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Trade, education, and the shrinking middle class

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A B S T R A C T

We develop a new model of trade in which educational institutions drive comparative advantage and the distribution of human capital within and across countries. Our framework exploits a multiplicity of sectors and a continuous support of human capital choices to demonstrate that freer trade can induce crowding out of the middle occupations toward the skill acquisition extremes in one country and simultaneous expansion of middle-income industries in another. Individual gains from trade may be non-monotonic in workers' ability, and middle ability agents can lose the most from trade liberalization. Comparing trade and education policies, our model indicates that targeted education subsidies like Trade Adjustment Assistance are the most effective mechanism to bolster the middle class.

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1. Introduction

Politicians tend to portray education as a universal panacea for rising income inequality and perceived competition with foreign exporters — a cure-all with which the industrialized world will be able to maintain a thriving middle class and ever-greater standards of living.[1] At the same time, popular sentiment reflects a growing perception that even a solid education no longer guarantees a good job or membership in the middle class.[2] In this paper, we explore a source of the disconnect between political rhetoric and public perception: the reality that workers' responses to globalization and technological change are not uniform. While many workers optimally respond to import competition or routinization by moving up the skill acquisition ladder, others self-select downward into lower skill occupations — the long run consequence of which may be polarization of educational attainment.

We argue in this paper that potential asymmetry in how workers' educational decisions respond to globalization should play a central role in positive and normative evaluations of trade and education policies. To that end, we build one of the first trade models in which human capital responses to globalization may be non-monotonic, with heterogeneous workers acquiring more or fewer skills in response to changes in the wage structure. Our framework highlights how trade and educational institutions interact to determine individuals' skill acquisition decisions and the pattern of comparative advantage across countries. We use this platform to study how education or trade policies can be used to attenuate the 'vanishing middle class' phenomenon recently observed in much of the industrialized world.

Our motivation stems from important recent empirical work that demonstrates three closely related trends: (*i*) the past few decades have witnessed a sharp 'hollowing-out' of middle class, middle-skill employment in a broad set of industrialized countries[3]; (*ii*) trade liberalization and increased import competition are at least partially responsible for some of the middle class job losses and wage decline[4]; and (*iii*) although some workers have responded to increased globalization by increasing human capital investment, others have responded by decreasing educational attainment.[5] Taken together, these three

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[1] e.g. "We [maintain growth] by investing in and reforming education and job training so that all Americans have the skills necessary to compete in the global economy" – President Obama, February 14, 2011 (S679).

[2] The Pew Research Center (2012) found that "85% of self-described middle-class adults say it is more difficult now than it was a decade ago for middle-class people to maintain their standard of living." (*Fewer, poorer, gloomier*) See also Pew Research Center (2014) for evidence that trade is increasingly cited as a cause (*Faith and skepticism about trade, foreign investment*).

[3] Goos and Manning (2007), Autor et al. (2003), Autor et al. (2006), Falvay et al. (2010), Goos et al. (2014).

[4] Hakobyan and McLaren (2010), Autor et al. (2013a, 2013b), Autor et al. (2015).

[5] Edmonds et al. (2009), Hickman and Olney (2011), and Atkin (2012).

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empirical observations suggest that globalization may be inducing polarization in human capital acquisition in concert with the (already well documented) polarization of wages and employment.

This paper proposes a new model to help us understand what might be driving this educational polarization, and which policies might best reverse the trend. Until now the theoretical literature has remained silent on the potential for globalization to induce non-monotonic changes in workers' incentives to acquire human capital. Standard modeling conventions are at least partly to blame. Until very recently, the trade literature has restricted models with endogenous human capital decisions to two-good (and often binary skill choice) settings, which implicitly preclude the possibility of non-monotonic skill change. Customary Stolper–Samuelson forces inherent to two-good models yield a stark theoretical prediction: opening to trade will induce skill upgrading or skill downgrading, but not both. For industrialized countries, these models lead to overly sanguine predictions in which all workers will simply acquire more skills to shift into export-oriented sectors, which in the long run will both increase aggregate human capital levels and mitigate income inequality. By the same logic, these models carry potentially dire predictions for countries with comparative advantage in low-skill sectors.

We find these predictions too simplistic, and so propose instead a flexible many-good, continuous-skill framework that allows us to develop a more nuanced understanding of skill polarization and potential policy responses. Our model features a continuum of heterogeneous agents who differ in their inherent ability to acquire skills through education. Agents choose among a continuum of occupational sectors (or tasks) of increasing complexity, each of which requires a minimum set of skills for employment. Wages are determined by sectoral technology and intermediate good (task) prices — and thus by trade openness — while the cost of human capital acquisition is determined by both individual level characteristics and the country-specific structure of educational institutions and policies. Faced with the resulting incentive structure, agents self-select into occupations by investing in the corresponding human capital, following a tractable assortative matching process based on the complementarity between innate ability and skill acquisition.[6]

We show that comparative advantage can be driven by differences in local educational institutions, which determine the cost of skill acquisition. Trade liberalization leads to a remapping of agents to occupations, as would changes in technology, physical trade costs, or educational institutions. The resulting shift in the demographics of human capital composition can take different forms. One plausible and particularly salient scenario is the hollowing-out of the mid-level occupations toward the higher and lower skill level extremes in one country, and expansion of mid-level occupations in the other.

In a two-country general equilibrium functional form example, we show that skill polarization could be brought about by rising foreign competition in mid-level intermediate goods or tasks, which we trace to differences in the relative convexity of costs of skill acquisition across countries. Intuitively, if ascending to the highest rungs of the educational ladder is relatively more costly in, for example, the less developed country, then the mid-level occupations there will attract disproportionately more and higher ability agents, who will drive down wages in those sectors worldwide. Trade liberalization by the more developed trading partner opens the door to increased competition in mid-skill sectors, inducing polarization in local wages, employment, skill attainment, and individual welfare. More generally, we argue that only in special cases would all agents' human capital decisions respond monotonically to trade liberalization. While the aggregate gains from trade are positive, the distributional consequences are generally complex and non-monotonic.

The model lends itself to policy analysis, and we consider the potential roles for education subsidies and trade policy in shaping the distribution of skills and income. We show that what matters for either policy intervention is not the overall level of education costs or trade taxes, but rather how the policy varies along the occupation/skill dimension. Uniform educational subsidies or trade taxes have no effect in our framework, since they do not influence marginal incentives to acquire skills. When targeted, both education subsidies and tariffs are capable of influencing human capital investment, although these instruments have important differences. Trade policies have distortionary demand-side effects that educational subsidies do not. But more importantly, we argue that political feasibility may be very different for the two instruments. Tariffs to protect middle class jobs are commonplace (Lu et al., 2012), but similarly targeted educational subsidies, which by definition would have to decline for the highest skill levels, are not. Highly targeted education programs like the (now besieged) Trade Adjustment Assistance (TAA) are the most valuable policy tools according to our model, but to be effective in moving displaced workers to higher wage export-oriented sectors, subsidies would have to be large enough to allow workers to reach potentially much higher rungs of the skill acquisition ladder.

Our theoretical approach builds on seminal contributions of Findlay and Kierzkowski (1983), who established the first model of endogenous skill acquisition in a Heckscher–Ohlin setting, and Grossman and Maggi (2000), who first pointed out the importance of the (exogenous) distribution of talent and complementarities between workers in driving comparative advantage. More recently, Jung and Mercenier (2008) propose a model of endogenous human capital decisions in the presence of outsourcing, but key assumptions preclude the possibility for non-monotonic skill responses to trade in their setting, too. Along another dimension, Davidson and Sly (2014) offer a complementary insight, showing that trade liberalization can exacerbate distortionary unproductive (signaling only) education when effort in school is imperfectly observable; we posit that their mechanism could obtain in our setting, too, though our focus is on productive skill attainment. Finally, the model itself incorporates elements from a variety of papers in the trade literature. In modeling occupational output as tradable tasks, we recall Grossman and Rossi-Hansberg (2008). The continuum framework is reminiscent of Dornbusch et al. (1977) and more recently of Yeaple (2005), Ohnsorge and Trefler (2007), Costinot and Vogel (2010), Helpman et al. (2010), and Anderson (2011), who also incorporate heterogeneous agent matching features into a continuum setting which, as here, can generate non-monotonic welfare consequences of trade. None of these models endogenize workers' human capital decisions or study the intersection between trade and education policies, however.

The remainder of the paper is structured as follows. The next section reviews our empirical motivation, tracing a common thread through a series of recent studies at the intersection of the trade and labor literatures. In Section 3, we introduce the model, analyze the effects of trade under a small country setting, and give the equilibrium conditions for the large country case. Section 4 presents a tractable example that delivers a two country general equilibrium case with non-monotonic skill change. In Section 5 we introduce the possibility of education subsidies and tariffs and study their effects. Section 6 concludes.

2. Empirical motivation

A series of important papers in the labor literature documents the first empirical regularity cited in the introduction: within a broad set of developed countries, workers have been systematically ‘sorting down’ — often into low-skill menial jobs — while others simultaneously have been ‘sorting up’ into higher skill jobs. Goos and Manning (2007) offer a compelling graphical depiction of this employment polarization, reproduced with permission. Based on employment changes in the

[6] This mapping mechanism was used early in the trade context by Grossman and Maggi (2000). See Milgrom and Roberts (1990) for the canonical application in the broader literature. Models with similar supermodularity/complementarity features within the trade literature include, e.g., Antras et al. (2006), Vogel (2007), Nocke and Yeaple (2008), Costinot and Vogel (2010), and Mrazova and Neary (2012).

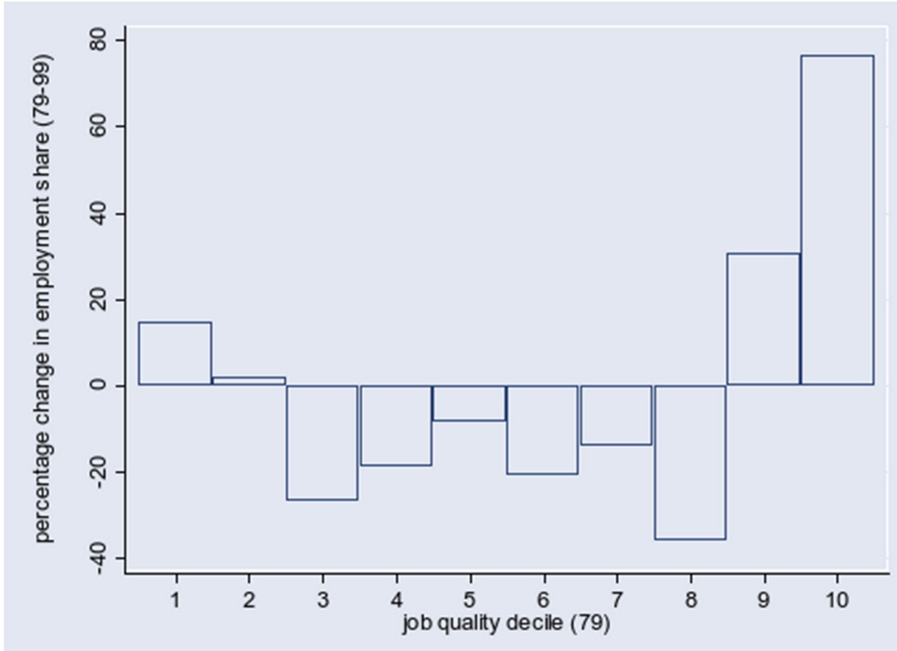

Fig. 1. Non-monotonic changes in employment (Goos and Manning, 2007).

