Chamber of Manufacturers of Components and Materials for Ready-Made Garments and Leather Goods, and the Argentine Footwear Manufacturer's Association.

Figure 7: Revealed Comparative Advantages of Manufactured Products in Selected Emerging Markets

Argentina	SITC	RCA	exports (millions)	Brazil	SITC	RCA	exports (millions)
Bovine & equine leather	6114	12.73	$648.7	Pig & cast iron	6712	18.29	$1,032.6
Lime	6611	9.16	$29.1	Bovine & equine leather	6114	7.33	$1,065.4
Wool yarn or animal hair	6512	5.51	$86.6	Chassis fitted with engines	7841	7.11	$272.4
Leather sheets or rolls	6112	5.02	$4.4	Asbestos manufactures	6638	6.36	$92.8
Trucks & vans	7821	4.01	$1,394.3	Ferro-alloys	6716	5.44	$1,248.7
Chile	**SITC**	**RCA**	**exports (millions)**	**China**	**SITC**	**RCA**	**exports (millions)**
Unwrought copper & copper alloys	6821	81.57	$15,287.5	Plastic ornaments	8933	6.36	$1,096.1
Sheets of plywood	6342	9.84	$282.2	Plaited products	6597	6.29	$308.6
Fibre building board of wood	6416	7.88	$239.3	Umbrellas & canes	8994	6.25	$1,595.5
Iron/steel rough forging & stampings	6793	4.98	$67.7	Toys	8942	5.93	$54,577.9
Unwrought silver	6811	4.91	$258.9	Manufactures N.E.S.	8999	5.71	$2,931.8
India	**SITC**	**RCA**	**exports (millions)**	**Indonesia**	**SITC**	**RCA**	**exports (millions)**
Jute woven fabrics	6545	33.64	$58.8	Wood-based panels	6344	79.21	$417.1
Kelem, schumacks & karamanie	6593	30.54	$43.3	Unwrought tin & alloys	6871	39.02	$1,459.5
Knotted carpets	6592	18.71	$279.9	Calf leather	6113	37.92	$83.2
Wool carpets	6594	17.2	$264.2	Worked tin & alloys	6872	26.92	$149.8
Leather articles used in machinery	6121	16.59	$0.7	Yarn (<85% synthetic fibres)	6516	14.71	$280.5
Malaysia	**SITC**	**RCA**	**exports (millions)**	**Mexico**	**SITC**	**RCA**	**exports (millions)**
Clothing accessories from rubber	8482	18.52	$2,030.9	Color T.V.	7611	10.72	$16,041.2
T.V. tubes & cathode rays	7761	17.95	$280.8	Tractors for semi-trailers	7832	9.57	$2,080.8
B&W T.V.	7612	16.05	$37.0	CPUs	7523	7.74	$6,194.0
Sheets of plywood	6342	11.52	$1,146.2	Refrigerators & freezers	7752	7.6	$2,070.6
Other radio receivers	7628	11.14	$779.7	Gas, liquid & electric meters	8731	7.11	$376.6

Russia	SITC	RCA	exports (millions)	Saudi Arabia	SITC	RCA	exports (millions)
Unwrought nickel & nickel alloys	6831	15.42	$4,441.1	Iron pipes	6781	3.84	$97.7
Pig & cast iron	6712	12.82	$1,232.2	Sheep & lamb leather	6115	2.92	$38.5
Nuclear reactors	7187	10	$1,121.6	Correspondence stationary	6422	2.07	$29.0
Iron/steel billets	6725	8.84	$4,859.7	Leather of other hides or skins	6116	0.89	$16.5
Iron & steel powders	6713	5.58	$367.7	Cement	6612	0.83	$107.3
South Africa	SITC	RCA	exports (millions)	Thailand	SITC	RCA	exports (millions)
Unwrought metals of platinum	6812	54.23	$7,534.7	Control & peripheral hardware	7525	12.64	$14,357.6
Ferro-alloys	6716	25.46	$2,462.0	Not mounted precious stones	6673	12.47	$452.4
Barbed wire	6932	10.62	$13.2	Tires & pneumatic for aircraft	6253	11.37	$62.3
Not mounted diamonds	6672	9.03	$3,826.8	Clothing accessories from rubber	8482	9.52	$920.1
Liquid & gas filters & purifiers	7436	8.84	$1,369.8	Centrifuges machinery parts N.E.S.	7439	8.43	$1,111.5
Turkey	SITC	RCA	exports (millions)				
Yarn for retail (>=85% synthetic fibres)	6515	39.01	$81.0				
Yarn of regenerated fibres	6518	29.2	$7.8				
Iron/steel rods	6732	17.96	$3,778.5				
Man-made pile & chenille woven fabrics	6539	15.29	$151.5				
Cement	6612	14.72	$1,187.2				

Source: Hausmann et al. (2011).

The new manufacturing revolution

Supply chains represented the way we assembled products in the 1980s to the 2010s. But additive manufacturing could soon replace supply chains. In additive manufacturing, a machine "prints" products layer-by-layer using a 3D graphics image. For example, to make a chair, a 3D printer deposits a millimeter-thick layer of plastic (or other material) where the legs should be. The printer continues to add millimeter-thick layers of material, and eventually, by printing "up," it prints the legs, the seat, and the back. The print head deposits layer upon layer until the entire chair is printed. Small-scale manufacturers (for lack of a better term) are already using 3D printing. A dentist's office might print certain types of tooth molds and orthodontic equipment, which would previously have required specialized and customized manufacturing at an off-site locale.

If additive manufacturing has its way, small-scale manufacturers will be able to download the designs for all of these parts and print them on site. Figure 8 lists several of the types of low- and medium-skill manufactured goods that 3D printers can already manufacture. Fashion products and artistic goods will almost certainly represent the bulk of this type of manufacturing. Small artists can design their products and manufacture them in any quantity, right at home. Consumer goods (like bicycles with working parts) will probably comprise another niche for manufacturers who will probably be able to economically produce and retail their own products. Specialist, industrial-use 3D printing promises (and threatens) to shorten and parse supply chains for complex manufacturing supply chains like airplanes, as producers can simply print (in metallic form) the parts they require. The medical industry also stands to gain enormously from 3D printing with the potential printing of specialized prosthetics and even organs in the future.

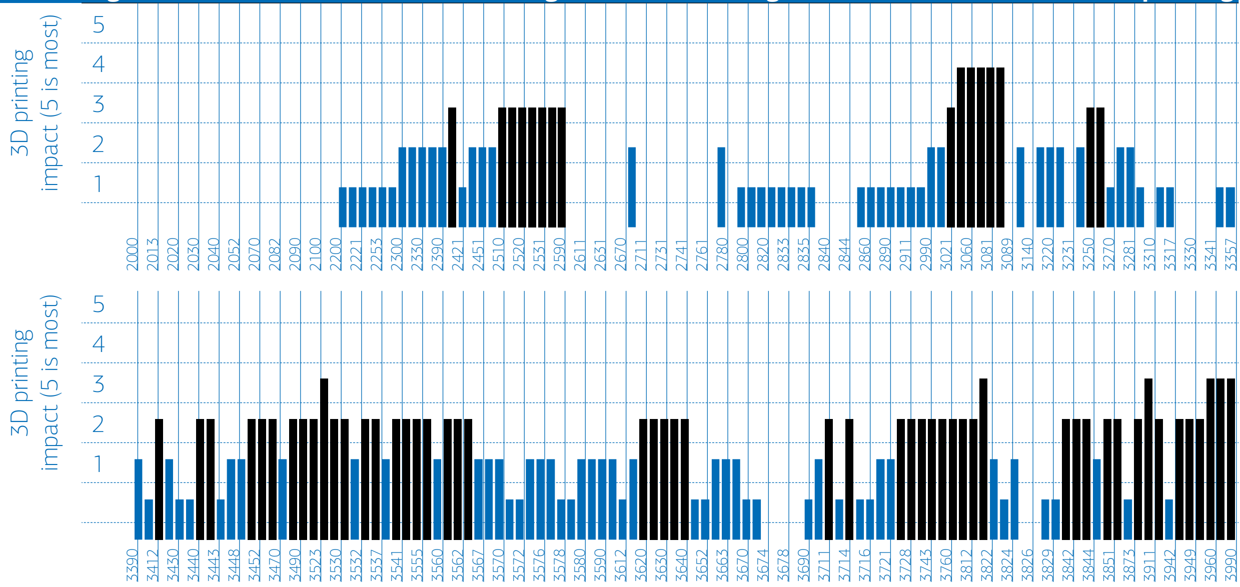
Additive manufacturing will radically change the nature of the manufacturing industry or at least parts of it. Figure 9 shows the estimated impacts on various sub-branches of the manufacturing industry (as organized by Standard Industrial Classification or SIC codes). It is unlikely that many changes will occur in the lower-numbered SIC code areas, which refer to food production. (Although many enterprising entrepreneurs are already printing food designs that are impossible to create with normal cooking and baking methods.) Most of the large-scale changes should occur in the higher-numbered SIC categories like costume jewelry and novelties (SIC code 3960), motor vehicle parts and accessories (SIC code 3714), and screw machine products (SIC code 3451) to name only a few. For small-sized production runs, additive manufacturing threatens the