United Kingdom between 1979 and 1999, Fig. 1 shows marked job growth at both the bottom and top two 'job quality' deciles (a proxy of skill), with a sharp reduction in employment for the occupations in between. Autor et al. (2003) and Autor et al. (2006) document similar findings for both wages and employment in the United States, Falvey et al. (2010) find the same trends in Portugal, and Goos et al. (2014) document the same trend among 16 Western-European countries.[7]

While a number of authors have posited alternative models to explain the polarization phenomenon through routinization, skill-biased technological change, or shifting consumer preferences,[8] there is strong empirical evidence that the fall in demand for mid-skill workers in the industrialized world is at least partly driven by globalization. Feenstra and Hanson (2003) make a powerful argument that trade plays an empirically large role in increasing income inequality apart from skill-biased technological change. More recently, Goos et al. (2014) conclude from a structural exercise that together routinization and occupational "offshorability" explain roughly three-quarters of the job polarization in Western Europe.

Several compelling recent studies establish a clear causal link between trade liberalization, local labor market effects, and the demand for skills.[9] Hakobyan and McLaren (2010) and Autor et al. (2013a) find significant local labor markets effects of trade exposure from NAFTA and rising import competition from China, respectively. Topalova (2007) and Kovak (2013) find similar labor market effects responses in India and Brazil. Using structural methods, Artuç et al. (2010) and Dix-Caneiro (2014) provide evidence of the important role played by trade in labor market dynamics using data from the U.S. and Brazil.[10] Bustos (2011) offers evidence of the effect of trade liberalization specifically on the demand for skill, while Autor et al. (2015) argue that trade has been more important than technology in driving aggregate U.S. job losses in tradable sectors.

A final piece of evidence in favor of globalization's role comes from the developing world. Two of the most comprehensive studies to date, Ravallion (2009) and a special report in *The Economist*[11] document a dramatic expansion of the middle class incomes in much of the developing world. Another study based on meta-analysis of household surveys, Dollar et al. (2013), demonstrates that the poorest 40% of households are keeping pace with (or even catching up with) average growth rates in much of the developing world, even as high income countries have seen an increase in inequality by the same measure.[12] As our model later makes clear, explanations for polarization based entirely on technological change or preferences generally would imply globally *universal* increases in employment polarization and income inequality. That hollowing-out is not universal argues in favor of trade as a potential driver of polarization in the rich world and simultaneous expansion of mid-level employment in (some) less developed countries.

Finally and most importantly, recent empirical work demonstrates that education can and does respond to globalization. An emerging literature finds that workers may increase or decrease educational attainment in response to openness, and that effects of liberalization may differ sharply across different groups within a country.[13] Atkin (2012) and Hickman and Olney (2011), offer compelling evidence that

[7] Goos et al. (2014) also find that the employment polarization effects of technological change and offshoring appear to be robust across different industry groups. In their online appendix (pp 17–19), they find no evidence of statistically significant cross-industry differences in the employment effects of offshoring, and very weak evidence (of stronger polarization) from technological change for manufacturing.

[8] See, e.g., Autor et al. (2006) and Autor and Dorn (2013). For earlier work suggestive of a demand-side story, see e.g. Katz and Murphy (1992), Bound and Johnson (1992), Juhn et al. (1993) and Berman et al. (1999).

[9] See Goldberg and Pavcnik (2007) for a review of the early literature.

[10] Other studies include Kambourov (2009), Cosar (2011), Cosar et al. (2011), and Menezes-Filho and Muendler (2011); see Dix-Carneiro (2012) for a review of this literature.

[11] "Burgeoning Bourgeoisie: A special Report on the New Middle Classes in Emerging Markets," February 14, 2009.

[12] See, e.g., Table 4, which shows the bottom 40% of households catching up to the local mean income in Latin America and the Caribbean (and holding pace in most of the developing world) in the last decade while the same group fell behind in high income countries.

[13] Looking at the reverse causality, Bombardini et al. (2012) provide compelling empirical evidence that the dispersion of human capital is an important driver of comparative advantage.

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individuals shifted their schooling decisions in response to trade openness in Mexico and the US, respectively. Using firm level data on hiring and job vacancies, Atkin (2012) shows that growth in manufacturing exports induced a markedly higher high school dropout rate in Mexico during the major trade reforms between 1986 and 2000, but that only for the most plausibly affected groups of students. In the U.S. context, Hickman and Olney (2011) use data from the U.S. Census and find that increased exposure to immigration and offshoring stimulated additional educational attainment by some groups of workers, largely through community colleges. Focussed instead on the interaction between poverty, child labor, and schooling, Edmonds et al. (2009) find that the sharp 1991 trade liberalization in India had a negative impact on schooling for children in the most adversely affected urban districts.

Taken together, the existing trade and labor literatures offer evidence that increased openness to trade could cause the distribution of human capital to change within (and across) countries. Short-run polarization of job opportunities and wage growth may lead to long run polarization in the attainment of skills and education in some countries, while mid-level skill attainment may increase in others. We now proceed to develop a model of this phenomenon.

3. The model

This section builds a model in which openness to trade can generate endogenous hollowing-out of mid-skill sectors, consistent with the observed "vanishing middle class". We examine the conditions under which trade can drive skill polarization by changing the equilibrium wage structure, and thus the incentives for workers to invest in education. This framework then serves as the foundation for both the functional form example in Section 4 and policy analysis in Section 5.

3.1. Set-up

Consider a country populated by a continuum of heterogeneous agents with unit mass. Individual agents differ in their inherent ability level (or equivalently, ability to learn), a, which is distributed continuously over the unit interval with cumulative distribution function $F(a)$ and corresponding density function $f(a)$. Every agent is endowed with a single unit of labor, which is supplied inelastically to the labor market.

The economy produces and consumes a single homogeneous final good, Y, using constant returns to scale technology and a continuum of intermediate tasks (or products) $j \in [0,1]$, where j may be thought of as an index of the intermediate sectors' technological sophistication. Each intermediate task is produced under constant returns and perfect competition, using labor with a particular skill level. Productivity is the same for all workers of an acquired skill type regardless of agents' inherent ability.[14] The final good serves as num\'eraire with price denoted by $p \equiv 1$. We choose units so that the real wage in every sector j is simply the trading price of the relevant intermediate good/task; i.e. $w(j) \equiv p(j)\ \forall\ j \in [0, 1]$. Agents consume the final good Y with non-satiated preferences.

In order to supply one unit of labor to sector j, agents have to acquire the required skill level through training and education. The cost (in units of the num\'eraire) to agent $a \in [0,1]$ of acquiring the required skill level for a given sector $j \in [0,1]$, is described by the function $c(j,a)$, which is twice continuously differentiable in each argument. The cost of skill acquisition is increasing in the technological sophistication of the sector, decreasing in the ability level of the agent, and convex across sectors for every agent.[15] Finally, the marginal cost of upgrading skills from one sector to the next is lower for high ability agents. This negative complementarity (or *sub-modularity*) of a and j in the education cost function is reflected in the negative cross partial derivative; this is the standard mechanism for ensuring assortative matching of higher ability individuals to higher education levels.[16] Formally, we make the following assumptions over the cost of skill acquisition:

Assumption 1.

$$\frac{\partial c(j,a)}{\partial j} > 0, \quad \frac{\partial c(j,a)}{\partial a} < 0$$
$$\frac{\partial^2 c(j,a)}{\partial j^2} > 0, \quad \frac{\partial^2 c(j,a)}{\partial j \partial a} < 0. \tag{3.1}$$

Additionally, in the interest of tractability, we will consider the following simplification:

$$c(j,a) \equiv h(a)g(j) \tag{3.2}$$

where the functions $h(\cdot)$ and $g(\cdot)$ are twice continuously differentiable and non-negative over the unit interval. Note that Assumption 1 implies that $h'(a) < 0$, $g'(j) > 0$ and $g''(j) > 0$ for all $j \in [0,1]$.

3.2. Optimal sorting and production

When deciding which sector to enter, every agent a chooses j to maximize his net real wage, $w(j) - c(j, a)$. Taking the wage schedule as given, the first order condition for each individual's optimal human capital level is then:

$$\frac{\partial c(j,a)}{\partial j} = \frac{dw(j)}{dj}, \tag{3.3}$$

Or, using superscript dots to denote derivatives with respect to j:

$$\dot{c}\ (j,a) = \dot{w}\ (j) = \dot{g}\ (j)h(a). \tag{3.4}$$

Intuitively, each agent will continue to move up the educational ladder until the benefit of incremental skill attainment (the associated increase in wages, $\dot{w}(j)$) is just outweighed by the cost, $\dot{c}(j, a)$. The second order condition of the agents' maximization problem ensures that the educational level implied by (3.4) is indeed optimal:

$$\ddot{w}(j) \leq \ddot{c}(j,a). \tag{3.5}$$

The technical requirement for this second order condition is that the wage schedule must be locally less convex than the cost function.[17] To prevent corner solutions at zero education, we also require that the educational cost $c(j,a)$ at the optimal j for any type a is non-prohibitive: i.e. $c(j(a),\ a) \leq w(j(a))\ \forall\ a$[18] Provided that education costs are non-prohibitive and the second order condition is satisfied globally with

[14] Alternatively, one can build worker heterogeneity into productivity (and hence wages) rather than educational costs. The two approaches are isomorphic in terms of sorting of workers across sectors, though aggregate output depends on whether ability is productive or not. We choose our approach for tractability.

[15] While we implicitly interpret skills as vertically differentiated over $j \in [0,1]$, nothing in the model precludes interpreting j instead as an index of horizontal skill differentiation where sectors are indexed by the cost of education, much in the spirit of Dornbusch et al. (1977); the key is that the indexed cost function has the same properties in (3.1).

[16] Put another way, we assume that the return to education is super-modular in a and j. (Log-supermodularity is sufficient but not necessary).

[17] Since the wage schedule is exogenous in a small open economy, the second order condition must be ensured by assumption over $w(j)$. If the country is large or autarkic, a convex final good production function will generally ensure that the SOC holds in equilibrium (ensuring positive supply).

[18] Again, for a large country or under autarky the wage schedule would adjust to ensure positive supply.

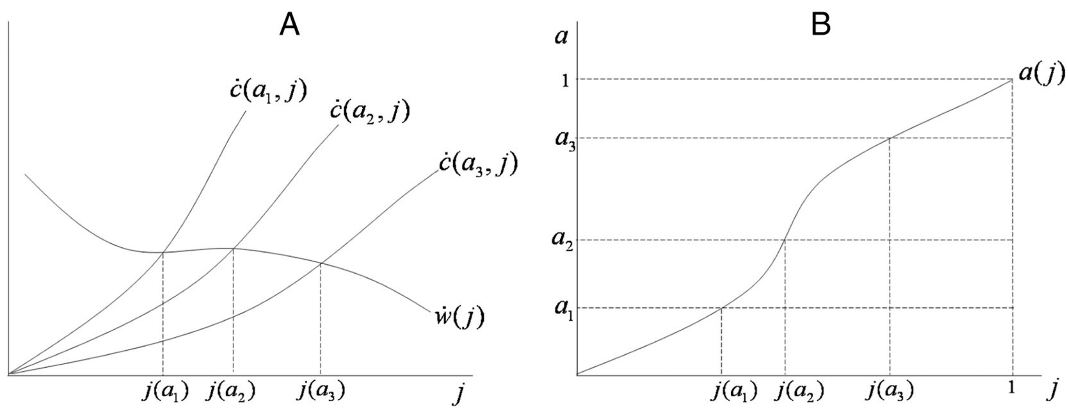

Fig. 2. Optimal sorting.

strict inequality, (3.4) implicitly defines a unique optimal value of j for each agent.