Additive manufacturing will radically change the nature of the manufacturing industry or at least parts of it

Figure 8: Areas Where 3D Printing is Changing Manufacturing

Area of 3-D Printing	Examples
Circuit Boards	circuit boards
Artistic goods and gifts	plastic balloons, collectibles
Consumer goods	plastic bicycles, others
Fashion products	dresses, shirts, and so forth
Specialised metal and titanium parts	working parts on airplanes, other parts
Medicinal products and organs	prosthetics, kidneys, heart valves, other parts.

Figure 9: Assessment of Extent of Change in Manufacturing Sub-Sectors as a Result of 3D printing



The bars in the figure show the estimated effects of additive manufacturing on each branch of the manufacturing industry (SIC codes 2000 to 3900). Five indicated the largest impact and 1 indicates little impact.

economies of scale of mass production.

These commercial and economic impacts promise to change the industrial landscape. First, traditional manufacturers, and particularly those relying on low-cost mass production in developing markets, should lose a large amount of business to do-it-yourself manufacturers. Chinese manufacturers in particular have a lot to lose. Second, relatively remote and under-industrialized developing countries should see large increases in small-scale manufacturing, even for mom and pop operations. Indian manufacturers (and similar countries) should see the largest gains. Third, if 3D printing catches on, wider changes in organizational forms and in the plastics industries will ensue.

Attributes that are compatible with additive manufacturing

Some attributes will play well to this new technology. The higher capital-to-labor ratios in many developing economies place these countries in an advantageous position to use capital-intensive, 3D printing. Figure 10 demonstrates the relationship between capital-to-labor ratios and revenue-to-asset ratios for manufacturers in a number of countries. The countries whose manufacturers export a smaller share of high-skill goods appear to have higher returns on their assets in terms of revenue. Russian manufacturers have average capital-to-labor ratios of around 0.43. However, they have the highest revenue-to-asset ratios of the countries we have illustrated in the figure (around 1.3). 3D goods require lower skills. This means that countries specializing in low-skill goods can benefit from 3D printing.

Emerging markets tend to deploy a large amount of capital in order to earn returns that are comparable with those of more developed market manufacturers. The two groups of countries have the same revenue-to-asset ratios of 1.07. (Each country's ratio is determined by its GDP) However, the two groups have very different capital-to-labor ratios. The group of emerging market countries has a capital-to-labor ratio of 0.62 while the group of developed countries has capital-to-labor ratios of 0.36. As such, emerging market manufacturers deploy far more capital (almost twice as much when expressed as a percentage of spending on labor) as developed country manufacturers. Thus, their best strategic option is to go into 3D printing.

Companies (and the countries where they are based) may respond to 3D printing more aptly if they have high investments in R&D and other intangibles. R&D spending among manufacturers in various emerging markets reveals how these companies pursue different strategies in their competition for market share

Figure 10: Countries that focus on lower-skill manufacturing exports can gain most from 3D Printing

	Global Strategic Focus	Capital to labour ratios	Revenue to asset ratios
Strategic Focus			
Emerging Markets			
Argentina	Medium-skilled	0.66	1.1
Chile	Medium-skilled	0.75	0.7
India	High-skilled	0.69	0.9
Malaysia	High-skilled	0.48	0.8
Russia	Low skilled	0.43	1.3
Thailand	High-skilled	0.48	1.1
Turkey	Medium-skilled	0.94	1.1
Developed market comparators			
Australia	Medium-skilled	0.16	0.9
Belgium	Medium-skilled	0.55	1.0
France	Medium-skilled	0.81	1.0
Germany	Medium-skilled	0.16	1.2
Denmark	High-skilled	0.14	1.0
UK	High-skilled	0.26	1.1

Source: WRDS (2012).

abroad. Indian companies spend almost 120% of their wage outlays on R&D. In contrast, Russian manufacturers spend only about 5% of the value of their annual spending on wages on R&D. These spending patterns reflect the strategies these countries' manufacturing firms have adopted when selling their products abroad. Russian manufacturers have focused on selling low-skill products. In consequence, these companies have not needed to invest in R&D. Such spending also reflects these companies' position in their investment cycle. Indian manufacturers probably spend such a large amount in order to "ramp up" spending on longer-lasting competencies in R&D-based, high-skill exports. In contrast, Turkish companies' low spending on R&D probably reflects the "cashing in" of previous R&D spending. This means that high spending on R&D can help poise a company to take advantage of 3D printing.

Spending on capital as opposed to labor does not tell us much about a company's ability to capture profits resulting from 3D printing. Emerging market manufacturers tend to spend roughly equal amounts on capital and labor (with the exception of India). Turkish, Chinese, and Russian manufacturers spend about a 1-to-1 ratio of money on capital and wages. In contrast, British and German manufacturers spend almost 3 times as much money on wages as on capital. At first glance, these expenses seem merely to reflect higher wage rates. However, these choices also reflect the voluntary strategic decisions of companies rather than simple, passive, acceptable accommodation to a high-wage labor market. Manufacturers in developed economies like the U.K. and Germany seek to compete in skill-intensive manufactured goods (we chose to list only two countries in Figure 11 to illustrate the general trends). They pursue their own strategies and 3D printing may change this.

Investments in human capital may also

High spending on R&D can help poise a company to take advantage of 3D printing

Figure 11: Countries with Intangible Assets May be Most Flexible in Responding to 3D Printing

Country	R&D to staff	Capital expend to Revenue	Staff expend to revenue	Intangible Assets to Total Assets	Revenue to Assets	wage/ employ*
Emerging Market						
India	118%	16%	8%	6%	113%	$21,200
Turkey	16%	8%	8%	6%	114%	$19,300
China	22%	8%	6%	1%	132%	$13,800
Russia	5%	12%	10%	3%	131%	$12, 700
Comparators						
United Kingdom	31%	6%	20%	29%	124%	$55,700
Germany	68%	5%	18%	17%	147%	$58,100

The data in the figure show ratios comparing companies' investment in knowledge capital to wage payments. We also show the effects of those investments in the form of return on assets (as revenue). We finally show annual wages paid to manufacturing companies' staff (in US dollar terms). * We have converted wage expenses per employee to US dollars using the middle of the year (June 2010) exchange rate for each country. East Asian countries (Japan and South Korea) do not report labour-related data (wages, employees and so forth). Source: WDRS (2012).

make companies able to respond to changes needed for 3D printing. Wages in the developed economies tend to far exceed those in developing economies. Figure 11 also shows the average amount of money spent by manufacturing companies in each country divided by the number of employees in those companies. As shown, wages in Germany and the U.K. outpace wages in countries like India, Turkey, China, and Russia by a factor of 5. At first glance, these wages seem to reflect the higher wage demands of workers living in more expensive countries. However, companies operating in these countries agree to pay these wages. These wages (at least in theory) should equal the value that these workers bring to their work of manufacturing goods for local or foreign consumption. The revenues of manufacturers from developed countries tend to edge out those of manufacturers in developing countries, although only marginally.

Differences in investments in intangible assets may also reveal possible differences in the way companies may respond to the challenge of 3D printing. In the several emerging market countries that we use as illustrations, investments in intangible assets never exceed 6% of total assets. In contrast, German manufacturers invest about 17% of total assets in intangibles and British manufacturers invest almost 30%. Asian manufacturers paint a similar picture. Figure 12 lists the value of total assets in our sample of manufacturers in six Asian economies and compares those assets with investments in intangible assets. These numbers seem to suggest an investment life cycle. Thai manufacturers appear to be building up investments in intangible assets (which they might use over time). These intangible assets make up about 5% of the total value of these Thai firms' assets. Japanese manufacturers have made investments in intangible assets worth about 4.5% of total assets, suggesting a higher equilibrium level of investment in intangibles that supports a strategy of competing in higher-skill manufactured goods. Korea and Taiwan appear to exhibit a similar pattern. Indonesia, in contrast, seems to focus on competing in low-skill manufactured goods. Indonesian manufacturers make relatively few investments in intangible assets (less than 1% of total assets by value). Chinese manufacturers appear to be living on previous investments in intangibles with the average value of intangible assets hovering at about 1.5% of total asset values. However, these data may reflect

Companies should be more like service firms to be able to make the successful jump to 3D printing

Figure 12: Total and Intangible Assets of Manufacturing Companies in Selected Asian Countries

	Companies in Selected Asian Countries	
Country	Total Assets in sample (millions USD)	Average Intangible
Thailand	$173	4.9%
Japan	$6,652	4.4%
South Korea	$1,485	3.7%
Taiwan	$768	2.2%
Indonesia	$112	2.0%
China	$1,465	1.5%

The figure shows the ratio of intangible assets held by each country's highest revenue 100 manufacturing enterprises (SIC codes 20 to 39) for 2010. In comparison, we show the total assets in US dollars in 2010. We use 2010 data in order to avoid the effects of the financial crisis on demand for each country's goods.

Chinese manufacturers being bloated on easy-to-obtain capital. In general, these data suggest that some manufacturers may be able to adapt 3D printing techniques more easily than others.

Their most notable characteristic is that companies should be more like service firms to be able to make the successful jump to 3D printing. New manufacturing relies much more on service sector value added than on industrial value added. Service workers design robots and new products, arrange for funding, and organize workers. The days of the large smoking factories, and even the sweatshops, have largely passed. Figure 13 shows the cross-country relationship between the adoption of sophisticated production processes and the extent of the trade of services in various countries worldwide. Simply put, more sophisticated production processes require more services. Unsurprisingly, Scandinavian countries like Sweden and Denmark appear to be poised to take advantage of new manufacturing. Other economies like the U.S. maintain their legacy methods of production: complex and yet not very service-based. Such an industrial arrangement will likely make these economies less competitive in the years ahead.

We cannot tell exactly which countries will seize the 3D printing revolution most successfully. Labor productivity differs across emerging markets. In general, productivity grew in Argentina by 16% from 2005 to 2010, by 11% in Brazil, 8% in the U.S., and 3% in Germany, Japan, and Turkey. Manufacturing covers a wide range of activities, from producing cars to producing certain kinds of foods. Each subsector (and company) will have its own particularities. As such, we cannot generalize about the specific activities companies can do to boost their labor productivity.

The growth rates of manufactured goods production in selected economies tell us something about the each country's desire to adopt 3D printing. Figure 13 shows the growth rates of manufactured goods production in a range of economies. Egypt appears at the head of the list, with an annual growth rate in manufacturing of about 70%. China's manufacturing output grew at a heady 22%. Saudi Arabia's manufacturing output (in U.S. dollar terms) has grown

Figure 13: Annual Growth Rates of the Value of Manufactured Goods in Selected Economies (2005-2011)

Country	Growth Rate	Country	Growth Rate
Argentina	16%	Indonesia	9%
Australia	6%	Japan	5%
Brazil	4%	South Korea	12%
Chile	10%	Malaysia	5%
China	22%	Mexico	7%
Colombia	4%	Pakistan	4%
Denmark	1%	Poland	15%
Egypt	72%	Romania	15%
France	2%	Russian Federation	4%
Germany	3%	Saudi Arabia	21%
Ghana	4%	South Africa	5%
Greece	2%	Thailand	15%
Hungary	9%	Turkey	10%
India	21%	United States	3%

Source: World Bank (2012).

Figure 14: Employment in Manufacturing in Selected Emerging Markets (in thousands)

	Argentina	Brazil	Indonesia	Malaysia	Mexico	Russia	Turkey
Food Products and Beverages	200	1541	1325	243	1151	1398	438
Tobacco Products	2	16	407	5	0	13	16
Textiles	54	447	909	30	116	172	408
Wearing Apparel; Dressing and Dyeing of Fur	124	911	950	122	68	220	619
Tanning and Dressing of Leather; Luggage, Handbags, Saddlery, Harness, and Footwear	53	786	302	12	839	73	95
Wood and of Products of Wood and Cork, except Furniture;	32	406	645	147	81	327	72
Paper and Paper Products	25	220	183	45	140	124	43
Publishing, Printing and Reproduction of Recorded Media	59	330	215	60	201	275	90
Coke, Refined Petroleum Products and Nuclear Fuel	10	183	23	24	61	121	13
Chemicals and Chemical Products	97	788	256	64	267	488	163
Rubber and Plastics Products	43	359	337	144	258	295	157
Other Non¬Metallic Mineral Products	32	528	549	58	272	598	236
Basic Metals	21	356	102	71	101	604	171
Fabricated Metal Products, except Machinery and Equipment	91	747	235	97	368	526	224
Machinery and Equipment NEC	68	648	90	87	88	1089	228
Office, Accounting and Computing Machinery	2	42	12	60	186	24	4
Electrical Machinery and Apparatus NEC	28	122	72	53	228	408	74
Radio, Television and Communication Equipment and Apparatus	6	137	159	354	0	185	23
Medical, Precision and Optical Instruments, Watches and Clocks	9	88	9	26	193	295	25
Motor Vehicles, Trailers and Semi¬Trailers	66	507	75	72	574	480	210
Other Transport Equipment	14	109	147	47	0	676	74
Furniture; Manufacturing NEC	73	561	691	115	317	268	227
Recycling	0	69	14	9	0	63	5
Total	1107	9902	7708	1945	5509	9126	3615

Source: ILO (2012).

by about 20% per year. In contrast, many developed countries' manufacturing output is growing far less quickly. Manufacturing output in the U.S. grew by only 3%, while Japan's grew by 5%. These growth rates suggest that each country may size the 3D printing revolution differently.

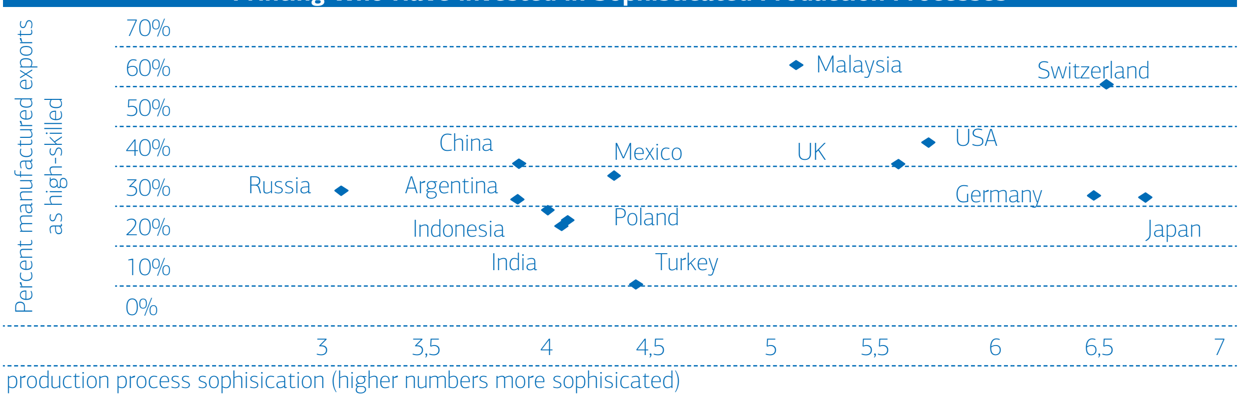
Large differences in employment in manufacturing sectors suggest that different countries will have different capacities to seize the 3D printing revolution. Figure 14 shows employment both in aggregate terms and in specific manufacturing sectors. Brazil and Russia employ almost 10 million persons each in manufacturing. The U.S. employs 14 million with far better results (in terms of total values of manufactured goods exported). Germany, for its part, employs about 8 million people in manufacturing. These data clearly suggest significant productivity differences between countries.