Rearranging the first order condition yields the following mapping from sectors to (self-selected) ability types:[19]

$$a(j) \equiv h^{-1}\left(\frac{\dot{w}(j)}{\dot{g}(j)}\right). \tag{3.6}$$

When $a(j)$ is strictly monotonic and thus invertible, we will denote the mapping of ability types to sectors by $j(a) = a^{-1}(j)$.

This mapping function plays a central role in the subsequent analysis, and so we take a moment to discuss first the intuition and then a few important technical points. In our setting, an individual's ability (a) is defined as her ease of learning. Higher ability individuals face lower marginal costs of skill upgrading, and so will choose to attain a higher skill set for any given wage structure. Since wages are assumed to vary only by skill-level j, it is immediate that the most able will also be in equilibrium the most skilled.

This mechanism is best illustrated with a pair of simple graphs. Fig. 2 depicts the optimal sorting of agents to sectors as a function of the local wage schedule and the cost of education for each agent. Panel A illustrates the optimal sectoral choice according to the first order condition in (3.4) for three different agents with ability types $a_1 < a_2 < a_3$; Panel B depicts the resulting mapping function from ability to occupational sectors according to (3.6). In Panel A, we see that the highest ability agent, a_3, has the lowest marginal cost of education for any task/skill-level j. Thus, from the first order condition and for any given derivative wage schedule, $\dot{w}(j)$, agent a_3 will choose a higher-skill occupation than lower ability agent a_2; likewise, agent a_2 will choose a higher education level than agent a_1. Mechanically, the self selection of higher ability agents into higher j sectors follows directly from the single crossing condition ($\frac{\partial^2 c(j,a)}{\partial j \partial a} \equiv \frac{\partial \dot{c}(j,a)}{\partial a} < 0$) in the last inequality of Assumption 1. The role of the second order condition is also immediately apparent, as it requires $\dot{w}(j)$ to cross $\dot{c}(j,a)$ from above at the optimal occupation, $j(a)$.[20]

Panel B traces out the locus of these optimal skill-level decisions for every ability type, $a \in [0,1]$. In doing so, Panel B depicts not only how individual ability types self-select to tasks, but also the *density* of workers in each sector. The steeper the mapping function $a(j)$, the greater the range of abilities mapped to a particular range of tasks and thus (for any underlying density of ability types, $f(a)$) the higher the employment in those sectors. Conversely, flatter regions in the $a(j)$ function indicate sectors that attract relatively narrow sets of ability levels, and hence tasks that attract low (or in the limit, no) employment. Formally, the derivative of the mapping function, $a'(j)$, multiplied by the density of the underlying ability distribution $f(a)$ determines the mass of workers in any given sector j.

From a technical standpoint, our assumptions so far ensure that the mapping function exhibits the following properties:

Lemma 3.1. *For a given strictly increasing wage schedule, $w(j)$:*

i) *$a(j)$ is non-decreasing (strictly increasing) in j if $\ddot{w}(j) \le \ddot{c}(j,a)$ ($\ddot{w}(j) < \ddot{c}(j,a)$) $\forall$ j, a.*
ii) *$a(j)$ is continuous (continuously differentiable) in j if $w(j) \in C^1 (C^2)$.*
iii) *$a'(j)$ is finite for all j if $w(j) \in C^2$.*

Proof. See Appendix A

Part *i*) implies that higher ability agents self-select into higher j sectors, and this mapping is strictly monotonic if the second order condition holds with strict inequality.[21] Property *ii*) says that if $w(j)$ is continuously differentiable (twice continuously differentiable), then the mapping function $a(j)$ is itself continuous (continuously differentiable).[22] Finally, property *iii*) rules out mass points in the allocation of abilities to sectors if the wage schedule is sufficiently smooth (twice continuously differentiable).[23]

Before continuing, a technical note: the mapping function $a(j)$ in this model implicitly adopts a single dimensional mapping between skill levels and tasks (or sectors). While this structure is common in the literature, it is clearly not the only way to model the relationship between skills and occupations. Several authors have considered how sectors combine different distributions of workers' skills in their production functions (e.g. Grossman and Maggi, 2000; Bombardini et al., 2014), or how firms match to workers of different types (e.g. Yeaple, 2005; Helpman et al., 2010). As long as the equilibrium relationship between sectoral sophistication and skill level is sufficiently pronounced, the comparative statics results that we illustrate below would generally come through in a richer framework.

3.3. Comparative statics of skill acquisition

From here, it is straightforward to evaluate the impact of changes in the wage schedule on the equilibrium skill distribution. Suppose, for instance, that there is exogenous wage compression, reflecting an across the board reduction in skill premia. Intuitively, this would reduce the incentive for skill upgrading, so that individuals would optimally self-select into lower skill sectors. Graphically, we can see this in Panel A of Fig. 2, where wage compression would cause the derivative wage

[19] The second inequality in Assumption 1 ensures that $h(\cdot)$ is invertible so that $a(j)$ is defined.

[20] For simplicity, we depict a wage schedule for which the second order condition holds globally with strict inequality (i.e. $\forall a$ $\dot{c}(a,j)$ crosses $\dot{w}(j)$ once and only once from below).

[21] The result implies moreover that if the wage schedule is everywhere less convex than the cost schedule, then there are no empty (zero-employment) sectors if $f(a) > 0$ $\forall$ $a \in [0, 1]$.

[22] Recall the assumption that $h(\cdot), g(\cdot) \in C^2$ in j.

[23] If the distribution of ability types is also without mass points (i.e. $f'(a)$ is everywhere finite) then this also implies that there are no mass points in employment.

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schedule $\dot{w}(j)$ to shift down, causing every agent to choose a lower j occupation, or 'sort down' in response to weaker incentives for skill upgrading.[24] Conversely, a universal increase in skill premia would increase the incentives for skill acquisition – graphically represented as a shift up in $\dot{w}(j)$ – which would induce every agent to acquire more skills, or 'sort up'.

Crucially, any change in the domestic wage schedule for which the *derivative* wage schedule, $\dot{w}(j)$, remains unchanged would have no impact on agents' occupational choices or aggregate output, provided that education costs are non-prohibitive.[25] Thus, *it is not the absolute level of wages, but rather the relative wage differences* – reflected in the derivative wage schedule – that determine sorting. (Welfare is another matter.)

The following proposition formalizes how equilibrium skill attainment responds to wages, assuming a parsimonious case of unique single crossing for all agents:

Proposition 3.1. *For any two wage schedules $w_1(j)$ and $w_2(j)$ and any agent a:*

i) *if $\dot{w}_1(j_1(a)) = \dot{w}_2(j_1(a))$, then agent a would choose the same sector under either wage schedule: $j_1(a) = j_2(a)$;*
ii) *if $\dot{w}_1(j_1(a)) > \dot{w}_2(j_1(a))$, then agent a would choose a higher sector under w_1 than under w_2: $j_1(a) > j_2(a)$; and*
iii) *if $\dot{w}_1(j_1(a)) < \dot{w}_2(j_1(a))$, then agent a would choose a lower sector under w_1 than under w_2: $j_1(a) < j_2(a)$.*

Proof. The result is immediate from the definition of $a(j)$ in (3.6).

Since our interest in this paper is primarily the potential for non-monotonic skill change – the simultaneous 'sorting up' and 'sorting down' of different groups of workers – we note that the proposition directly implies the following:[26]

Corollary 3.2. *Non-monotonic skill change occurs if and only if there exists a pair of sectors $\{j_a, j_b\}$, each in the unit interval, such that $\dot{w}_1(j_a) < \dot{w}_2(j_a)$ and $\dot{w}_1(j_b) > \dot{w}_2(j_b)$;* i.e. *if skill premia are compressed in some regions of the job-skill ladder and expand in others.*

Thus, for any change in the wage schedule for which wage premia increase across some sectors and decline across others, the result would be one or more regions of localized skill-polarization. Note that changes in absolute wages do not matter for this result: wages could rise in every sector and still generate a non-monotonic endogenous skill response, since marginal educational decisions respond only to *skill premia* – i.e., the derivative-wage schedule – as long as education costs are non-prohibitive.

Together, Proposition 3.1 and Corollary 3.2 can be used to predict the potential effects of trade liberalization or changes in a country's terms of trade on the equilibrium distribution of skills and employment in an economy. In a small open economy setting with one-to-one production, prices (and thus wages) are set exogenously in world markets, so that in principle anything can happen to the equilibrium wage schedule. Any shift in the wage structure that induces greater wage compression (reduced skill premia) at the low end of the educational ladder and less wage compression (higher skill premia) at the high end would induce a vanishing middle class phenomenon. In the next section, we consider one possibility driven exclusively by trade liberalization with a country with different educational institutions, though of course there are many potential drivers of wage changes that could yield similar predictions.

The model can also accommodate local technological change, which would mimic the effects of an exogenous change in wages. Holding world prices fixed, technological change that differentially increases productivity at the low and high ends of the task spectrum would have the same effect on skill attainment as an exogenous relative decline in the wages paid to mid-skill sectors, leading to 'hollowing-out' in the skill distribution.[27] In contrast, skill-biased technological change (SBTC) would have a monotonic effect on skill-acquisition, inducing all workers to shift up the skill ladder. We return to this point later in the paper.

Now that we have analyzed the sorting mechanism, we close the model by defining appropriate equilibrium conditions. We will do so first for the case of a small open economy before turning attention to the case of two large countries.

3.4. Equilibrium conditions for a small open economy

Under our simple one-to-one production function, the domestic supply schedule for intermediates is given by the labor allocation of workers across sectors. Thus, domestic output of a given intermediate good $j \in [0,1]$ is simply the density of workers of each type in the population, multiplied by the density of worker types in each sector:

$$y_s(j) = a'(j) f(a(j)). \tag{3.7}$$

Notice that the supply of intermediates depends on both the wage schedule and the cost of skill acquisition, via the $a(j)$ mapping function.

Based on the total supply of intermediates, domestic output of the final good is given by $Y \equiv \psi(\overrightarrow{y})$, where $\psi(\cdot)$ denotes the constant returns technology used to produce the final good, $\overrightarrow{y}$ is used to describe the complete $y(j)$ schedule over $j \in [0, 1]$, and each $y(j) \equiv y_s(j) + y_t(j)$ includes net imports of intermediate products, $y_t(j)$.[28] We denote the total local unit factor demand for intermediate j by $x(j) \equiv x_j(\overrightarrow{w}, 1)$,[29] and note that in general it depends on the complete wage schedule.

The equilibrium conditions are then as follows. *Full employment* requires that every worker of every type is fully employed, i.e.:

$$f(a) = j'(a) y_s(j(a)) \quad \forall a \in [0, 1], \tag{3.8}$$

where the left hand side is labor supply of each worker type, and the right hand side represents equilibrium labor demand, with $j'(a)$ being short-hand for dividing by $a'(j(a))$, i.e. scaling by the range of types who work in a particular sector.[30] *Market clearing* for each intermediate implies:

$$y(j) = y_s(j) + y_t(j) = x(j) Y \quad \forall j \in [0, 1]. \tag{3.9}$$

[24] In a dynamic framework in which agents cannot recoup the costs of over-education (in essence reselling their degrees), we would expect agents to remain in their same jobs or, if $\dot{w}(j) < 0$ in the relevant region, to shift into lower-skill work for which they are then overqualified.