What can emerging markets do to seize the 3D printing revolution? They can focus on specific professional education. For example, Mexican auto manufacturers could provide training for their employees on auto assembly, car design, and other techniques. In that way, they could reduce the numbers of employees and hopefully increase salaries in the process. Chemical producers and rubber producers could also provide specific education (along with the producers in the various sub-branches of manufacturing shown above). Work-related education would do more to raise productivity in the short term than general university-level bachelors' and/or masters' degrees.

These companies could also implement quality management programs like the ISO 9000 certification programs. New 3D printing production lines will require new, sophisticated production processes and designs. By focusing on quality, fewer workers would be needed (as they would print new products correctly the first time). Quality programs would also raise demand for manufactured goods from these emerging markets as customers often choose manufactured goods from developed economies because of perceived or real differences in quality. Forward-thinking manufacturers in Asia always implement these kinds of quality certification programs. Other manufacturers would be wise to follow suit.

Work-related education would do more to raise productivity in the short term than general university-level bachelors' and/or masters' degrees

Figure 15: Manufacturers Keen on Competing in High-Skilled Manufacturing Revolving Around 3D Printing Who Have Invested in Sophisticated Production Processes



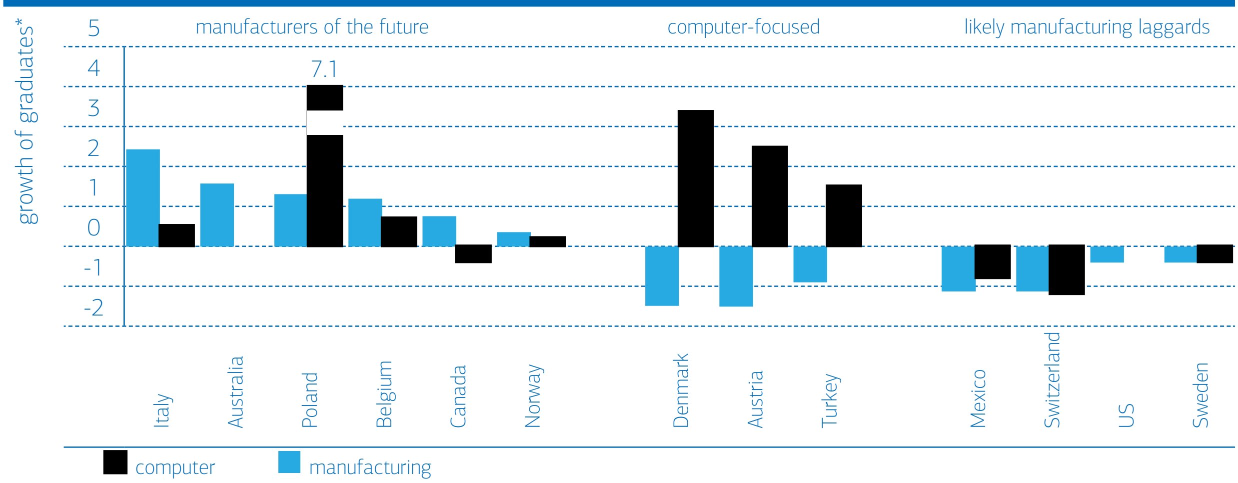
New technologies promise to make emerging market manufacturing companies more reliant on providing services than ever before. In the 2000s, an idea required about 6 months to progress from a computer-assisted design (CAD) template to Walmart's shelves. Yet, a new technology offers the potential to reduce that time from 6 months to 6 days. Additive manufacturing and product design templates that are already available on the internet promise (or threaten, depending on your point of view) to change the face of manufacturing.

Will the OECD recapture some manufacturing?

By and large, OECD manufacturers have adapted to the forces that are reshaping the manufacturing landscape. However, not all OECD countries have responded equally well, particularly on a wider industrial level. Figure 16 shows the extent to which university students in various OECD member countries choose degrees in manufacturing and computer science. By this measure, the U.S. seems relatively poorly placed to take advantage of the large-scale changes that are expected in manufacturing in the coming years. The number of university graduates with degrees manufacturing has decreased slightly from the 2000s while the number of computer scientists has remained relatively constant. In contrast, Italian university graduates will have the skills needed to take advantage of changes in the manufacturing industry. The number of students studying manufacturing there has doubled in the last decade, and the number of computer scientists has shown healthy growth. The U.S. labor markets respond with much more flexibility to changes in demand than Italian labor markets. However, the Italians still seem a better bet for taking advantage of changes in manufacturing in the medium-term. Italian education seems to employ a far better model for technical schools in emerging markets than U.S. education.

What can laggard core OECD manufacturers do to make their manufacturing sectors more competitive, along with other emerging market manufacturers seeking to rise to the level of the core OECD? Human resource directors can encourage their staff to learn computer assisted design (CAD) and product design skills. Training in many of these skills already exists on the Internet; all that employers need to do is give their staff the time to study them (and hopefully use them). Second, emerging market manufacturers, especially, can focus on the long tail of demand in both OECD and emerging markets. Manufacturers in India, Brazil, Russia, and other emerging markets will have a difficult time competing with General Electric's resources and head start. These manufacturers in emerging markets should not try to mass-produce a better magnetic resonance imager (to take one example from GE's product line). Instead, they should explore niche imaging technologies. They can offer local service and features that GE cannot profitably offer. By treating these manufactured goods more like services, emerging market manufacturers can take a page from the core OECD's playbook.

Figure 16: North America Lags Behind in the Training the Manufacturers of Tomorrow



* The growth of graduates indicator shows the ratio of the number of graduates in 2010 over 2000 subtracted from a similar ratio of the growth of graduates in all subjects. For example, in Italy, the number of students studying manufacturing in university was about two times higher than in 2000 -- after subtracting a similar ratio describing the total increase in the total university student population. Source: OECD (2012).

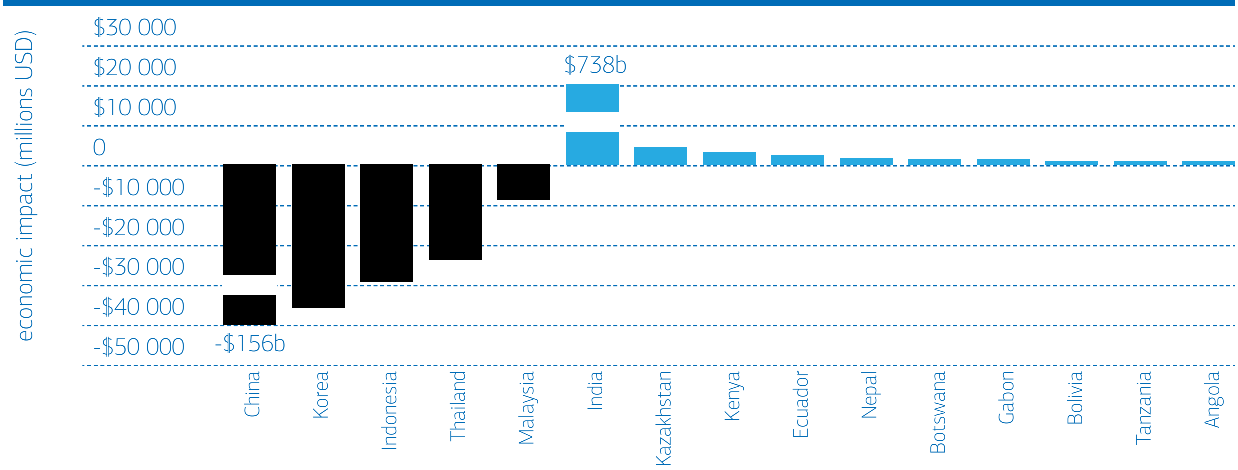
Emerging market winners and losers

A fair amount of the developing world will benefit from cheaper, local manufactured goods. Figure 17 gives an idea of the estimated gains for many countries. India will be the largest gainer globally with roughly $740 billion dollars in extra manufacturing. In order to benefit from new manufacturing (at least in our model), countries need to incorporate costly and difficult logistical arrangements (or otherwise have high transport costs), have large populations, have a high level of poverty (but not be too poor to afford plastic inputs and CAD lessons), have the ability to pay for final goods, and be under-industrialized.

Based on our model, new manufacturing will have little effect on the U.S., Western Europe, and Japan for several reasons. First, much small-scale manufacturing will return to these economies but larger-scale, domestic manufacturing will shrink. The net effect is a wash, speaking on a macroeconomic scale and giving or taking a few billion dollars. Second, many of these countries already focus on high-skill manufacturing, a type of manufacturing that is relatively untouched by new manufacturing. Printing circuit boards and complex design elements cannot currently be accomplished through cheaper organizational methods. These countries' manufacturers have already adopted many of the tenants of new manufacturing and have pioneered new techniques like 3D printing.

New manufacturing will also have few effects on manufacturers in developing economies like Sudan or Nicaragua. In Almaty, Kazakhstan, for example, one can easily imagine relatively large numbers of young men and women downloading (through torrents.ru) a product design from the internet and printing it on a richer friend's 3D printer. Vibrant university sectors, networks of friendships in commercial places, and relatively high incomes allow producers to learn new skills and chase customers with their customized designed goods. In contrast, in Khartoum or Managa, one would have a harder time imagining large numbers of people playing with computers, buying plastics, and commanding a decent price in city marketplaces for

Figure 17: Do It Yourself Comes to Manufacturing - A Boon for Pre-Emerging Markets



The graph shows the estimated gains and loses to various countries of the wide-spread adoption of new manufacturing techniques which allow for domestic production of low skilled and medium skilled manufactured goods. We created these estimates by calculating the percent of GDP involved in low and medium skill manufactured goods. We subtracted exports for net exporters and added manufactured imports. We then used regression analysis to derive the predicted proportion of manufactured goods for each country in our dataset. Regression predictors included extent of industrialisation, population size (in log values), poverty rates, literacy and computer coverage, income per capita andtransport costs (from the World Bank's Doing Business database). We report the difference between predicted and actual manufacturing (in US dollar terms). See Appendix for more details on the methodology.

their wares. The statistics from our model tend to agree. However, anything is possible.

For core OECD countries, new manufacturing and 3D printing methods will probably not bring back many jobs. These countries already possess larger manufacturing firms that are able to employ staff as needed. Shorter-term contracting and consulting practices have already permeated most of these economies, particularly in the U.S. Much of the 3D printing Americans do will not contribute to GDP or job creation any more than blogging did in the 2000s. Americans simply have enough manufactured goods, although they may prefer goods located on the long tail of their preferences rather than standard, mass-produced fare. For countries like Malaysia, China, and other low-wage manufacturers, 3D printing will also reduce employment in the short-run.

For many developing countries, a bit of labor-intensive technology will serve local development well. Consumers in these markets have not satiated their desire for manufactured goods. These markets will produce manufactured goods without going through the process of industrialization. Figure 18 illustrates the pro-employment effect that technologies like 3D printing will have on developing countries. As previously mentioned, India is way ahead in the manufacturing game. New manufacturing, and particularly, 3D printing, helps provide manufactured goods in a country where it is notoriously difficult to import these goods from abroad. Local production also helps to put the large

Figure 18: Adding Jobs – But Mostly in the Developing World and Mostly for Small and Medium Enterprises

Country	Average manufacturing employment *	Added jobs**
Azerbaijan	-	165,000
Bulgaria	2,380	50,000
Brazil	22,990	1.9 million
India	3,430	18 million
Mexico	32,400	1 million
Philippines	2,410	1.5 million
Romania	4,920	250,000
Russia	34,930	2.4 million
South Africa	7,740	350,000
Spain	24,930	300,000
Ukraine	22,950	450,000
Comparators		
Germany	16,607	
Japan	4,710	
United Kingdom	6,390	

* We report average employment rather than median employment in order to give the reader a sense of the size of the economy. Larger economies tend to agglomerate employment into larger companies – bringing up the average and providing a better basis for judging the effect of job creation in the next column. ** We estimated added jobs from 3D printing by using the difference of each country manufacturing share of GDP with its optimal (expected) level from Figure 18. We used the ratio of manufacturing employment to each percent share of GDP in manufacturing in order to turn our under-manufacturing estimates into under-employment estimates. Data on manufacturing employment come from the ILO in 2008 or latest available). We have fit unavailable data (like India) using regression techniques – guessing the level of employment in manufacturing to total population based on GDP per capita. We have used old estimates of manufacturing employment (from the early 2000s) as a reality check for our estimates.

populations of Brazil, Mexico, the Philippines, and Russia to work. As shown in the figure, the larger the population (and the more spread out), the larger the expected employment benefits will be of do-it-yourself additive manufacturing.

For all economies, but particularly in emerging markets, new production techniques will lead to the de-concentration of many manufacturing companies. Figure 18 also shows the average number of employees in manufacturing companies in several countries. Brazil, Mexico, and Russia have average manufacturing firm sizes of over 20,000 workers (with many firms having far lower numbers than the average). In contrast, the average number of employees in Japanese manufacturing firms hovered at about 4,710 in 2010. Even the employment-loving German manufacturing companies average only 16,600 workers – fewer than the averages in Russia, Mexico, and Brazil. Technologies like 3D printing will provide the impetus for de-concentration that "normal" economic forces have not yet provided.

Companies in some emerging markets will want to focus on high-skill manufactures in order to succeed in 3D printing. Politicians in many emerging markets will want to encourage manufacturers to compete in high-skill products. Production processes and sophistication should support such a strategy. Yet, the sophistication of production processes in a number of emerging markets needs to increased dramatically in order to execute this strategy. Figure 19 provides calculations of the improvement required in production process sophistication scores in order to compete with best-in-class manufacturers. For example, for their proportion of high-skill manufactured exports, Russian manufacturers would need to almost double their production process sophistication scores. Similarly, Argentina, China, Indonesia, and Poland will require significant needed upgrades in production processes.

These data also indicate that countries like Turkey and Malaysia do not need to engage in substantial production process upgrades. These countries have chosen competitive strategies that avoid high-skill exports. Because of their level of high-skill manufactures exports, producers in these countries probably have production processes that roughly correspond to their needs. So, 3D printing will be important.

Figure 19: Improvements needed in Production Sophistication to reach Best-in-Class for Chosen Level of High-Skilled Manufactured Exports

Country	current score	required improvement
Russian Federation	3.09	3.51
Argentina	3.86	2.74
China	3.87	2.73
Indonesia	3.99	2.61
Poland	4.05	2.55
India	4.08	2.52
Mexico	4.28	2.32
Malaysia	5.08	1.52
UK	5.53	1.07
USA	5.66	0.94
Germany	6.38	0.22
Turkey	4.38	0.22
Switzerland	6.44	0.16
Japan	6.61	0.00

Implications: Profiting from new manufacturing

New manufacturing, or manufacturing relying on intellectual property, lean production methods, and even new production methods like 3D printing, will spread to the emerging markets. What can manufacturers in the core OECD countries do to keep their competitive advantage? What can manufacturers (and would-be manufacturers) in emerging markets do to profit from the large-scale changes on the horizon?