[25] To see this mathematically, note that the mapping function from ability types to sectors/skill levels depends only on the derivative wage schedule, $\dot{w}(j)$ in Eq. (3.6), conditional on a participation constraint to ensure that the first order condition for optimal self-selection holds with equality for all agents.

[26] Graphically, the corollary implies that non-monotonic skill change will occur if (and only if) the new and old derivative wage schedules cross at least once over the range of tasks.

[27] For instance, suppose $w(j) = p(j)b(j)$, where $b(j)$ is a task-specific productivity term and $p(j)$ represents the exogenous world price of task j. An (exogenous) unskill-biased technological shift that decreases $\dot{b}(j)$ would drive down wage premia in lock step, according to $d\dot{w}(j) = p(j)d\dot{b}(j)$. Conversely, skill biased technological change (i.e. an increase in $\dot{b}(j)$) would have the opposite effect, driving up skill premia and thus skill attainment.

[28] $y_t(j) < 0$ indicates a net export.

[29] Recall that constant returns to scale technology implies that conditional factor demand for each intermediate j may be written $x_j^T(\overrightarrow{w}, Y) = x_j(\overrightarrow{w}, 1) Y \equiv \text{argmin}_{x_j} \overrightarrow{w} \cdot \overrightarrow{x}$ s.t. $\psi(\overrightarrow{x}) \geq Y$.

[30] Note that it is equivalent to require full employment per sector, i.e. $a'(j) f(a(j)) = y_s(j) \quad \forall j \in [0, 1]$. Either way, (3.8) implies that total employment in the economy across all types (or sectors) is equal to the population mass: $\int_0^1 j'(a) y_s(j(a)) da = \int_0^1 a'(j) f(a(j)) dj = 1$.

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The *zero profit* condition in aggregate good production requires total revenue to equal total factor payments so that:

$$Y \equiv \psi\left(\vec{y}\right) = \int_0^1 w(j)[a'(j)f(a(j)) + y_t(j)]dj. \tag{3.10}$$

Finally consumers' *balanced budget* condition requires that consumption expenditure on the final good equals workers' net income[31]:

$$Y^c = \int_0^1 [w(j(a)) - c(a, j(a))]da, \tag{3.11}$$

where Y^c denotes aggregate consumption of the final good. Any trade imbalance in intermediates is made up by shipments of the final good Y.[32]

For a small open economy, the system described by Eqs. (3.8)–(3.11) pins down, for any exogenously given price/wage schedule, the equilibrium allocation of agents to occupational sectors, intermediate production levels and trade, as well as aggregate final good output and consumption.

3.5. Equilibrium conditions for large economies

To endogenize the wage schedule when Home is large, we now introduce a second country, Foreign (variables denoted by *). Let Foreign mirror Home in all aspects except the educational cost structure: Foreign has the same unit mass of population with an identical ability distribution, the same non-satiated preferences and inelastic labor supply, and the same production technology for intermediates and the final good. We restrict attention to differences in educational institutions because this is the novel force driving comparative advantage, and ultimately the focus of this paper.[33]

Under autarky each economy is characterized by a system of equilibrium conditions analogous to Eqs. (3.8)–(3.11) above. Solving these, together with the autarkic condition that trade is zero ($\vec{y}_t = \vec{y}_t^* = \vec{0}$) yields the autarkic equilibrium wage schedules, which we denote by $w_A(j)$ for Home and $w_A^*(j)$ for Foreign. The equilibrium wage schedules in turn pin down all other variables of interest. Notice that the first order condition for optimal educational investment (Eq. (3.4)) implies that more convex (in j) educational costs will induce a steeper autarkic equilibrium wage schedule (all else equal). Intuitively, when skill upgrading is increasingly expensive for more sophisticated (high j) sectors, wage increases must be higher to induce workers to enter the most demanding occupations. Since relative autarkic prices signal comparative advantage, the convexity of educational costs will also determine the pattern of comparative advantage and trade, as we explore further in the next section.

Under free trade, intermediates can be traded on the world market. The set of world market clearing conditions for intermediates is therefore:

$$y(j) + y^*(j) = x(j)Y + x^*(j)Y^* \quad \forall j \in [0, 1]. \tag{3.12}$$

Additionally, we require that Home imports equal Foreign exports and vice-versa:

$$y_t(j) = -y_t^*(j) \quad \forall j \in [0, 1]. \tag{3.13}$$

The remaining equilibrium conditions – full employment, zero profit, and balanced budget in Eqs. (3.8), (3.10), and (3.11) respectively – are the same as before, for both Home and Foreign. Together, these equilibrium conditions jointly determine the unified free trade equilibrium wage schedule, which we denote by $w_{FT}(j)$. Note that factor price equalization is implied by the law of one price, as we have identity production functions and there is free trade in intermediates. The common wage schedule then pins down the allocation of workers across sectors and thus the distribution of human capital within and across countries, the supply of intermediates, aggregate output, and consumption in each country, as well as the pattern of trade. Note that for any sectors in which only one country produces in equilibrium, the market clearing condition in (3.12) has a single term on the left hand side, so that only the producing country's educational cost structure will influence the wage directly.

In general, the market clearing conditions can be characterized by a differential equation of the wage schedule over j. Collapsing the system of intermediate market clearing conditions (of which there are an uncountable infinity) to a single differential equation yields enormous returns in model tractability: namely, equilibrium properties can be summarized by the behavior of the wage schedule over $j \in [0,1]$ as above. At the same time, however, given that the equilibrium wage schedule is the solution to a differential equation of the third order,[34] it should not be surprising that closed form solutions prove the exception rather than the rule.

The following section describes a case in which specific functional forms offer clean analytical solutions in the general equilibrium model. In generating a set of closed form results, we both demonstrate the mechanics of the model and highlight the role of educational institutions in determining comparative advantage and the implications of trade for human capital acquisition, welfare, and income distribution.

4. A general equilibrium example

This section develops a concrete two-country general equilibrium example of our model that illustrates the potential for simultaneous 'sorting up' and 'sorting down' of moderate ability agents in response to trade liberalization. Comparing equilibrium outcomes under autarky and free trade, we generate predictions for the long run effects of trade liberalization.[35] We focus on a case in which the only difference between countries lies in educational institutions; we abstract from other cross-country differences because our goal is to highlight the role of educational institutions. A short discussion at the end of this section explores the complementary effects of cross-country differences in technology, skill-biased technological change (SBTC), non-traded goods, and differential offshorability in contributing to skill polarization.

In this example, we add structure to the general model by selecting specific functional forms for educational costs and final goods production. The crucial economic feature of our functional form assumptions lies in the relative convexity of the two educational cost structures, which determine comparative advantage and therefore the implications of trade liberalization. Specifically, we assume that the foreign educational cost structure is more convex in j than is the domestic cost structure. Intuitively, as individuals move up the educational ladder, our assumption is that the marginal cost of additional skill upgrading rises faster in the foreign country than it does at home. This assumption effectively adopts a developed country perspective, in which the foreign trading partner is interpreted as a less developed country.

[31] Tariff revenue, if appropriate, would simply be added to the RHS of (3.11).

[32] If Y is not tradable, then balanced trade in intermediates requires: $\int_0^1 w(j)y_t(j)dj = 0$. (Moreover, if some intermediates are not traded in equilibrium (and Y is non-tradable), then the price of the numeraire in Home may differ from the world market price of Y).

[33] Since technology differences are the main focus of the seminal work by Dornbusch et al. (1977), we silence that well understood mechanism in the baseline version of our model. We discuss the potential role played by cross-country differences in technology at the end of Section 4.

[34] $y(j)$ depends on $a'(j)$, which is a function of $\dot{w}(j)$ and $\ddot{w}(j)$ while $x(j)$ depends in general on the complete $w(j)$ schedule. Moreover, in a model with multiple final goods in which aggregate final goods output depends on its own price (i.e. $Y(p)$), the market clearing condition would instead be given by fourth order differential equation.

[35] Transition dynamics are sufficiently complicated that they lie beyond the scope of this paper. We explore dynamics in models with endogenous (but monotonic) skill acquisition in Blanchard and Willmann (2011) and Blanchard and Willmann (2014).

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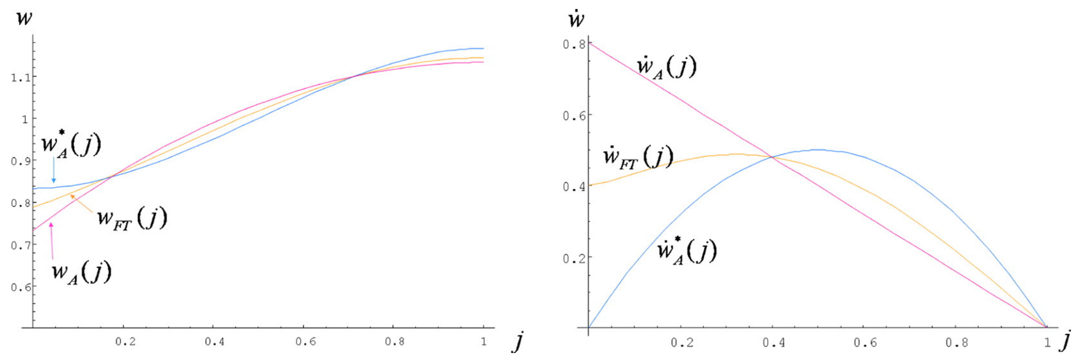

Fig. 3. Equilibrium wage schedules (levels and slopes).

In practice, the relative convexity assumption is consistent with evidence that costs or other barriers to education make the shift from primary to secondary to tertiary education increasingly difficult in developing countries relative to the industrialized world. The UNESCO Institute for Statistics offers direct evidence of educational costs through country-level data on per-student education expenditures at the primary, secondary, and tertiary levels. One recent study, UNESCO (2011), shows that the ratio of per-student secondary school costs relative to primary school costs is often many times higher in developing countries (particularly in Sub-Saharan Africa) than in wealthier countries.[36] In raw UNESCO statistics from 2012 (the most recent year with broad cross-country reporting), the same trend is evident in tertiary education: per-student expenditure on tertiary education relative to secondary education is typically many times higher in developing countries than in industrialized nations.[37] Additional support can be drawn from cross-country data on skill attainment and returns to education. Barro and Lee (2013) find sharp differences in the pattern of educational attainment between advanced and developing economies, particularly at post-secondary levels.[38] At the same time, Psacharopoulos (1985) and Ram (1996) offer compelling evidence that the returns to higher education are highest in developing countries (particularly Sub-Saharan Africa), which suggests that the difference in educational attainment observed by Barro and Lee is at least partly driven by differences in the cost and availability of education.

Returning to the example, let the cost of education in the home and foreign countries be given by the following functional forms, in line with the evidence cited above:

$$c[j,a] = \frac{(1-a)}{a} * \frac{2j^2}{5} \tag{4.1}$$

and

$$c^*[j,a] = \frac{(1-a)}{a} * \frac{2j^3}{3}. \tag{4.2}$$

These educational cost functions offer both tractability and a plausible case in which both countries produce the entire range of goods in equilibrium.[39] Again, we emphasize that this example is for illustrative purpose; this is one of many functional form structures that can generate non-monotonic skill change in equilibrium.[40] Importantly, the absolute educational cost levels could be higher across the board in Foreign than in Home without changing the pattern of production in our model, since only the relative *derivative* cost schedules enter the first order condition for optimal worker sorting (again, subject to the condition that education costs are not prohibitive).[41]

On the factor demand side, we work with Leontief production of the final good, which offers tractability by abstracting from possible substitution effects across intermediates.[42] With $\psi(\vec{y}) \equiv \min\{y_0, \ldots, y_1\}$, unit factor demand is simply one in each sector and country, regardless of the wage schedule; thus, $x(j) \equiv x_j(\vec{w}, 1) = x^*(j) = 1$. Remaining assumptions (one-to-one production, inelastically supplied labor, perfect competition, etc). Finally, for tractability, let $F(a)U[0,1]$, such that $f(a) = 1$ for all a in both countries are as in the general model set-up described in Section 3.