New manufacturing will probably destroy more production than it creates

The Internet destroyed RCA Records, Capitol Records, and other companies. Similarly, a person in India who wants a German-designed lamp can simply print it (or contract with a local company to print it). New manufacturing will significantly reduce the need for large fac-

Figure 20: Market Destroying Effects of Manufacturing "Servicization"

Company	Revenue	Likely Impact
South Korea		
SK Holdings	W91b	Telecom and distributions services will absorb many of the changes taking place in the energy and chemicals affiliates. The company has already spent a fortune to turn its operations into service and innovation based centres of excellence.
POSCO	$60b	Steel, engineering & construction, trade, ICT, energy, chemicals & materials, and other affiliated holdings already converted to innovation-led, service-based quasi-autonomous units. Little further impact.
China		
SAIC Motors	¥312m	With 10 marks of cars, the motor company's competitive advantage far from obvious. For example, Saic-Iveco Hongyan Commercial Vehicle Company could offer study dump trucks cheaply. In a world where parts and whole assemblies online, its competitive advantage much less certain.
CSR Corporation	¥63m	Producer of locomotives – and large investment in innovation. New technologies threaten to dissipate the company's innovation advantages (as others copy costlessly).
China National Building Material Co	¥51m	Cement business likely to see little change – but light weight materials and other affiliated bodies likely to see large changes.
Sinochem	¥39m	little impact because company already diversified into real estate, agriculture and finance.
Russia		
GAZPROM OAO	р3.6b	A rarity among large petrol companies – Gazprom focuses on gaz (and petrol). No focus on innovation or multiple business lines – like similar companies in OECD.
Kamaz	р73m	Kamaz – like Saic-Iveco – focuses on trucks (and metal production). Company relies heavily on low prices and focus on CIS markets. Most of its products vulnerable to easy printing in an additive manufacturing world.
SOLLERS JSC	р 55m	Car manufacturer which relies heavily on foreign partners with names like Isuzu and SsangYong. Also focused on low cost advantage and domestic market. No visible unique selling point.

Source: company websites and independent analysis from industry experts.

tories, machines that press parts into final products, shipping, warehousing, product tracking, and accounting. When China starts to produce locally and begins to fill its own needs, its percentage of manufacturing to GDP will decline as will its proportion of manufacturing exports. Figure 20 illustrates the probable effects of new manufacturing on revenues and operations for several manufacturing companies in emerging markets. The comparison between South Korea and China/Russia proves particularly instructive. Korean companies appear to be similar to their core OECD peers with a focus on innovation and product diversification. Chinese companies still have a product focus. Russian companies seem to be very focused on low-cost advantages and on targeting domestic markets. In some cases, these companies may adapt by focusing on high-skill products or adopting new manufacturing methods of their own. In other cases like record and movie sales, these revenues will be gone forever.

In the previous manufacturing model, places like Shenzhen could mass-produce parts and materials for assembly in China and/or elsewhere using low-cost labor. Countries across the world from Indonesia to Rwanda have sought to imitate this model. Areas like Myanmar, Oaxaca, Kalmykia, and Guizhou cannot expect to copy the Shenzhen Model. Low-wage, low-value, repetitive, labor-intensive manufacturing methods will not provide the same road to riches as in the past. We predict that countries currently following such a path will probably see their competitive position erode very quickly. China (of course), Indonesia, Thailand, and Malaysia serve as obvious examples. South Korea will probably lose manufacturing work as a result of competition as manufacturers in other countries copy its methods without being required to copy its high cost of labor.

OECD manufacturers (and their peers in emerging markets) will be service workers

By and large, OECD manufacturers have adapted to the forces reshaping the manufacturing landscape. However, not all OECD countries have responded equally well, particularly at the wider industrial level. Figure 21 shows the extent to which university students in various OECD member countries choose degrees in manufacturing and computer science. By this measure, the U.S. seems relatively poorly placed to take advantage of the large-scale changes that are expected in manufacturing in the coming years. The number of university graduates studying manufacturing has decreased slightly since the 2000s while the number of computer scientists has remained relatively constant. In contrast, Italian university graduates will have the skills needed to take advantage of changes in the manufacturing industry. The number of students studying manufacturing has doubled in the last decade, and the number of computer scientists has shown healthy growth. U.S. labor markets respond with much more flexibility to changes in demand than Italian labor markets. However, the Italians still seem a better bet for taking advantage of changes in manufacturing in the medium term. Italian education offers a far better model for technical schools in emerging markets than U.S. education.

What can laggard core OECD member manufacturers and emerging market manufacturers seeking to rise to the level of the core OECD do to make their manufacturing sectors more competitive? Human resource directors can encourage their staff to learn computer assisted design (CAD) and product design skills. Training in many of these skills already exists on the Internet; all employers need to do is give their staff the time to study them (and hopefully use them). Second, emerging market manufacturers, especially, can focus on the long tail of demand in both OECD and emerging markets. Manufacturers in India, Brazil, Russia, and other emerging markets will have a difficult time competing with General Electric's resources and head start. These manufacturers in emerging markets should not try to mass-produce a better magnetic resonance imager (to take one example from GE's product line). Instead, they should explore niche imaging technologies. They can offer local service and features that GE cannot profitably offer. By treating these manufactured goods more like services, emerging market manufacturers can take a page out of the core OECD's playbook.

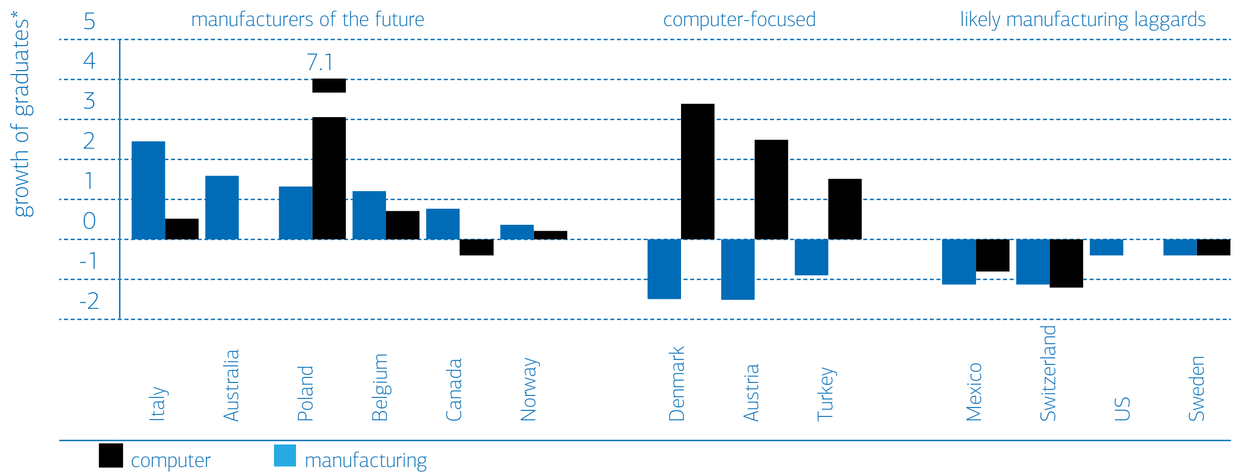
Hire a good IP lawyer – but don't expect very much

Imagine the day when anyone can go online to the U.S. Patent office website and download the schematics for a new product, like a Rubik's Cube. The Rubik's Cube, for readers under 30 years old, tortured millions as they twisted and turned its sides to try and match the colors on all 6 of the cube's sides. If you want to print your own Rubik's Cube, you only need to see the patent application, redraw the figure in a popular sketching program like Google's Sketch Up, and print out a copy. The reader can find motors, shelves, complex hydraulics systems —anything you want —at the U.S. Patent Office. Search costs and the cost of making molds and acquiring the manufacturing equipment needed to make Rubik's Cubes, motors, and other goods have proved too expensive in the past. Now, many of the designs are already available online – for free.

New manufacturing, and particularly 3D printing, promises (threatens) to do to manufactured goods what digitization and the internet did to music, movies, and other intellectual property. Any small 3D printing shop in Raipur, India can download a CAD file from the Internet and print products often too complex to manufacture by hand (or machine!). While liberating for some, such a system could discourage manufacturing innovations and the patents that follow. Figure 22 illustrates the number of patents registered in 2010 in the top 20 patenting countries worldwide. In a world of 3D printing and patent downloads, roughly 490,000 American patents would become immediately and freely available to consumers worldwide. The chilling effects on manufacturing innovation could prove serious.

Patent infringement cases could provide millions of dollars' worth of juicy cases to lawyers. From 2008 until roughly the middle of 2012, over 15,500 patent infringement cases appeared in U.S. courts of first instance and their appellate courts. Some of these lawsuits involved large companies suing other companies, like Lucent Technologies v. Gateway Inc. in 2009. However, once 3D printing allows almost any computer-literate user to download and use product specifications, the number of patent in-

Figure 21: North America Lags Behind in Training the Manufacturers of Tomorrow



* The growth of graduates indicator shows the ratio of the number of graduates in 2010 over 2000 subtracted from a similar ratio of the growth of graduates in all subjects. For example, in Italy, the number of students studying manufacturing in university was about two times higher than in 2000 -- after subtracting a similar ratio describing the total increase in the total university student population. Source: OECD (2012).

fringement cases could blossom. In all likelihood, patent infringement litigation will follow the course of copyright infringement litigation over online copy and the distribution of music, videos, books and so forth. Many of the recent cases, like the U.S. circuit court's ruling in Cartoon Network v. CSC Holdings, have tended to focus more on the fundament legal underpinnings of governing the protection of intellectual property and less on the actual damages involved in the case.

Emerging market manufacturers, especially, can focus on the long tail of demand in both OECD and emerging markets

Manufacturing executives face both an opportunity and a threat in regard to patents and intellectual property. On the one hand, they can benefit from easier access to product specifications and the relatively immediate use of new product ideas and concepts. On the other hand, they face little incentive to engage in mass manufacturing knowing that popular products can be quickly and easily copied. These two tendencies should (and hopefully will) encourage manufacturing executives in developing markets to work with courts and prosecutors to define a relatively liberal property rights regime (and its enforcement) in their own country. Instead of simply engaging (or not) in litigation, these executives have a chance to lobby their legislators for more 3D-printer-friendly intellectual property rights laws.

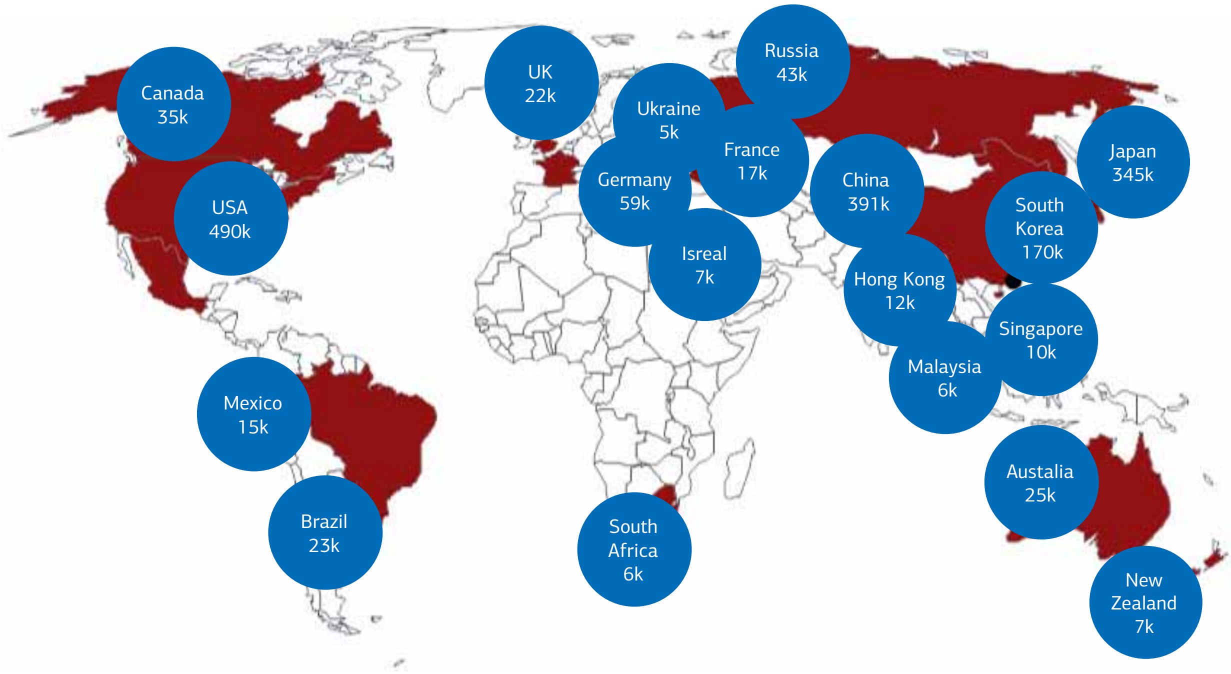
Invest in the petrol and plastics industries

Worldwide demand for plastics will increase as more people print products at home and at work, pushing up petrol prices as well as shares of plastics manufacturers. Crude oil has a direct link with the plastic objects emerging from 3D printer because it serves as the primary input into the creation of plastic resins (basically, little white balls of plastic that machines melt down and turn into more complicated structures). These plastic resins serve as the raw material used to create final plastic goods and, more importantly, profits for plastic-goods manufacturers. Demand for the plastics used to print goods (if large enough) directly impacts the price of crude oil and share prices of plastics producers. Figure 23 illustrates the historic correlation between "crude" plastics prices (in the form of resins used to make plastics) and crude oil. The figure also shows the share price of the U.S.'s largest producer of plastics, Huntsman Chemical Corporation. In broad terms, the three prices move together. The large-scale uptake of 3D printing should cause increases in petrol and plastics share prices.

Our econometric analysis suggests that 3D printing in the next 3 to 4 years will lead to significant increases in plastics prices and the share price of plastics companies. Current independent estimates place the growth of the 3D printing and manufacturing business at about $3 billion in 2016, up from the roughly $1 billion this year (Wohlers Associates, 2012). Such an increase should lead to increases in the demand for plastics, particularly in developing markets where plastics consumption equals roughly 1/10 to 1/5 of levels in the core OECD countries (Plastics Europe, 2012). Increases in plastics demand have traditionally correlated with positive changes in plastics producers prices (a 10% increase in the price of plastics has historically translated to a 6.6% increase the share prices of major plastics manufacturers). Increases in the demand for plastics has also correlated with changes in crude oil prices with roughly an 8% change in oil prices leading to a 1% change in plastics prices (Weinhagen, 2006).