Following the solution procedure outlined in the previous section, we solve for the closed form equilibrium wage schedules in autarky and under free trade. Fig. 3 plots both the real wage schedules (on the left) and the derivative wage schedules (on the right) over j, using subscripts ($_A$) for autarky and ($_{FT}$) for free trade. Comparing autarky with free trade, we see that free trade dampens the skill premium (i.e. $\dot{w}(j)$) at low levels of j and increases the skill premium for higher j sectors at home, while the opposite holds in the foreign country. This makes sense. In autarky, the relative convexity of the foreign education cost function drives up wages in the high j sectors, since wages must be sufficient to induce enough individuals to incur the high cost of incremental education.[43] The marginal cost of skill upgrading for high j sectors is lower in the home country, and so autarkic wages need not be as high. When the home and foreign countries open to trade, prices (and thus wages) in high j sectors fall in the foreign country and rise at home. The opposite holds in the mid-range sectors, where wages rise abroad and fall at home. In the lowest j sectors, the wage level rises at home, even as the skill premium falls; intuitively, this is because foreign competition in the mid-skill sectors pushes more able (higher a) individuals into the lower j sectors, and these higher ability individuals need a smaller skill premium to induce them to acquire the relevant skill set.

Fig. 4 illustrates the change in the allocation of agents to skill levels following a move from autarky to free trade. In autarky, Leontief

[36] See, e.g., Fig. 35 on page 75, which shows that the ratio of per-pupil public expenditure on secondary school relative to primary school is as much as 4 times higher in some developing countries than in developed nations. Fig. 36 (p. 76) demonstrates that the private burden of educational costs is also borne disproportionately by secondary school students in developing countries. Also see Table 15, pp. 226–235.

[37] In 2012, the highest ratio of tertiary-to-secondary unit education costs was in African countries (some of which had ratios of tertiary-to-secondary unit costs near or above 10), India (3.6), Sri Lanka (3.5), and Indonesia (2.3). The same ratio was dramatically smaller for the few developed countries reporting data, including Belgium (.86), Japan (.99), New Zealand (1.25), and France (1.3). Data available from http://www.uis.unesco.org/.

[38] In 2010, 18% of adults over age 15 had completed tertiary education in the advanced economies, compared with 3% in South Asia and 1% in Sub-Saharan Africa.

[39] Appendix A1.2 features modified functional forms that deliver a case of "limited diversification" in which one country is the sole producer of certain goods under free trade; none of our qualitative depend on complete diversification.

[40] From Corollary 3.2, trade will induce non-monotonic skill responses as long as the pre- and post-trade derivative wage schedules cross at least once over $j \in (0, 1)$. If education cost is the only difference across countries, this requires that the derivative cost schedules, $\dot{c}^*(j, a)$ and $\dot{c}(j, a)$, cross for at least one ability level, $a \in (0, 1)$, in the interior of the unit interval.

[41] To verify, simply add a constant to $c^*[j, a]$) and note that the sorting mechanism will be unchanged (as long as education costs remain non-prohibitive).

[42] More generally, substitution effects would dampen the magnitude of wage schedule changes, but would not overturn our qualitative findings; the technical benefit of the Leontief structure is that $x_j(\vec{w}, 1) = 1 \forall j$ so that the intermediates market clearing condition is only a second order differential equation (rather than third order) with a closed form solution.

[43] Under the Leontief (or any super-convex) aggregate production structure, all tasks will be produced even at very high cost.

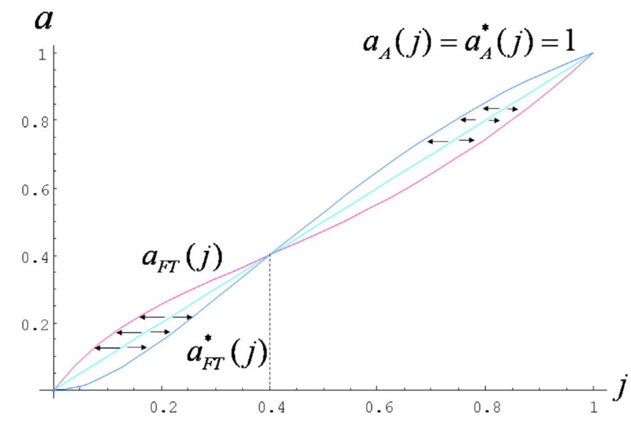

Fig. 4. Mappings $a_{FT}(j)$ and $a_{FT}{}^*(j)$.

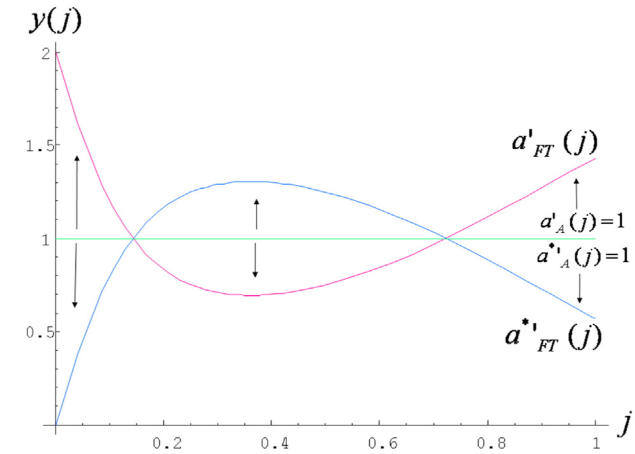

Fig. 5. Employment density by sector: autarky and free trade.

technology implies a uniform allocation of workers across sectors according to: $a_A(j) = a_A^*(j) = j$, which is represented by the light blue diagonal on the 45 degree line in Fig. 4. Under free trade, the sectoral mappings take a polynomial form (we omit the functional forms here for brevity): Home's free trade $a(j)$ mapping is in pink, while the foreign free trade mapping is in dark blue. Where the free trade mapping function lies above the diagonal in Fig. 4, the corresponding ability type self-selects into a lower j sector under free trade; i.e. agents sort down. By contrast, where the free trade mapping function lies below the forty-five degree line, agents self select into higher j occupations and acquire more human capital in the case of free trade. Overall, Home agents in the lower portion of the ability distribution select to lower j sectors, while agents above a= .4 shift up, thus vacating the middle j sectors toward the skill-acquisition extremes. The effects in Foreign are simply the reverse.

Fig. 5 depicts the resulting shift in employment density across sectors, which is equivalent to the supply of each intermediate task in equilibrium. Again, note that the Leontief technology ensures uniform employment distributions in autarky, depicted in green. Free trade pushes Home workers to the skill acquisition extremes — analogous to the empirical findings by Goos and Manning (2007) reproduced in Fig. 1 — while 'middle class' employment increases in Foreign under free trade. Foreign has comparative advantage in middle j sectors, while Home has comparative advantage in both low and high j sectors.

We now turn to the welfare implications of freer trade, focusing first on the Home country. Notice that the welfare consequences of moving from autarky to free trade depend on the change in both real wages and the realized (real) costs of education. We take each part in turn, showing first the real wage effects, then the changing costs of equilibrium educational attainment, and finally the net welfare effects by ability type.

The two panels in Fig. 6 depict respectively the change in the real wage in sector j following trade liberalization, and the change in the real wage of agent a given her optimal sectoral choice under each trading regime.[44]

The first panel shows that real wages rise for the low and high j sectors, and fall for intermediate sectors. (These wage changes are again broadly consistent with empirical evidence: recall the U.S. wage polarization demonstrated by Autor et al. (2006).) The second panel takes into account the induced occupational shift, confirming that the change in realized real wages is non-monotonic across workers: agents with low ability earn higher real wages under trade, agents with high ability do as well, and agents in the lower-middle portion of the ability distribution see their real wages fall. The lower ability workers' wages fall more when we account for their occupational shift downward into lower j sectors. Conversely, the higher ability workers do even better as they sort into higher j sectors where wages are rising.

Fig. 7 shows the change in the real cost of education across workers. As noted earlier, agents in the lower forty percent of the ability distribution optimally sort down (thus reducing their education costs) while agents in the upper part of the distribution increase skill acquisition and thus pay more for education.

In Fig. 8 we then see the net welfare change for Home's population. Relative to looking only at real wage changes, where the 'biggest loser' from trade liberalization sat at roughly the lowest quartile ($a \simeq .25$), accounting for the changing cost of education shifts the identity of individual most hurt by trade toward the median to roughly $a \simeq .4$. To understand why, consider the plight of the agent $a = .6$. Although her real wage has increased, the increased cost of education required to achieve the higher paying job more than offsets the wage gain so that the net welfare change is negative. Conversely, agent $a = .2$ suffers a substantial real wage loss yet enjoys a modest net welfare improvement due to his now lower cost of education. (A crucial caveat to this second statement is that lower costs of education cannot be recovered if they are sunk.[45])

The net welfare effects in the foreign country are a mirror image of what happens at Home. In Foreign, the real wage increases most for those individuals in the middle of the ability distribution, where comparative advantage is strongest. Workers in the lower forty percent of the ability distribution sort up into higher-skill jobs (gravitating to higher wages), but incur higher education costs in the process. Higher ability agents, meanwhile, face higher opportunity costs of skill acquisition and thus sort downward, saving on education costs. The net welfare effect of trade in Foreign sees the middle ability agents gaining the most from trade, while the very highest and lowest ends of the population distribution lose, as they now face import competition that drives down prices/wages. Fig. 9 summarizes, depicting both the Home and Foreign net welfare changes moving from autarky to free trade, by worker ability type.

Note that this quantitative example can easily be modified to allow more or less dramatic results. For instance, if the foreign educational cost function were even *more convex* in j than in the example presented above, Home's comparative advantage in the higher j sectors would be even sharper, which would push more of the displaced former mid-

44 The equilibrium real wage in a given sector $\hat{j}$ is given by $w_0 + \int_0^{\hat{j}} \dot{w}(j)dj$, where the base wage in sector $j = 0$ is determined by $w_0 \equiv 1 - \int_0^1 \dot{w}(j)dj$ according to the zero profit conditions.

45 In a dynamic framework with unanticipated trade shocks, older generations would not be able to recover the sunk cost of education, although workers might still be able to acquire additional (potentially mid-career) education. Short run, post trade liberalization, welfare thus would be lower for older lower ability agents relative to Fig. 8. If instead we interpret skills as horizontally differentiated, workers may not be able to "sort down" at all, if indeed they would need to acquire a new skill set to do so.