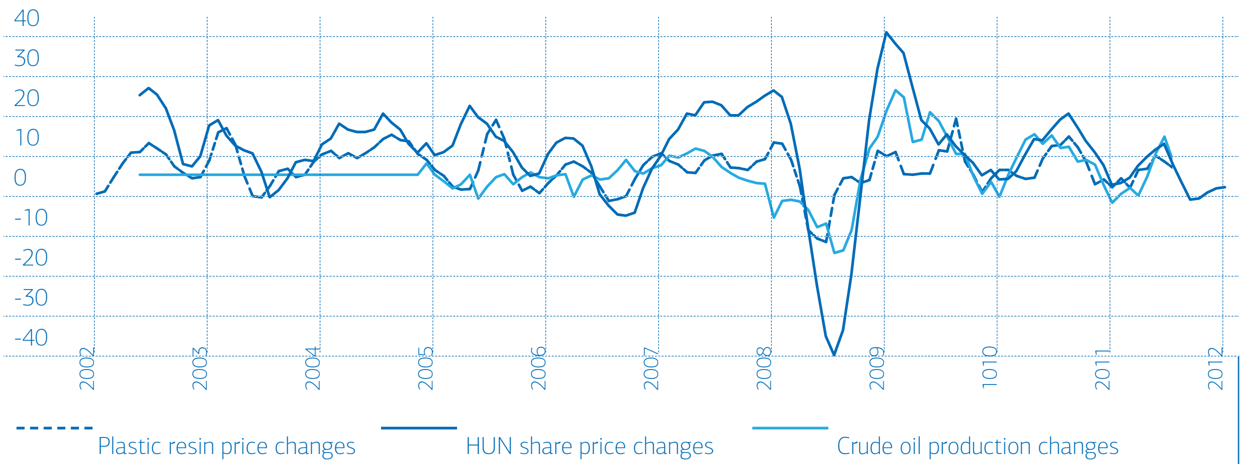
We estimate that realistic predictions on the growth of the 3D printing industry in the next 2 to 3 years will cause a 3% to 4% increase in the price of plastics, a 1.5% increase in plastics share prices, and negligible impacts on petrol prices. Figure 24 shows the results of simulations we ran as we looked at the possible scenarios for petrol production, plastic resin

Figure 22: Over 1.7 million in frustrated inventions per year



The graph shows the number of patent applications filed by residents and non-residents of each of the countries shown in the figure. We show only the top 20 countries – ranked by number of applications – for 2010. Source: World Bank (2012).

Figure 23: The Link Between Crude Prices and Plastics Mean Additive Manufacturing Could Stoke Demand for Petrol and Plastics Stocks

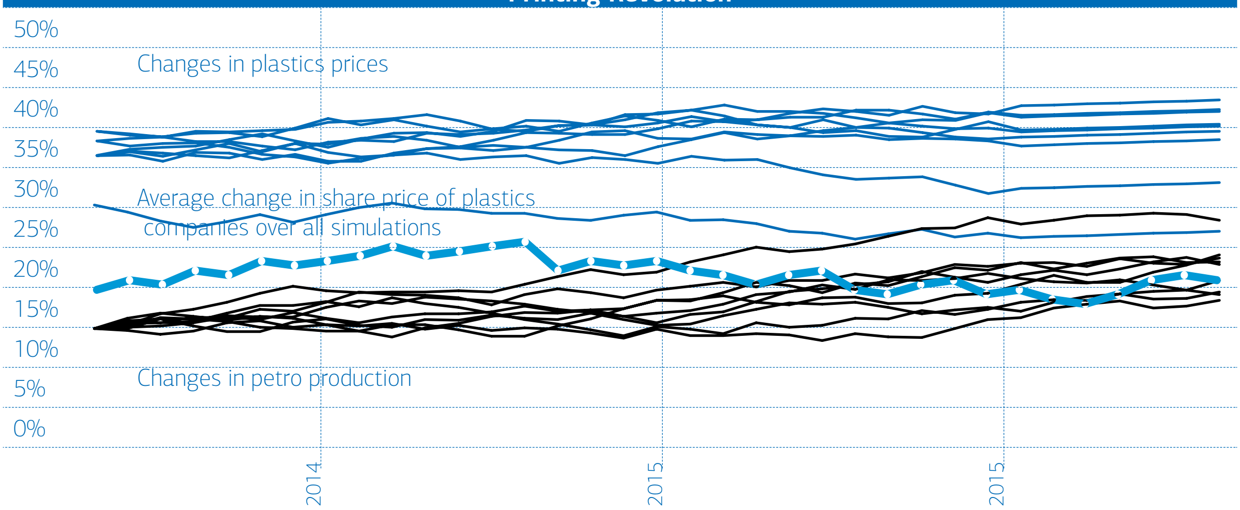


The data in the figure show the monthly changes in prices of plastic resin, crude oil production and the share price of one of the US's largest maker of plastics (Huntsman Chemical Corporation). Each of these series has roughly a 0.3 correlation coefficient with each other. Source: Bureau Labour Statistics (2012) and WDRS (for share price changes).

prices and plastics companies' share prices (using date from the U.S.-only). The multiple lines show the change in prices if the 3D printing industry grows according to industry estimates and if random shocks affect the evolution of that growth. For example, plastics prices should start up about 35%-40% in 2014 and then increase along a trend over the next two years. However, if plastics prices exhibit the same kind of volatility they displayed in the past, they could evolve along any of the trajectories shown in the figure. Economists call these lines a "random walk along a trend" (or technically a "integrated stochastic time series" for the economists in the audience). In practice, such trends mean that plastic prices should rise with increased demand although random events like a shipment delivery failure in the Southwest of the U.S. or a plastics fire in a warehouse in Brazil could cause bumps in the evolution of these prices.

Investors in plastics (and in the manufacturing techniques that use 3D printing) should benefit the most from these technical changes affecting the entire manufacturing industry. Most of the gains from this increased demand (and rising plastics prices) will accrue to developed market economies, particularly the U.S. and Asia, which produce roughly 50% of the world's plastics. However, certain plastics companies should benefit more than others. Berry Plastics Group Inc. (ticker BERY on the NYSE) and Silgan Holdings Inc. (ticker SLGN on the NASDAQ) represent two companies that are likely to benefit from increased plastics demand and prices. The NYSE and the NASDAQ represent well-capitalized and highly accessible capital markets, which investors who are interested in profiting from long-term trends in 3D printing can easily enter. On the other hand, General Plastic Industrial Co. Ltd. (stock identifier 6128 on the Taipei Stock Exchange) and National Plastic Technologies Ltd. (stock identifier 531287 on the Bombay Stock Exchange) appear to be less sparkling candidates for investment. Their relative lack of liquidity and foreign accessibility to these markets make investments in these kinds of companies more difficult. Higher stock prices mean more profits and more employment for these companies list-

Figure 24: Simulation of Effects on Plastics and Plastic Producer Prices of 3D Printing Revolution



The data in the figure shows simultations showing the impact on petrol prices, plastics (resin) prices and plastics companies' share prices of increases in demand for plastics stemming from 3D printing. In brief, we have estimated parameters (using regression) for the change in prices related to changes in demand and the standard deviation of those changes. We have used these standard deviations in Monte Carlo simulations. Source: authors.

ed on the NYSE, the NASDAQ and other well-heeled exchanges. As such, higher employment in the core OECD's plastics companies represents just one more way that new manufacturing will bring manufacturing (or at least manufacturing jobs) back home.

Conclusions

What effect will new manufacturing technologies like 3D printing have on emerging markets? In preparing this brief, we have found that emerging markets like India will probably see a net positive effect. China will almost certainly lose out in the next wave of manufacturing. Upper-income OECD countries, particularly Germany, the U.S., and Japan, will probably continue producing high-value goods. Because these economies have a strong skilled labor and service-based orientation, they will be able to respond quickly to additive manufacturing. Additive manufacturing, meaning, printing products, will disrupt the old, low-wage, supply-chain-driven approach to cost competition and economic development. Roughly one third of all manufacturing sub-sectors will undergo radical change as a result of additive manufacturing.

Several implications for the future derive from new manufacturing; and it will probably destroy more production than it creates. Printing centers will bring manufacturing to the third world in large amounts. OECD manufacturers (and their peers in emerging markets) will function as service providers. Manufacturers should adopt small, flexible organizational structures. They should hire good IP lawyers, but they should not expect them to make very much headway. Finally, individuals and companies looking to take advantage of new manufacturing should invest in the petrol and plastics industries.

As a fourth step, we did a "reality check" of our analysis. We compared groupings with our own personal knowledge of these cities. We also consulted experts from the various countries in case we had doubts about underlying data (such as the Global Competitive Report rankings for example). We wanted to make sure that business executives working in the cities on our list would also recommend their cities to foreign businessmen and businesswomen. We did not want to find ourselves in a position where we recommended a city that large numbers of readers living in those cities would recommend against.

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