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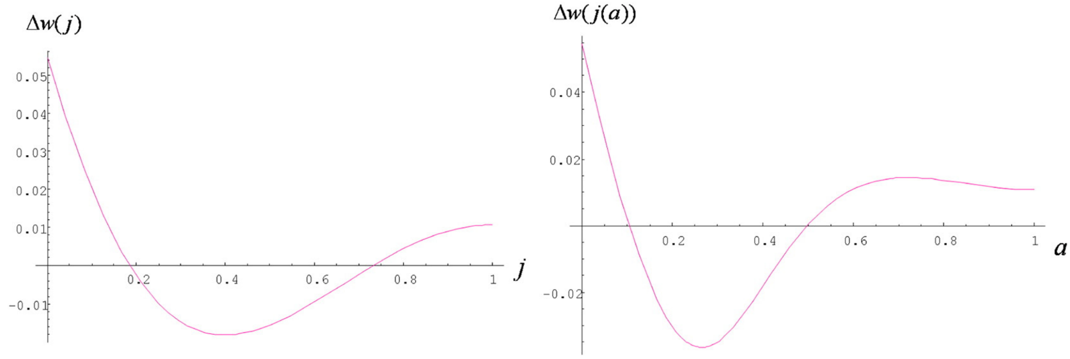

Fig. 6. Effect of trade on wages at home.

range Home workers into higher j, more skill-intensive sectors in the free trade equilibrium. Conversely, if the foreign educational cost function were *less convex* in j than in the case illustrated above, trade would push a greater share of Home's displaced mid-range workers into lower j sectors, leaving only those in the higher-middle range to shift up into more sophisticated sectors following trade liberalization.[46] Intuitively, the relative difficulty of skill acquisition determines citizens' educational decisions and thus the equilibrium structure of prices and production. If technology and the underlying distribution of individuals' abilities are equal across countries, as we assume, the cross-country differences in the marginal costs of educational attainment will drive the pattern of comparative advantage and trade.

Our functional form example delivers a concrete case in which differences in educational institutions alone are sufficient to drive comparative advantage and the 'hollowing-out' of mid-range skill attainment from trade liberalization. In the example, trade generates clear and quantifiable implications for wages, skill attainment, and welfare both within and across countries. In the process, we have highlighted the interdependence of education and trade in driving the equilibrium distribution of human capital. Against this backdrop, the potential role for education policy is immediate. Before we turn to these issues in Section 5, however, we pause for a moment to consider two modeling features that are silenced in the preceding example: technology and the potential for non-traded goods or differential "offshorability". While adding these elements would by definition alter particular mechanisms of the model, we argue below that the potential role of educational institutions in shaping human capital responses to trade would remain unchanged.

4.1. Discussion: technology and tradability

At this point it is sensible to ask how Ricardian technological differences across countries, technological change (particularly routinization or SBTC), or differences in tradability across sectors influence the key implications of our theoretical exercise. It is entirely possible that, with the right assumptions, these forces could generate labor market polarization in our framework, even in the absence of differences in educational institutions. But as we argue below, while these factors are also potentially able to explain the hollowing-out phenomenon, they do not change the fundamental way in which differences in educational institutions contribute to comparative advantage and the equilibrium distribution of human capital.

First, it is obvious that under certain assumptions Ricardian technological differences could yield the same pattern of comparative advantage and trade seen in Fig. 5.[47] Differences in technology and educational institutions are roughly isomorphic from a modeling perspective, since each influences both equilibrium production costs and marginal skill acquisition decisions. The economic and policy interpretations of the two are very different, however. And while the role of technology in shaping comparative advantage is well understood from Dornbusch et al. (1977) and many others, the role of educational institutions has been largely overlooked. Our example demonstrates that empirically plausible cross-country differences in educational institutions can substitute for differences in technology in driving comparative advantage and hollowing-out.

Thinking instead about changes in technology over time, technological change would have to be non-monotonic, exhibiting positive skill-bias at top of the task spectrum (to induce skill upgrading by the most able individuals) and *negative* skill-bias at the lower end (to temper the incentives for skill upgrading by lower ability workers), in order to generate polarization. To the extent that we view this possibility as the result of "routinization" (possibly together with SBTC), this explanation is both plausible and empirically supported.[48] At the same time, however, routinization would predict the same hollowing-out pattern in *every* country, not just in the industrialized world. This second prediction squares less clearly with the data, given the expansion of the middle class in many developing countries (Ravallion, 2009; Dollar et al., 2013).[49] While technological change clearly plays a central role in recent labor market shifts, our multi-country framework suggests it is unlikely to be the only explanation.

Next we ask whether differential "offshorability" across sectors or non-traded goods could explain hollowing-out. The answer depends on our assumptions over tradability and underlying comparative advantage. If non-traded sectors are the endogenous result of uniform transport costs and Home's comparative advantage is increasing monotonically in the skill-intensity of each sector j, as in Dornbusch et al. (1977), increased tradability cannot explain hollowing-out. Uniform trade costs generate ranges of non-traded goods/tasks for which comparative advantage is narrowest and therefore dominated by transportation costs. With monotonic comparative advantage, these non-traded sectors would be those demanding intermediate skill levels. A reduction in trade costs would chip away at the margins of middle-skill employment, but employment in the still-non-traded mid-skill sectors would remain steady or even rise as "nearby" workers shift into these

[46] For example, adapting our basic example to make the foreign cost function more convex, $c^*(a;j) = \frac{1-a}{a}\frac{20j^3}{3}$, yields (all else equal) a free trade equilibrium in which all Home workers with ability $a > .04$ shift up into higher j sectors following trade. (In our benchmark example above, this threshold is $a = .4$.) If instead we decrease the convexity of the foreign education function to $c^*(a;j) = \frac{1-a}{a}\frac{j^3}{3}$, the model generates a free trade equilibrium in which individuals with ability greater than $a = .8$ will self select upward following trade liberalization.

[47] If the Home country is exogenously assumed to hold Ricardian comparative advantage (lower unit labor requirements) at the lower and upper ranges of occupational sectors (j), then trade liberalization would have the same effect on the distribution of employment and skill acquisition as in our example.

[48] Goos et al. (2014) and Autor et al. (2015) find that routinization has played an important empirical role in labor market polarization in Europe and the U.S., respectively.

[49] At the same time, income inequality has been rising in other developing countries. See the discussion in Section 2.

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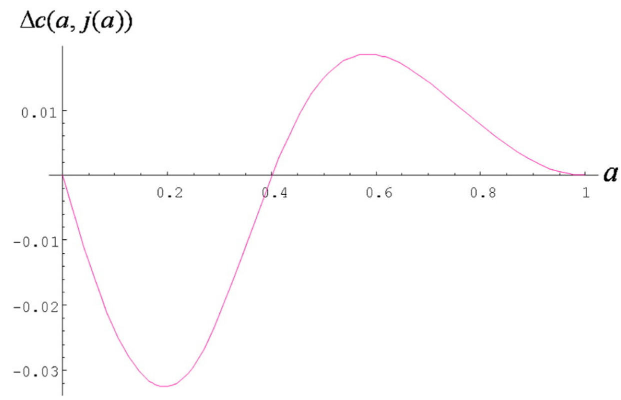

Fig. 7. Change in the home real cost of education across workers.

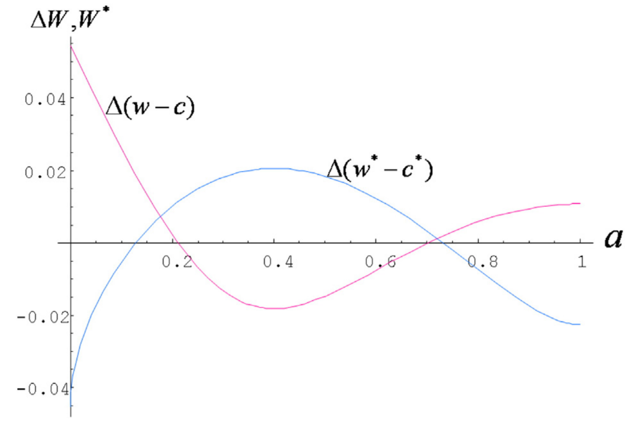

Fig. 9. Opposing individual welfare effect of trade in home and foreign.

protected occupations. To generate hollowing-out, the middle-skill sectors instead would need to be the *most* exposed to foreign competition.

If instead we simply *assume* that mid-skill sectors are the most offshorable (or similarly, that low-skill sectors are non-tradable), then opening to trade could cause hollowing-out in the Home country. With increased tradability in mid-skill sectors, some mid-skill workers would shift down into the more protected low-skill sectors while others would shift up into higher-skill export sectors, roughly in line with our example. There is empirical support for this assumption, but evidence on differential tradability across sectors is still decidedly mixed: Blinder and Krueger (2013) argue that higher skilled occupations are more tradable than lower-skill jobs, while Baumgarten et al. (2013) suggest the opposite; Blinder (2009), Crino (2009), and Geishecker and Görg (2013) offer similarly mixed findings. Most recently, Goos et al. (2014) offer a compelling argument that the intermediate skill sectors may be the most offshorable, based on their own coding of the Blinder et. al. data. If true, our model would certainly concur with their own conclusion that differentially greater offshorability in mid-skill occupations likely contributes to the hollowing-out phenomenon.

In reality, skill and employment polarization is driven by a combination of factors that play complementary and compounding roles in shaping comparative advantage across countries and over time. Fundamentally, starting from any given equilibrium – with or without Ricardian technological differences, routinization, or differential offshorability – changes in educational institutions will shift workers' incentives to acquire skills, and thus comparative advantage, through the mechanisms highlighted in our basic example. The potential role of educational policy to reverse (or exacerbate) skill polarization is immediate.

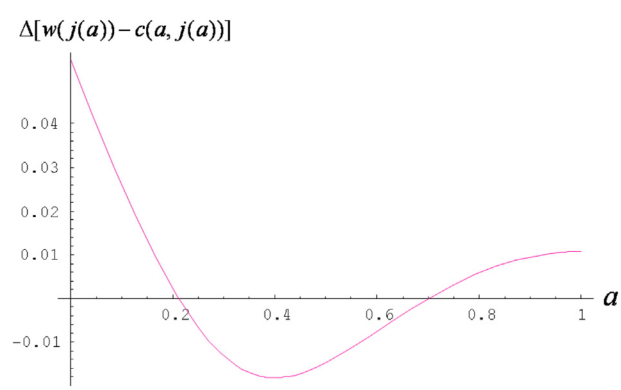

Fig. 8. Net welfare effect of trade in the home country.

5. Policy implications

Our model lends itself readily to policy analysis. In the following subsections, we focus on the potential role of educational policy and trade protection in shaping the distribution of income and human capital. We highlight in particular the United States' Trade Adjustment Assistance (TAA) program and the extent to which trade and education policy instruments are substitutable.

5.1. Educational policy

In practice, education policies take many forms. In essence, however, educational initiatives can be summarized as either increasing educational productivity or decreasing the costs of education borne by students. Here, we focus on the latter as it is simpler from a modeling perspective and isomorphic in its underlying effect on skill-acquisition decisions.[50]

We define an educational subsidy, $s(j)$, as a payment (in units of the numeraire) to offset the cost of acquiring the skill set required for employment in a given sector/task j. The subsidy cannot be conditioned on the inherent ability level a of the agent, which we take to be unobservable. All subsidies are financed by a poll tax to maintain a balanced government budget.[51]

The effect of a subsidy program on educational outcomes follows immediately from the first order condition for individuals' optimal educational choices in (3.4). Introducing an educational subsidy leads to the following augmented first order condition; an agent of ability type a will choose his optimal skill-level/occupation j^o according to:

$$\dot{c}\ (j^o, a) - \dot{s}\ (j^o) = \dot{w}\ (j^o), \tag{5.1}$$

where $\dot{s}(j)$ is the first derivative of the subsidy function with respect to j (assuming $s(\cdot)$ is differentiable).[52] Thus, starting from an individual's optimal educational choice, $j^o(a)$, introducing a subsidy scheme in which $\dot{s}(j^o) > 0$ will lower the marginal cost of skill-upgrading, causing that agent to self-select upward into a higher wage, higher skill sector. If instead $\dot{s}(j^o) < 0$, the new subsidy – even if positive for every sector – will

[50] Specifically, increasing education productivity would have the same (positive) effect on individuals' skill acquisition decisions as reducing the cost of education, but the former would simultaneously increase worker productivity (conditional on education level) while the latter does not.

[51] Note that in several countries educational subsidies have to be repaid ex post out of the (education augmented) income. This would correspond in our framework to a more progressive subsidy schedule, as discussed below.

[52] We also focus on a case in which the left hand side of the augmented first order condition in (5.1) satisfies the derivative property assumptions (convexity, single crossing) we made regarding the educational cost function in (3.1).

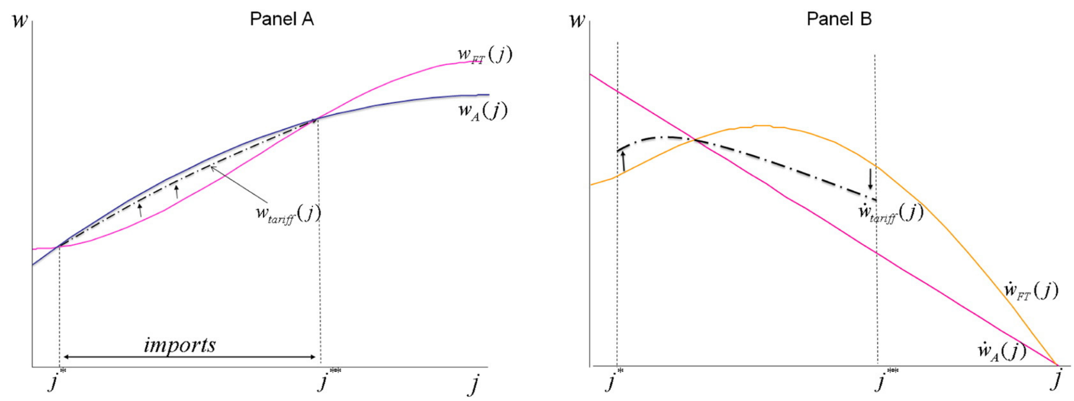

Fig. 10. Effects of an import tariff.

increase the opportunity cost of skill upgrading, causing the same agent to self-select downward into a lower skill, lower wage sector.[53]

More formally, the following result restates this logic, under a small country setting and a 'nice' case scenario in which the optimal educational choice is unique for every agent $a \in [0, 1]$.[54] An educational subsidy scheme, summarized by $s(j)$ over $j \in [0,1]$, has the following effects on individuals' skill acquisition decisions:

Proposition 5.1. *If $c(j, a) + s(j)$ satisfies properties analogous to (3.1), then for each $j \in (0, 1)$ the educational subsidy schedule $s(j)$ has the following (local) effects:*

i) *if $\dot{s}(j) = 0$ then $a(j, \vec{s}) = a(j, \vec{s} = 0)$;*
ii) *if $\dot{s}(j) > 0$ then $a(j, \vec{s}) \leq a(j, \vec{s} = 0)$;*
iii) *if $\dot{s}(j) < 0$ then $a(j, \vec{s}) \geq a(j, \vec{s} = 0)$.*

The results follow directly from the augmented first order condition in (5.1).

Part (*i*) implies that a uniform subsidy that offers the same benefit to workers in all sectors would not affect individuals' educational choices; rather, it is the change in the *marginal* costs of education that matters. (Indeed, a uniform subsidy simply cancels the poll tax, given full employment.) Parts *ii*) and *iii*) restate the earlier intuition. If the subsidy scheme offers higher subsidies at higher education levels so that $\dot{s} > 0$ across the board, then all agents would sort monotonically into higher skilled occupations. In instead educational subsidies are concentrated systematically at the lower rungs of the educational ladder (i.e. $\dot{s}(j) > 0 \; \forall \, j$), then agents will sort monotonically downward.

Turning to welfare, notice that a subsidy plan that induces skill-upgrading is necessarily regressive. Those who acquire the most skills (and in our model are also the highest wage individuals) benefit the most from the subsidy scheme. Conversely, individuals at the lower end of the spectrum also take advantage of education subsidies, but pay more in the poll tax than they receive (by virtue of the government's balanced budget provision.) Many of the education subsidies that exist in practice seem to have this structure through proportionality rules — for instance, tax credits that allow individuals to write off educational expenses with no lifetime limit share the feature that those in school the longest receive the greatest subsidy for their training. That said, the regressive nature of a subsidy scheme may be mitigated or overturned if the funds required to pay for the subsidy are raised via general, progressive income taxation, or if the subsidy has to be repaid by the recipient out of her lifetime personal earnings.

Pushing the distributional effects of policy intervention further, we can now ask how an activist government might use educational policy to soften the impact of globalization.[55] The negative impact of trade — at least in the example discussed earlier — is borne by mid-skill, middle-income individuals. If the government, possibly in the interest of political stability that relies on a sizable middle class, wants to counteract the 'vanishing middle class' phenomenon, it would have to provide an educational subsidy schedule that features a positive slope for low ability agents and a negative (or at least much flatter) slope for higher ability agents. Such targeted education subsidies toward middle class workers would effectively constitute a production subsidy to import-competing sectors. From an efficiency point of view, such a policy is clearly counter-productive, as redistribution could be more efficiently achieved through more direct means.[56] Moreover, a "middle class" education subsidy would bolster employment in the senescent import-competing sectors, which may prove to be untenable in the longer term.

Contrast this approach with a program like the TAA, which is designed to move displaced workers out of import-competing sectors through education subsidies and worker re-training programs. Our model would imply that moving displaced workers out of import competing occupations would require either *substantial* educational subsides, sufficient to induce movement to much more sophisticated (higher *j*) export-oriented sectors (and in turn sharpening the country's comparative advantage), or softening the blow from sorting down into less sophisticated sectors, for instance, through long-term wage top-ups, another feature of the TAA.[57] More generally, our model highlights the importance of the marginal returns to education in shaping workers' choices; to the extent that programs like the TAA offer only small subsides for additional training, they may prove insufficient to encourage workers to incur the potentially large adjustment costs required to move to potentially far more sophisticated export sectors. At the same time, modest and time-limited wage top-ups may not fully compensate workers who sort down into lower-wage (but potentially secure) employment.

[53] Note that if we interpret sectors over *j* as horizontally differentiated, the latter scenario is particularly plausible. Consider, for example, the recent expansion of scholarship programs specifically for physicians' assistants and nurses.

[54] i.e. before and after the introduction of the subsidy, the second order condition of each individual's optimal skill-acquisition decision is satisfied globally, so that the derivative educational cost schedule (net of subsidy) crosses the derivative wage schedule once and only once from below over $j \in [0, 1]$.

[55] Despite the negative efficiency consequences, we explore this possibility as one that seems consistent with many politicians' stated goals.

[56] If the country is large enough to influence the world market price schedule, then targeted middle class education subsidies would also improve the terms-of-trade and thereby shift part of the efficiency cost of middle class education subsidies onto foreign competitors. But a favorable shift in the terms-of-trade can be more efficiently achieved by trade policy as will be discussed in the next sub-section.

[57] The TAA is also an important source of extended unemployment benefits for eligible workers directly displaced by foreign competition.

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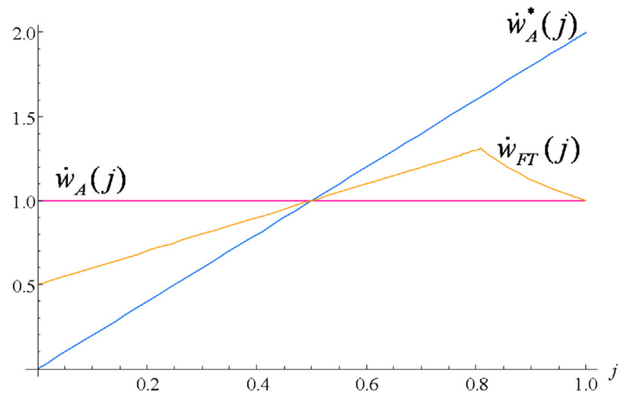

Fig. 11. Wage schedules under autarky and free trade.

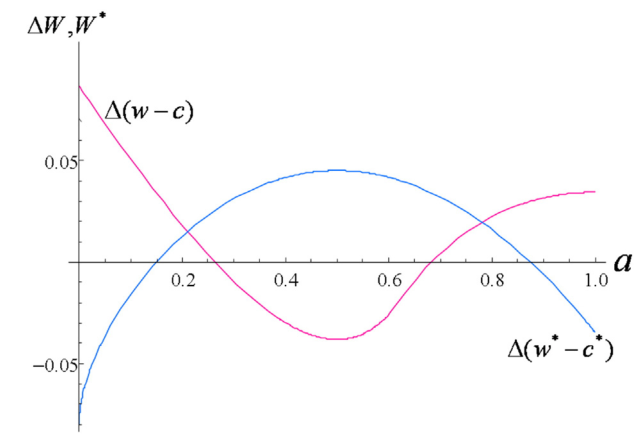

Fig. 13. Net welfare effect of trade in the home country.

5.2. Trade policy

Turning to trade policy, recall that an import tariff is sometimes best understood as a combination of production subsidy and consumption tax. Using this well-known analogy offers an immediate insight for comparing the effects of import tariffs with the effects of educational subsidies; the latter, when financed by a poll tax, do not impose direct consumption-side distortions, but the former do. This distinction plays a central (and familiar) role, as it implies that tariffs are second best as a policy instrument from an efficiency point of view. But as we note below, the political ranking of the two may turn out to be quite different.

Our argument proceeds in two steps. First, we demonstrate that tariffs and education subsidies can be isomorphic in their influence over individuals' skill-acquisition decisions. We then discuss the key differences between the two policies in efficiency and political terms.

To fix ideas, we initially adopt a small country perspective and abstract from potential trade policy effects on local (factor) demand (which are anyway silent if the production technology for the final good is Leontief, as in our earlier example). Let the specific tariff (or export subsidy) for good j (in units of the num\'eraire) be given by $t(j)$, so that the net domestic price/wage is now given by $w^d(j) \equiv w(j) + t(j)$, where $w(j)$ denotes the exogenous world price of good/task j.

The direct effect of a specific tariff (or export subsidy) on human capital decisions is identical to that of an educational subsidy. This is readily apparent from the augmented first order condition of the individuals' educational decision, which takes the form:

$$\dot{c}(j,a) = \dot{w}(j) + \dot{t}(j),$$

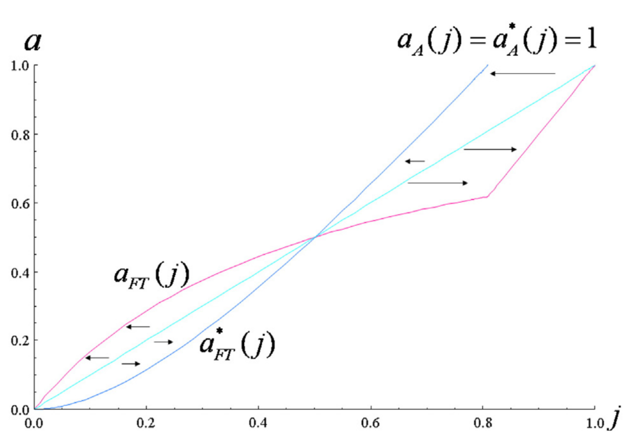

Fig. 12. Ability-sector mappings under autarky and free trade.

where $\dot{t}(j)$ is the derivative of the trade tax/subsidy schedule with respect to j.[58] As with an education subsidy, a uniform specific trade tax (or export subsidy) across all tasks will have no effect on agents' human capital decisions if (and only if) $\dot{t}(j) = 0 \; \forall \; j$.[59] If the trade tax/subsidy schedule exhibits positive or negative slope, on the other hand, then it affects individuals' skill acquisition decisions: a positive (negative) slope induces individuals to choose a higher (lower) skilled education level. In this way, trade taxes and educational subsidies are isomorphic in their effects on individuals' decisions over skill acquisition.

Beyond their effects on educational choices, however, trade and education policies carry important differences. The first is economic efficiency. Unlike education subsidies, which do not directly impact equilibrium prices, trade taxes impose demand-side distortions at the cost of downstream producers and consumers. In our model, while the first order effect of the import tariff (export) is to increase the relative wage paid to a given task – which will (weakly) increase the set of workers training or acquiring the relevant skill set for that job – the higher domestic wage for that task will reduce domestic demand for those newly trained workers. (The Leontief structure of our functional form example offers the limiting case in which these demand side distortions go to zero; more generally they obtain.) Outside the small country setting, the world price/wage will fall, partially offsetting the intended effect. Moreover, relative to education subsidies, these demand-side distortions exacerbate the terms of trade effects of tariffs (or export subsidies) by simultaneously increasing supply and reducing demand for affected goods/tasks.

The second key difference lies in the less clearly defined landscape of political feasibility. The fact that educational subsidies are often proportional to private educational investment — and therefore regressive — raises the question of whether sharply progressive educational subsidies are politically feasible. Political rhetoric argues against progressivity at the top end in particular; public support for higher education is uniformly strong in most industrialized countries. In contrast, targeted trade policy is commonplace (Lu et al., 2012) and protecting "middle class jobs" features prominently in today's political rhetoric. Thus, we now ask how trade policy could be used to bolster the middle class, failing the political feasibility of educational reforms.

Suppose a policymaker seeks to mitigate the impact of globalization on the middle class through import protection.[60] To stem job losses in import-competing mid-skill level occupations, the tariff schedule

[58] Again we assume that $c(j, a) - t(j)$ satisfies properties analogous to (3.1).

[59] An ad-valorem tax/subsidy schedule would have an effect, of course, as its specific equivalent would imply a higher net wage derivative schedule for more skilled (higher wage) sectors.

[60] Consistent with commonly observed policy measures and WTO rules, we consider the effect of imposing tariffs only on imported goods, without introducing trade policy on the export side.

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would need to dampen the wage consequences of trade liberalization. Graphically, this would 'close the lens' between the autarkic and free trade wage schedules; we show an example of one such post-tariff wage schedule in Panel A of Fig. 10. Perhaps less obviously, dampening the wage consequences of trade in this way would necessarily affect the derivative wage schedule, and likely not continuously. Jumps occur at the thresholds j^* and j^{**}, that separate exported from imported intermediates, as depicted in Panel B of Fig. 10. These discontinuities in the derivative wage schedule induce two 'empty' regions, as agents on the left side of those regions sort down and those on the right side sort up.[61] These 'empty' sectors have no domestic employment, and are thus Ricardian-like regions in which the foreign country would be the sole producer worldwide, in line with the Dornbusch et al. (1977) framework. The upshot is that substantial levels of tariff protection could have the unintended consequence of dismantling some previously export-competing industries just below and above the lower and upper discontinuities.

It is clear that this type of import protection will shelter the middle class from global competition in mid-range sectors, and may thus also serve a policymaker's goal of influencing human capital decisions and the pattern of employment in the desired way. But again, tariffs also impose demand-side distortions that targeted educational subsidies would not. Subsidies to education constitute a first best policy for shifting the distribution of human capital, while trade taxes/subsidies are clearly second best.[62]

6. Conclusion

In this paper we develop a model of endogenous skill acquisition in which trade liberalization can induce polarization of both employment and educational attainment. The welfare costs of trade can be greatest for mid-skill, middle-income workers, even as employment and comparative advantage increase at the low and high ends of the skill distribution.

The model sheds light on the potential differential impacts of strengthening educational institutions. We find that progressive education policy that offers the greatest subsidies for education at the lower and middle rungs of the educational ladder can bolster middle class employment and mid-level skill attainment. But these effects work against the tide of foreign competition in import-competing sectors and thus may prove untenable in the long run. Conversely, educational subsidies at the higher rungs of the skill-acquisition ladder sharpen comparative advantage, but are de facto regressive and still leave some former mid-skill workers to "sort down" into lower skill sectors. Import protection can stem middle class losses, but at the cost of local consumption and production distortions, in addition to the potential geopolitical consequences via trade retaliation or WTO censure. We conclude that highly targeted education subsidies and wage top-ups via programs like the United States' Trade Adjustment Assistance are the first best policy for an activist government seeking to bolster the middle class.

Going forward, our model provides a new framework with which to study the aggregate empirical relationship between trade and differential educational outcomes at the primary, secondary, or tertiary levels. The model can also be used to evaluate policy in practice: our finding that uniform 'across the board' education subsidies to education are unlikely to even the distribution of human capital within a country suggests that highly focussed educational policies such as Brazil's may be well-founded. Finally, our model offers a foundation for exploring the interaction between technological change, trade, and education; with sufficient structure, quantitative analysis built on our model could be used to predict the welfare effects of trade apart from technological innovation, while explicitly recognizing the endogeneity of worker's human capital decisions.

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Appendix A

A.1. Proof of Lemma 3.1

1. Taking the derivative of $a(j)$ with respect to j yields[63]:

$$a'(j) = \frac{1}{h'\left(\frac{\dot w}{\dot g}\right)}\left[\frac{\ddot w\,\dot g - \dot w\,\ddot g}{\dot g^2}\right]. \tag{A1.1}$$

Substituting from the first order condition in (3.4):

$$a'(j) = \frac{1}{h'\left(\frac{\dot w}{\dot g}\right)}\left[\frac{\ddot w\,\dot g - h(a)\,\dot g\,\ddot g}{\dot g^2}\right]. \tag{A1.2}$$

Then, from the definition of the cost function:

$$a'(j) = \frac{1}{h'\left(\frac{\dot w}{\dot g}\right)}\left[\frac{\dot g\,(\ddot w - \ddot c)}{\dot g^2}\right] \geq 0, \tag{A1.3}$$

using the second order condition ($\ddot c \geq \ddot w$) and the assumptions on the cost function in (3.1), which imply that $\dot g > 0$ and $h'(x) < 0$ if $x > 0$. By assumption, $\dot w \geq 0\ \forall\ j$, so

$$a'(j) = \underbrace{\frac{1}{h'\left(\frac{\dot w}{\dot g}\right)}}_{(-)}\left[\frac{\dot g\,(\ddot w - \ddot c)}{\dot g^2}\right] > 0 \Leftrightarrow \ddot c > \ddot w. \diamond \tag{A1.4}$$

2. From the definition of $a(j)$:

$$a(j) = h^{-1}\left(\frac{\dot w}{\dot g}\right). \tag{A1.5}$$

Both $g(\cdot)$ and $h(\cdot)$ are twice continuously differentiable and invertible by assumption. Thus, $a(j)$ is continuous in j if $\dot w(j)$ is continuous (i.e. $w(j) \in C^1$). Moreover, $a(j)$ is continuously differentiable in j if $\ddot w(j)$ is continuous (i.e. $w(j) \in C^2$).

3. From part (1) above:

$$a'(j) = \frac{1}{h'\left(\frac{\dot w}{\dot g}\right)}\left[\frac{\ddot w\,\dot g - \dot w\,\ddot g}{\dot g^2}\right]. \tag{A1.6}$$

Again from our earlier assumptions, $h'(\cdot)$, $\dot g$, and $\ddot g$ are finite, and $\dot g > 0$. Thus, $a'(j) < \infty$ if and only if $\ddot w\,\dot g - \dot w\,g < \infty$. A sufficient condition is $w(j) \in C^2$, as stated in the lemma.

[61] The extent to which this happens clearly depends on the height of the jumps which is determined by the tariff schedule.

[62] Trade taxes are, however the first best tool for manipulating the terms of trade (following the usual logic), and so *some* manipulation of educational decisions via trade taxes remains optimal for large countries.

[63] An alternate proof may be derived by taking the total derivative of the first order condition in (3.4), with respect to j and a, rearranging, then noting that under the second order condition that $\ddot w(j) \leq \ddot c(j)$, $a'(j) \geq 0$ if and only if $\frac{\partial c(j,a)}{\partial j \partial a} < 0$ (i.e. if a and j are sub modular in $c(\cdot)$), as assumed.

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A.2. GE example extension: limited diversification

In the baseline example, every task is carried out in both countries in equilibrium; that is, even under free trade, the production of intermediates remains fully diversified across the entire range of occupations. This needn't hold in general. We now present a modified case where trade induces one trading partner to stop production of a particular subset of intermediates, a phenomenon that is certainly relevant in reality, where for example certain inputs can be sourced locally only at very high cost. Suppose the educational costs take the following (slightly modified) form

$$c[j,a] = \frac{1}{a} * \frac{j^2}{2} \tag{A1.7}$$

$$c^*[j,a] = \frac{1}{a} * \frac{2j^3}{3} \tag{A1.8}$$

and assume the same production technology for the final good as before. We can solve for the autarky and free trade equilibrium wage schedules:

$$\dot{w}_A = 1, \tag{A1.9}$$

$$\dot{w}_A^* = 2j, \tag{A1.10}$$

$$\dot{w}_{FT} = \begin{cases} \dfrac{j+2j^2}{2j} & j < \frac{1}{4}\left(1+\sqrt{5}\right) \\ \dfrac{j}{2j-1} & j \geq \frac{1}{4}\left(1+\sqrt{5}\right) \end{cases} \tag{A1.11}$$

These are graphically depicted in Fig. 11. Note that the free trade equilibrium slope of the wage schedule (sandwiched between the autarky schedules) consists of two parts: up to $j = \frac{1}{4}(1+\sqrt{5}) \equiv \bar{j}$ both countries produce each task, whereas above only the home country does. This is because at the upper bound ($j = 1$) the marginal costs of education for the most able agents in both countries differ: the domestic agent with $a = 1$ only has half as high a marginal cost as the foreign agent, $a^* = 1$. Hence in equilibrium, the most able foreign agent does not find it worthwhile to acquire the sophisticated skills necessary to carry out the most sophisticated task. Instead she chooses $\bar{j} < 1$.[64]

As before, graphing the ability-to-task mappings under autarky and free trade in Fig. 12 indicates how trade liberalization affects the skill acquisition decisions: to the left of the intersection agents at home sort down, whereas higher ability agents sort up and acquire more sophisticated skills, and the opposite happens in the foreign country. Thus the result that domestic agents vacate the middle obtains here as well.

Finally, comparing the wage change and the change in the cost of education gives the welfare effects depicted in Fig. 13. Again we see that the middle ability agents at home lose out whereas agents at the bottom and top benefit from trade, and the welfare effects in the foreign country are the opposite. We have therefore confirmed that our previous result is robust to the possibility that countries restrict the range of tasks they produce in response to trade liberalization.

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[64] We find this threshold by using the boundary condition $\dot{c}(a = 1, j = 1) = \dot{w}$ to determine the constant of integration of the w-dot schedule that equates home supply to world demand. Since 'smooth pasting' of the wage schedules for the upper and lower ranges implies the same derivative at the threshold, we find the threshold by plugging $a^* = 1$ into the 'only home production' schedule already determined. 'Smooth pasting' then pins down the constant of integration of the schedule to the left where both countries produce.

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